DIAGNOSTIC REASONING APPROACHES AND SUCCESS RATES IN BOMB DISPOSAL

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Graduate College of the
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in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
May, 2023

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SUCCESS RATES IN BOMB DISPOSAL

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Date of Degree: MAY, 2023

Title of Study: DIAGNOSTIC REASONING APPROACHES AND SUCCESS RATES IN BOMB DISPOSAL

Major Field: FORENSIC SCIENCES

Abstract: As professions, medicine and bomb disposal have many similarities, with one easily recognizable commonality being that practitioners in both disciplines rely on decision-making that is objective, dispassionate, and to the largest extent possible, grounded in scientific theory. Using research methodologies honed over decades in the medical community, this study investigates diagnostic reasoning approaches and success rates in the bomb disposal community, as viewed through the lens of improvised explosive device (IED) circuit analysis, which includes component identification, hazard assessment, and circuit type-by-function determination. The population for this study consisted of current and former military and civilian bomb technicians, and factors such as years of bomb disposal experience, length of initial training, and specialized IED training were analyzed to determine effects on success rates. A convergent mixed-methods design with a pragmatistic worldview was used, and the data gathered suggests that overall, no variables assessed had any effect on a bomb technician's ability to successfully perform component identification, assessment of associated hazards, and determination of circuit type-by-function. Quantitatively, average success rates for study participants, by independent variable, showed no statistically significant differences, except for those who attended specific bomb disposal schools for their initial training, and only for circuit type-by-function determinations. Average success rates for study participants were 20% for component identification; 16% for associated hazards; and 51% for circuit type-by-function. Qualitatively, over 90% of participants used Type 1 decision-making (i.e., heuristics and pattern matching) as their diagnostic reasoning approach, and focused on component identification and circuit configurations in determining hazards associated with devices, and circuit type-by-function. Additionally, an analysis of component and hazard selections clearly suggests that bomb technicians key in on specific components, and these selections drive their further analysis. Self-assessed confidence-level data also suggests that study participants significantly over-rated their ability to recognize components, assess hazards, and determine circuit type-by-function. The results of this study can be used by thought leaders and trainers in the bomb disposal community to push for fostering and improving diagnostic reasoning skills, problem-solving, and critical thinking, which in turn should lead to a reduction in operational errors during IED response operations.

TABLE OF CONTENTS

Chapter Page

Chapter Page

Chapter Page

Chapter Page

LIST OF TABLES

Table Page

Table Page

LIST OF FIGURES

Figure Page

Figure Page

Figure Page

CHAPTER I

INTRODUCTION

Introduction to the Study

Decision-making is an ongoing and continual cognitive process in the human brain. Some decisions are made consciously, while others take place subconsciously, but all have implications for how people perceive the world; interpret, store, and retrieve new information; and interact with their environment and other individuals. While volumes have been written about conscious decision-making (e.g., Engel, and Singer, 2008; Qudrat-Ullah, Spector., and Davidsen, 2010; Schoenfeld, 2011; Kochenderfer, et al., 2015; Brown, D2021), far less is known about decision-making that takes place just outside normal levels of perception, or subconsciously. In his book *Blink: The Power of Thinking Without Thinking*, Gladwell (2006) discusses a cognitive phenomenon called thin-slicing, which he describes as “the ability of our unconscious to find patterns in situations and behavior based on very narrow slices of experience”
(p. 23).

According to Gladwell, thin-slicing can refer either to making decision based on limited amounts of relevant information while ignoring irrelevant information, or it can manifest as an ability to simplify large amounts of information into a readily available and highly usable form to assist in rapid decision-making. According to the author, these types of decision-making strategies are seen not only in routine, daily decision-making activities, but in professional decision-making situations, as well as under crisis and high-risk conditions where an incorrect decision can have lethal consequences. Two professions where the consequences of decision-making are self-evident, whether under routine or extraordinary circumstances, are medicine and bomb disposal.

Medicine and bomb disposal, as professions, have many similarities, although not always apparent. One facet that is readily observable however, is that practitioners in both disciplines rely, for the most part, on decision-making that is objective, dispassionate, and grounded in scientific theory and methodology, or in the parlance of the medical profession, clinical judgement. However, although bomb technicians and medical professionals make use of science and scientific methods, neither bomb disposal nor medicine are a science unto themselves, being instead, disciplines that rely on interpretive practices of science and clinical reasoning. This distinction is critical in understanding decision-making in these disciplines, as unlike physics or chemistry, there are no immutable laws that govern how a physician, physician's assistant, nurse, or bomb technician must, or will apply their knowledge, only standards-of-care and best-practices. And irrespective of flow-charts and other decision aids, the ultimate decision-making tool in both bomb disposal and medicine is the practitioner.

Montgomery (2005) states, "Physicians draw on their diagnostic skills and clinical experience as well as scientific information and clinical research when they exercise clinical judgment." And just as a physician will look at a patient's signs and symptoms, and use their own education and training, combined with clinical experience and empirical data to diagnose an illness and formulate a treatment strategy, the bomb technician will do the same to identify a potential destructive device, understand the hazards it presents, and formulate a plan to treat (i.e., render safe or neutralize) the device. Yet, according to Groopman (2007), research has shown that a physician will interrupt a patient describing their symptoms within the first eighteen seconds of information gathering, and a decision on treatment is often made within that first eighteen seconds.

While medical diagnoses made this way are often correct, they can often be catastrophically wrong. According to Knoche and Kalinyak (2015), "…misdiagnosis results in an estimated 40,000 to 80,000 U.S. hospital deaths annually, and approximately 5% of autopsies identify lethal diagnostic errors for which a correct diagnosis with proper treatment could have averted the death." To juxtapose this with bomb disposal, while research has not been conducted to ascertain damages caused by diagnostic error in the bomb disposal field, or the length of time on average it takes a bomb technician to draw conclusions about a suspect hazardous device just encountered, it is easy to understand, even for a laymen, that if a bomb technician misdiagnoses a destructive device, and it detonates, the effects are more often than not, catastrophic, even if just to property. With respect to decision-making time however, it is well-established that returning a scene to normalcy as quickly as possible is almost always a priority, tools used for diagnostic in bomb disposal are almost always visual, and minimizing time-on-target is the best protective measure in the bomb technician's self-protection arsenal.

Unlike the bomb disposal field however, the medical community has undertaken a systematic analysis of decision-making processes related to diagnostic reasoning approaches in an attempt to reduce the number of errors that occur during, and as a result of the diagnostics process. In fact, the study of diagnostic reason has become a discipline unto itself in the medical profession, and diagnostic reasoning has begun to be taught as part of many medical school curriculums. This study attempts to bring some of the diagnostic reasoning research methodologies used in the medical community to bear on the bomb disposal community in an effort to better understand the diagnostic reasoning approaches used by bomb technicians, and quantify potential diagnostic success rates.

Background of the Study

According to the literature, a number of studies have investigated various aspects of cognitive behavior in the bomb disposal community. In an effort to discover which personality characteristics enabled successful British bomb technicians to cope with the stresses of bomb disposal duty, Cooper (1982) examined shared personality traits. Two additional studies during that period also focused on stress in British bomb technicians, but looked at psychological and physiological manifestations of stress (Cox, Hallam, O'Connor, & Rachman, 1983; and O'Connor, Hallam, & Rachman, 1985). However, these two studies are far less interested in how stress affects performance, than whether bomb technicians experience stress differently than other vocational groups, or "non-successful" bomb technicians.

Hogan and Hogan (1985) looked at psychological and physical performance characteristics during U.S. Explosive Ordnance Disposal training, to determine if associations existed. These included factors like vocational preference, personality, and physical fitness. McCormick and Clutch (1991) also evaluated standard cognitive demands placed on U.S. Explosive Ordnance Disposal students during the second phase of training. Humphrey (2000) researched cognition in the U.S. bomb disposal community, investigating the predictive ability of the Armed Services Vocational Aptitude Battery (ASVAB) to determine academic success during initial bomb disposal training. He concluded that the ASVAB failed to be a valid predictor of success during training, even though at the time it was, and for many years remained, the only cognitive measurement instrument used to predict suitability for military bomb disposal training.

White, Young, and Rumsey (Young, 2000; Campbell, 2001), looked at individual motivation as a predictor for academic success, and according to their findings, there appeared to be a link between motivation and success. Then in 2002, Bates reexamined the interaction between stress and performance during U.S. military bomb disposal training, and included risk factors like general cognitive ability, inattention and impulsivity, problem-solving, anxiety, personality dimensions, social relations, and stressful events. In laymen's terms, Bates (2002) found that bomb technicians experience stress differently than non-bomb technicians, having a characteristic that some people might call, fearlessness.

Finally, two additional studies, Bundy and Sims (2007), and Bundy and Shearer (2012), reexamined cognition in bomb technicians. The former looking at similarities in learning style preferences among bomb technicians, both military and civilian from 12 different countries, and the latter looking at personality traits as a predictor of success in U.S. Army Explosive Ordnance Disposal trainees. In both studies, the data suggests that bomb technicians have common cognitive profiles, and can be used as predictors of success in the bomb disposal field.

In short, cognitive and behavioral factors affecting bomb technicians have been of some interest to the research community, but this has largely been conducted with military participants, and the civilian bomb disposal community has been largely ignored. Additionally, research has focused on cognitive abilities, rather than cognitive processes. Conversely, the medical profession has studied both cognitive ability and cognitive processes in medical professionals, attempting to reduce error rates, i.e., medical mistakes, and improve medical education and training (Olson and Graber, 2020). In fact, the medical community, and its research into diagnostic reasoning, is given credit for turning diagnostic reasoning into what has become tantamount to its own discipline, with international recognition, and supporting its own theories based on various conceptual frameworks, taxonomies, and empirical observation (Banda, 2009).

Although intuitive in some ways and obtuse in others, many similarities exist between medical diagnostics and IED diagnostics. However, if a nurse, physician's assistant, or physician make a misdiagnosis, and it results in lethal consequences, most often only the patient is affected. For the bomb technician, if a misdiagnosis is made while rendering safe a piece of ordnance, or an improvised explosive device, and the device initiates, the potential exists for not only the bomb technician to lose their life, but innocent bystanders as well. According to the EOD Warrior Foundation (n.d.), since its inception in June 1941, 343 U.S. Explosive Ordnance Disposal technicians have lost their lives performing bomb disposal duties, and this number does not include the 15 public safety bomb techs that have died performing bomb disposal duties since the early 1900s

(Bomb Technician Memorial Foundation, n.d.). These numbers also do not include bomb technicians that have sustained minor injuries, undergone catastrophic amputations, or suffered traumatic brain injuries while dealing with destructive devices.

It should also not be lost on the reader as well, that some of the same equipment used by physicians to diagnose issues with the bio-mechanical, electro-chemical entity that is the human body, are used by bomb technicians, for example, x-ray systems and spectroscopy, to name only two. And while equipment used to gather information to perform diagnostics is often of great benefit to the diagnostician, the equipment itself is not diagnostics, and is only an input to what can arguably be considered the greatest diagnostic tool available to date, the human brain. This creates somewhat of a paradox and challenge with respect to not only new or inexperienced diagnosticians, whether in the medical profession or bomb disposal field, because these individuals are often called up to perform the same duties, perform at an equal level, and share the same responsibilities as experienced practitioners. In the nursing profession, it is well documented that a nursing student's ability to formulate an accurate diagnosis, think critically, and synthesize large amounts of disparate information about processes, procedures, and protocols is particularly challenging, as they have just begun to develop these skills (Kuiper, Pesut, & Kautz, 2009; Lunney, 2010; Kaddoura, 2011; Silva et al., 2011; Yildirim & Ozkahraman, 2011; Turk, Tugrul, & Sahbaz, 2013; Carvalho de Sousa, de Oliveira Lopes, & Lopez, 2016).

Even with the impressive body of knowledge available in the medical community regarding diagnostic reasoning, it is clear from a cursory review of the literature, that a deeper understanding of the cognitive skills associated with diagnostic reasoning is being sought in order to reduce diagnostic error rates, which, according to Graber (2013), are estimated to be between 10% and 20%. In an earlier article, Graber (2005), states that 75% of diagnostic errors can be attributed to failures in physician thinking. In a report from the 7th International Diagnostic Error in Medicine Conference, Bruce et al (2016) states, “More work is required to fully understand the burden and causes of diagnostic failures, and this research is intimately intertwined with developing effective strategies to reduce diagnostic error.” Croskerry (2009), also underscores the importance of diagnostic reasoning, and aptly points out, “The critical importance of this area…is reflected in two Nobel prizes having been awarded in human decision-making, Herbert Simon in 1978, and Daniel Kahneman in 2002.” Given the significance that diagnostics plays in the bomb disposal field, it seems the roles that diagnostic reasoning and diagnostic error play in bomb technician decision-making, should be investigated further.

Statement of the Problem

The bomb technician’s job is physically, mentally, and emotionally demanding. It requires a cursory knowledge of both physical and social sciences, from physics, chemistry, and electronics, to sociology, and psychology. The former is needed to understand how a device might potentially function and the damage it may cause if initiated. The latter to understand why a bomb builder might construct a particular device, how the bomb builder’s state of mind influenced the device’s construction, and the possible reasons the bomber wants to damage or destroy a particular target. Understanding device construction, and more specifically how a device functions, is crucial in both formulating a successful render safe procedure and mitigating any potential risks, if the device should function. Because devices, and device construction, can be so varied, diagnostic reasoning is a critical skill in the bomb disposal field. To date, no formal studies have looked at the relationship between diagnostic reasoning and diagnostic success in the bomb disposal field. The purpose of this study is to examine the relationship between diagnostic reasoning and diagnostic success in the bomb disposal field, along with the effects experience, training, and education may play in success rates.

Purpose of the Study

The aim of this study was to identify and describe the diagnostic reasoning approaches used, and relative success rates achieved by bomb technicians when analyzing potential improvised explosive device circuitry. Demographic factors such as years of experience, education level, and training were defined as independent variables for this study. Numeric scores in three diagnostic categories defined as dependent variables:

1) Electronic component identification,

2) Evaluation of associated hazards, and

3) Determination of circuit type-by-function

Rationale

One of the most widely recognized early Greek medical texts is the Hippocratic Oath (NIH, 2012), which contains a tenant which is one of the most recognizable tenants of medical practice, which loosely translated is “first do no harm.” And while not a direct equivalent, in that it is more of presage than an admonishment, there is a tenant in the U.S. EOD community which is often emblazed across challenge coins, underscoring the importance of diagnostic reasoning in the bomb disposal field, and succinctly defines the rationale for this study. It reads, “Initial Success or Total Failure.”

The data collected during this study has many potential uses, but none more important than gaining a better understanding of how bomb technicians gather and analyze information, what items of information they determine to be most significant, and the extent to which education, training, and experience play in making accurate decisions regarding IED circuitry, which is arguably the most hazardous item a bomb technician is likely to face in their career. By understanding these things, it may be possible to improve training to maximize successful outcomes, and reduce deaths and injuries in the bomb disposal career field. Additionally, data from this study has the potential to directly inform shortfalls in current training related to IED electronics, and highlight specific areas of need in component recognition, and overall hazard analysis.

Theoretical Framework

How bomb technicians think about problems and make decisions regarding render safe procedures is a mostly invisible and poorly understood process. To further complicate matters, a lack of research in this area in the bomb disposal field means that there are no existing theoretical models considered unique to cognitive processes used within the discipline. Because the situations and conditions under which decision-making is performed in the bomb disposal field are so varied, with few situations or conditions ever replicating a previous incident, finding theoretical models from other disciplines with similar discontinuities was challenging. However, given the multidimensional and complex nature of medical diagnostics, it seems an appropriate theoretical lens through which to try to better understand reasoning and problem-solving processes in the bomb disposal field.

According to Yazdani and Abardeh (2019), researchers have been exploring diagnostic reasoning in the medical community since the 1980s, and can be broken down into 1) theories and models based on the process of clinical reasoning, 2) theories and models based on knowledge structure, and 3) compilation theories and models. Each of these will be discussed in Chapter 2 during the literature review, because elements of each have relevance to the discussion of diagnostic reasoning in the bomb disposal field, but even given the longevity of research in the medical field, the authors state that few robust or universally accepted theoretical models related to diagnostic reasoning exist in this field either. Regardless, several theoretical models have gained wider acceptance in the medical community, and it is from these models that the theoretical underpinnings for further exploration of diagnostic reasoning in the bomb disposal community has emerged. These are the *hypothetico-deductive*, and *pattern recognition* models, and *illness script*, *dual processing*, and *cognitive continuum* theories.

In brief, the *hypothetico-deductive model*, which was first proposed by Elstein, et al (1978), contends that diagnosticians generate a limited number of hypotheses or problem statements they feel best suit the information being assessed, and work toward finding a solution, and answer to the problem set identified. Conversely, the *pattern recognition model* takes the approach that a diagnostician looks at a patient's signs and symptoms, and directly compares those patterns with similar diseases, and selects the most similar pattern (Barrows and Tamblyn, 1980). The *pattern recognition model* also does not consider complexities of the cognitive process to be of any significance in diagnostic reasoning (Marcum, 2012).

Illness script theory suggests that diagnosticians create list-like structures representing existing knowledge gained in the clinical setting, and use those structures to perform their analysis (Barrows and Feltovich, 1987). The authors suggest that illness scripts can develop at any time during the acquisition of experience leading to expertise, and permanently changes the diagnostician's knowledge structure.

Dual-processing theory posits that two different processing modes are at play when diagnostics is undertaken (Evans, 2008). In the first system, referred to in the literature as Type 1, analysis takes place intuitively, and has similar characteristics with perception, meaning that it is fast, and seemingly automatic. Type 2 on the other hand, is a slow, rule-based, deliberative process. As the reader may have already noted, *pattern recognition* is the theoretical framework for Type 1, the intuitive system, and *hypothetico-deductive models* for Type 2, the analytic system.

The final diagnostic reasoning theory underpinning this study, is *cognitive continuum theory*. According to Hammond (1996), *cognitive continuum theory* places the outcomes of the cognitive problem-solving process on two poles, one intuitive and the other analytical, with various forms and modes of that cognition having a relational order along a continuum. Hamm (1988) admonished readers not to think of *cognitive continuum theory* as a way to explain how a diagnostician thinks analytically or intuitively, but rather as framework for describing features of the cognitive process and how those features correlate to the task being performed, in that it only provides techniques for describing cognitive modes, rather than providing an explanation of cognitive attributes related to intuition and analysis.

Each of these models and theories will be discussed further in Chapter 2.

Research Questions

The research questions for this study are as follow:

1) What form, or forms of diagnostic reasoning are used by bomb technicians when analyzing potential improvised explosive device circuitry?
2) For each diagnostic reasoning approach used, can variables be identified that affect diagnostic success rates?

Variables

This study used both *dependent* and *independent* variables. The dependent variables in this study included 1) circuit components, 2) associated hazards, and 3) circuit type-by-function. Each circuit included in this study has a fixed list of components used to construct that circuit, and this study's Expert Panel has assigned which hazards and type-by-function constitute correct diagnostic responses for each circuit.

Relative to independent variables, there are nine (9) independent variables used for this study. These include:

- Country of Service
- Years Bomb Disposal Experience
- Initial Bomb Disposal Training
- Length of Initial Training
- Self-Assessed Knowledge Level
- Specialized Training
- Formal Electronics Education or Training
- Electronics Trainer Experience
- Highest Education Level

While the importance of some of these variables may seem obvious, others are of special importance to the bomb disposal community because of the inconsistencies that exist from country to country in numbers of IED incidents that occur, types of devices encountered, and how bomb disposal is treated occupationally. For example, a bomb technician in Israel may personally conduct hundreds of render safe operations a year, while a bomb technician in the US or UK may have personally conducted only one or two in the same period. This leads to a fairly significant disparity in length and types of training, with initial training for bomb technicians being much longer, sometimes years in some countries, where in countries that see few sophisticated devices, initial bomb disposal training may only last weeks or months.

Individual organizational and situational concerns related to quantities and types of IEDs encountered in any given country, region, or area-of-operation also changes the dynamic of what is considered advance training, since in countries where more advanced devices are encountered by bomb technicians, introductory electronics training may be weeks or months long, covering electronics theory in addition to simple circuit construction, but in other countries where burning time-fuse, black-powder filled pipe bombs may be more the norm, introductory electronics training may only be hours-to-days long, and consist of nothing more than, in the all-too-literal words of Rick Haworth, "twisting wires." (Haworth, personal communication, Spring, 2020). This means that "introductory" electronics training in some countries is far more advanced than "advanced" electronics training in others. This is the reason this study asked participants to identify *Specialized* and *Formal* electronics training rather than *Advanced*, or some other descriptive, yet ill-defined term.

Experience as an electronics trainer was also captured, because if study participants training other bomb technicians have low success rates, it stands to reason that those they teach, at least initially, will also tend toward lower success rates. Whether this is a function of the instructor putting out incorrect information, or a student simply misinterpreting information being taught for whatever reason, it would be impossible to determine these types of correlations without identifying students taught by a particular instructor and then looking at that students success rates, and this is beyond the scope of this study.

Regardless, each of these variables used in this study has potential implication for how well a study participant is able to identify circuit components, hazards associated with those components, and assess the circuit type-by-function. *Country of Service* has implications for the types and varieties of circuits that study participant may have encountered, while *Years of Bomb Disposal Experience* has implications for the number of possible IED incident responses a study participant may have made during their career. Correlations for these variables are examined in relation to success rates in component identification, understanding hazards associated with different types of components and circuits, and selection of circuit types-by-function.

Independent variables such as *Initial Bomb Disposal Training*, indicating from which bomb disposal school a study participant received their initial train, and *Length of Initial Training*, as well as *Specialized Training*, are examined to see if graduates from specific bomb disposal schools, length of initial training, or specialized training correlate to higher diagnostic success rates. Similarly, levels of non-bomb technician specific electronics training and formal education levels were examined for correlations to success rates in component identification, understanding hazards associated with different types of components and circuits, and selection of circuit types-by-function.

Significance of the Study

As stated previously, while a great deal of research has been conducted on diagnostic reasoning and success in the medical field, far less, if any research has been conducted on the same for bomb disposal. This study adds greatly to the existing body of knowledge in this area as it relates to the bomb disposal field, and to a lesser degree, the diagnostic reasoning field in general. More importantly however, the results of this study provides thought leaders and managers in the bomb disposal field, as well as educators and trainers responsible for initial training and certification of bomb technicians, with new information that has the potential to cultivate and improve diagnostic reasoning and critical thinking skills in new bomb technicians. By knowing and understanding the diagnostic reasoning approaches used by bomb technicians to successfully analyze potential IED circuits, and where diagnostic errors occur, the bomb disposal field can begin to turn errors into successes, and potentially prevent bodily injury, and unnecessary loss of life.

Definition of Terms

Bomb Disposal. Bomb disposal is the term commonly used to describe the separate but interrelated fields of military Explosive Ordnance Disposal (EOD), and civilian public safety operations involving the rendering safe and disposal of ordnance, improvised explosive, and other hazardous devices.

Bomb Technician. Any military service member or public safety officer trained to identify, render safe, and dispose of commercial, military, or improvised explosive devices and incendiaries.

Explosive Ordnance Disposal. "The detection, identification, field evaluation, rendering–safe, recovery, and final disposal of unexploded explosive ordnance (UXO). It may also include the rendering–safe and/or disposal of EO [explosive ordnance] which has become hazardous by damage or deterioration, when the disposal of such EO requires techniques, procedures, or equipment which exceed the normal requirements for routine disposal." (Department of the Navy, 1992)

Render Safe Procedure. Bomb disposal procedures involving the use of special methods and tools especially designed for the interruption of functions or separation of essential components of unexploded ordnance or improvised explosive devices. These tools and methods are applied to prevent an unwanted detonation of explosive components.

The Real Definition of EOD. "The science of vague assumptions, based on debatable figures derived from inconclusive experiments, performed by persons of doubtful reliability and questionable mental capability, with instruments of problematic accuracy" (Defence EOD School, 1991, p. 26-1).

Diagnostics: The use of tools, methods, processes, or procedures to determine the state or condition of a biological, mechanical, or electrical system or systems.

Diagnostic Reasoning: The cognitive process or processes leading to the identification of a hypothesis that best explains medical, experimental, or scientific findings.

Dual Process Theory: Dual process theory is a theory used to represent and explain how people think. Dual process theory consists of two types of thinking, identified as Type 1 or System 1 thinking, and Type 2 or System 2 thinking. Type 1 thinking being intuitive, with pattern recognition and use of heuristics at its roots. Type 2 thinking is analytical, using a hypothetico-deductive reasoning as its core process.

Hazardous Device. See Improvised Explosive Device.

Improvised Explosive Device. An improvised explosive device (IED), often referred to as a *hazardous device* in the civilian bomb disposal community, is defined as, "A device placed or fabricated in an improvised manner incorporating destructive, lethal, noxious, pyrotechnic, incendiary chemicals or hazardous materials designed to destroy, disfigure, distract or harass. It may incorporate military stores, but are normally devised from non-military components." (Department of the Air Force, 2004)

Assumptions and Limitations

Regardless of the type of research being conducted, there is always the potential for bias to be introduced by the researcher, whether that is in the form of the research methodology used, the study population investigated, who within that population is selected for participation, how the study instrument is made available to participants, and even interpretation of the data collected. Pannucci and Wilkins (2010) state that this occurs whether the researcher is aware of these biases or not, but should be acknowledged or controlled to the extent possible. Striving toward this goal, this study acknowledges the following parameters:

- This study examined diagnostic reasoning approaches and success rates in military and public safety bomb technicians as it applies only to electronic component recognition, hazard assessment, and type-by-function determination for potential IED circuits.

- The population studied was current and former English-speaking bomb technicians from the global bomb disposal community.
- Diagnostic reasoning approaches and success rates were measured using an online data collection instrument whose design was informed by research conducted in the medical community.

All of these factors contribute in one form or another to intentional or unintentional bias, and by their very nature, generate certain assumptions by the researcher as to what can or cannot be done, or what can or cannot be accomplished during the study. As such, the following assumptions were employed during the study:

1. Diagnostic reasoning research methodologies applied in the medical community will have similar usefulness in the bomb disposal community. Since only research methods are being replicated, not discipline-specific content, this should not skew, or invalidate findings.
2. The data collection instrument used, and scenarios employed in this study, were capable of capturing data required to assess the diagnostic reasoning approaches used by individual bomb technicians.
3. The circuits used in the scenarios contained in this study are representative of those that may potentially be encountered by bomb technicians in the field. An expert panel was used to help validate circuits used to ensure applicability.
4. Terminology used for components, hazards, and circuit types-by-function are similar enough internationally that bomb technicians from different English-speaking countries will recognize them as viable checkbox options. A free-text field was provided for each area to help mitigate the effects any potential

mismatch in terminology by allowing the bomb technicians to add items if desired.

5. Because participation in this study is voluntary, it was assumed that only bomb technicians who have a personal interest in electronics would volunteer to participate in the study. While this may skew results toward higher success rates than may be representative for the average bomb technician, it should have little impact on data related to diagnostic reasoning approaches, as even bomb technicians with a personal interest in electronics will have varying levels of training, and self-assess electronics skill levels.
6. Participants who completed the scenarios did so individually, without assistance from other bomb technicians or subject matter experts. For the purposes of analysis, it was considered acceptable for a study participant to have googled, or otherwise looked up material to use in completing the study, because this is still an individualized approach, it is not acceptable for this to be a collective effort, which would represent a convergence of multiple individual approaches.
7. The study population sampled was representative of individuals in the larger, global bomb technician community.

Limitations of this study are attributed to the following factors:

1. This study does not account for potential differences in diagnostic reasoning approaches or success rates influenced by gender, ethnicity, or cultural factors.

2. Data, and ultimately analysis and interpretation of that data, are limited by the adequacy of instrumentation, and availability of participants.
3. The data collection instrument used for this study was a self-reporting instruments, and inherently subject to problems associated with self-reporting instrumentation.
4. The data collection instrument used for this study was a web-based instrument, therefore, only participants with computers and internet connections were able to participate.
5. Data was not able to be captured on diagnostic reasoning approaches and success rates for non-English-speaking bomb technicians, and therefor limited the ability to generalize finding from this study to non-English-speaking bomb technician communities.
6. This study was limited to diagnostic reasoning approaches as used by participants at a static point in time, and does not address potential variations in findings due to length of time since circuit diagnostics were last attempted by participants, or time elapsed since last performing bomb disposal duties.

Organization of Remaining Chapters

The remaining chapters consist of a review of the literature underpinning the fundamental theoretical principles of this study (Chapter 2); a discussion of the research methodology used (Chapter 3); an analysis and findings from data collected (Chapter 4); this researcher's conclusions drawn based on the findings and recommendations for additional research on diagnostics as it applies to bomb disposal (Chapter 5).

CHAPTER II

LITERATURE REVIEW

"Ignorance more frequently begets confidence than does knowledge."

– Charles Darwin

It is often difficult to know where a problem begins and where it ends. With respect to investigating diagnostic reasoning approaches and success rates in the bomb disposal community, literature needs to be reviewed in several areas to include: the significance of, or why it is important to look at diagnostic reasoning approaches and success rates; what constitutes error, and how error is measured; cognition studies in both the bomb disposal and medical communities; and causes of diagnostic failure or success. Collectively, background literature in these areas should provide readers with a better understanding of the nature of the issues faced when examining problem-solving and diagnostic reasoning in the bomb disposal community, and why investigating this issue has significance.

Bomb Technicians, IEDs, and Expert Testimony

There is often a great deal of debate among practitioners in the bomb disposal community regarding what constitutes a destructive device. Although the term *destructive device* has a specific definition under the National Firearms Act (Bureau of Alcohol, Tobacco, Firearms & Explosives, 2009), it includes such items as improvised explosive devices (IEDs), improvised incendiary devices such as Molotov Cocktails, and military ordnance modified for criminal and terrorist use. These devices can range from dry-ice and water filled soda bottles, and small black-powder or pyrotechnic filled tubes similar to firecrackers, to vehicle-borne IEDs filled with thousands of pounds of high explosives. Firing systems for such devices can also vary greatly ranging from fire-cracker-like burning time fuse, to remote control circuitry that can be initiated from anywhere across the globe. All of this makes the job of a bomb technician more difficult, not only from a render-safe perspective, but from a device diagnostics perspective as well.

Bomb technicians are also often required, being "experts" on such devices, to give testimony in trials related to the use of destructive devices. Admissibility of evidence related to destructive devices is changing however, and what constitutes providing expert testimony is becoming more tenuous. This is particularly true in situations where incomplete devices are recovered after a render safe procedure (RSP) has been performed, evidence is collected from a post-blast scene, or a "bomb maker's" shack has been discovered, and only pieces and parts of incomplete devices are found. Render safe procedures are almost always destructive in nature and intended to separate components a destructive device's firing circuit to prevent a destructive device from functioning. This may include use of an explosively actuated tool known as a dearmer or disruptor, or placement of a countercharge that uses energetic materials (i.e., explosives) to tear the device apart and scatter components. The term *post-blast* refers to investigation of a potential crime scene after an explosion has occurred, where collection and preservation of evidence is undertaken to determine potential origin and cause of the explosion.

Even when a fully-functional device, meaning a device that has not been rendered safe, but still has the potential to be initiated either through some action of the bomb builder (command detonation), an action taken by the intended target of the bomb (victim operated), or after a predetermined period has elapsed (time) has been recovered, bomb technicians have to be concerned as to the veracity of evidence they are providing about a device's construction and functionality. Prosecutors have begun requiring what bomb technicians believe to be unreasonable levels of proof regarding the logic used to determine the viability of a device, citing standards set forth in what is known as the Daubert decision, and the Daubert Amendment to Rule 702 (Public Safety Bomb Technician, personal communication, Summer, 2016). It is important that bomb technicians understand these standards, and what implications they actually have for not only themselves, but the bomb technician community in general.

Under *FRE 702. Testimony by Expert Witnesses*, a witness who is qualified as an expert by knowledge, skill, experience, training, or education may testify in the form of an opinion or otherwise if:

(a) the expert's scientific, technical, or other specialized knowledge will help the trier of fact to understand the evidence or to determine a fact in issue;

(b) the testimony is based on sufficient facts or data;

(c) the testimony is the product of reliable principles and methods; and

(d) the expert has reliably applied the principles and methods to the facts of the case.

In the Daubert Amendment to Rule 702, the U.S. House of Representatives Committee on the Judiciary clarified Daubert, stating, “Daubert set forth a non-exclusive checklist for trial courts to use in assessing the reliability of scientific expert testimony.” The Committee goes on to say, “No attempt has been made to ‘codify’ these specific factors. Daubert itself emphasized that the factors were neither exclusive nor dispositive…The standards set forth in the amendment are broad enough to require consideration of any or all of the specific Daubert factors where appropriate.” (Legal Information Institute, n.d.) According to Dahl (2019) “The Committee is considering a possible amendment that would add the following requirement to the list of Rule 702’s admissibility factors: (e) the expert does not claim a degree of confidence that is unsupported by a reliable application of the principles and methods.”

After examining criminal cases on expert testimony and improvised explosive devices (IEDs), it is clear to this author that testimony for the prosecution regarding IEDs generally falls into one of two categories: 1) testimony related to forensic analysis, or 2) opinion presented by bomb disposal practitioners, or former practitioners in the field of bomb disposal. The reader does not have to look far to find that the field of forensic science, and opinion provided as a result of forensic analysis, is subject to close scrutiny by the courts, as studies in recent years have uncovered everything from direct falsification of forensic analysis data to shockingly high rates of measurement error when the results are subjected to independent validation and verification, or technical peer review (National Research Council, 1992; Aitken and Taroni, 2004; Holdren and Lander, 2016; President's Council of Advisors on Science and Technology, 2016). This will be covered further in the section on Measuring Error.

Interestingly, in the Daubert decision the court expressly states that error rates should be considered as a factor to determine if a particular scientific method is sufficiently reliable to be admissible, and yet, according to most legal scholars, it has rarely been used to exclude exaggerated or unproven forensic science evidence (Ward, 2018). Running parallel to this, is the courts apparent willingness to allow admissibility of bomb technician expert opinion based on experience, which implies that the bomb technicians level of experience is sufficient to help the trier of fact determine the viability of, and potential damage that could be caused by the device in question. Such deference is generally conferred based on standards for expert testimony admissibility, as outlined in FRE 702, which codifies the position that experts are not required to come from a scientific background (Legal Information Institute, 2011).

Although all bomb technicians in the U.S. have a basic level of training on the construction, functioning, and blast effects of IEDs, additional education, training, experience, and self-guided study creates a stratification between what can be considered a novice or expert in the bomb disposal field. This stratification becomes even more apparent in post-blast device reconstruction, where recreation of the entire device, or a determination as to firing and functioning of that device, must be ascertained solely from a visual examination of components, many of which may have been damaged by a render safe procedure, or a detonation of the device itself.

To understand why this might, or should impact deference provided bomb technicians by the courts with respect to their testimony, some basic facts should be taken into consideration. According to John Stewart (2018), Unit Chief at the FBI's Hazardous Devices School, there are approximately 3,100 certified public safety bomb technicians in the US. These bomb technicians belong to one of 469 squads scattered across the US states and territories, and according to the National Bomb Squad Commander's Advisory Board (NBSCAB), over 86% of bomb technicians are "part-time" technicians, meaning that being a bomb technician is a collateral duty, and not their primary job.

Taking this into consideration, alongside data from the ATF stating there were only 131 actual IED incidents in the US in 2018 (United States Bomb Data Center, 2018), it becomes difficult to understand why the courts confer technical expertise to bomb technicians based on experience, when averaged out, data suggests that individual bomb technicians, and even entire squads, may encounter less than one actual IED a year. This lack of apparent experience responding to actual IEDs appears to have some validity, as data gathered in a longitudinal study covering a period from 2005-2010 of bomb squads in the US reported that that a significant number of squads responded to no IED incidents -- real, hoax, or suspicious packages -- in any given year (Bundy and Heaven, 2012).

Additionally, the accuracy and reliability of some tools used in bomb disposal also appears questionable. For example, in calendar year 2020, military bomb technicians identified that ammunition used in the Percussion Actuated Non-Electric (PAN) disruptor, the primary tool for conducting render safe procedures in both the military and public safety bomb technician communities, have peak pressure differentials between cartridges of as much as 40%, causing large variances in projectile velocities, targeting accuracy, and barrier penetration. According to technicians, these variances often caused complication when attempting to conduct precision render safe operations. This is an example of a single piece of equipment, but many more exist.

Unfortunately, little data exists as to the general reliability or accuracy of the tools a bomb technician uses, or any individual bomb technician's level of knowledge, skills, or abilities. And even though the courts suggest that the general technical knowledge and practices of a community should be one factor in determining admissibility of opinions proffered by its practitioners, it is not always a sufficient characteristic. Courts have also begun to reject ambiguity, a condition where evidence is incomplete (Phillips, et al, 2001), and subjectivity, a condition where interpretation rests on an individual's experience or belief (Thornton and Peterson, 2002). As such, it would behoove the bomb disposal community to begin thinking about gathering data to quantify error rates for tools and procedures, as well as justification for the deference the community is afforded.

Clearly then, while a bomb technician's evidence is not on trial, his or her conclusions regarding that evidence certainly are. Setting aside for a moment the original intent of the 2000 Amendment, it is clear that even before the Daubert decision, courts felt that too much latitude was given to what was being purported in court cases, as "scientific evidence." According to Segal (2018), the first test of admissibility of scientific evidence in federal court occurred in the D.C. Circuit in 1923 in Frye v. United States. In this case, the court was asked to consider the admissibility of the results of an early lie detector test. In this case, the court opined that to be admissible, a scientific methodology "must be sufficiently established to have gained general acceptance in the particular field in which it belongs." (Frye v. United States, 1923) This criteria for admissibility became known as the "general acceptance test," and guided the courts admissibility standards until 1993, when, as a result of the Daubert decision, the Supreme Court displaced this test (Segal, 2018). Where this becomes problematic for the bomb disposal community, is that even while deference is generally given to bomb technician testimony based on perceived status as “experts” in the bomb disposal discipline, very little testimony given by bomb technicians is founded on analysis using the scientific method, or even an understanding of scientific principles, taking more of an *ipse dixit* approach.

Ipse dixit is Latin, and translated means “he said it himself,” which more can more loosely be translated as “It is because I say it is,” and according to Gutheil and Bursztajn (2003), testimony based on *ipse dixit* fails to offer the systematic or methodological approach required in a post-Daubert world. In general, the approach most bomb technicians use to draw conclusions regarding the nature of a device (i.e., its construction and how it functions, to include possible blast or fragmentation effects), is *assessment* (i.e., opinion based on knowledge gained from training and experience, usually lacking scientific rigor), rather than *analysis* (i.e., using well-established scientific principles and methods that can be independently validated and verified to gather data and draw conclusions). In fact, most bomb technicians lack certification as investigators, and have only passing familiarity with elements of the scientific method, unless they have taken additional training beyond bomb technician certification, as only bomb disposal techniques are taught during Hazardous Devices School, and very little attention is given to the scientific principles that underpin those techniques.

In defense of their own expertise, bomb technicians will often claim that their assessment of a device, or a devices capabilities and functioning, is based on scientific principles; however, when pressed on their understanding of scientific principles, it is clear that their assessments are not grounded in scientific fact, but rather subjective opinion or anecdotal evidence. This is not to say that the information delivered during training courses is necessarily inaccurate or misleading, but these courses are not designed for, nor are they intended to teach scientific principles to new bomb technicians; instead, the focus is on teaching bomb technicians what procedures should be followed in what circumstances, and how to use specific or specialized tools to accomplish a particular mission or resolve an incident.

Another option a court may choose to invoke regarding a bomb technician's testimony is "judicial notice," which eases the burden on bomb technicians for establishing that their opinion is based on scientific principles. This approach can be fraught with peril however, as even though judicial notice provides courts a mechanism by which to admit testimony without a Daubert inquiry, the courts clearly remain in favor of scientific rigor. This is evidenced by the original Daubert opinion, which touched briefly on the use of judicial notice, stating in a footnote, "…theories that are so firmly established as to have attained the status of scientific law, such as the laws of thermodynamics, properly are subject to judicial notice under Fed. Rule Evid. 201." (Daubert v. Merrell Dow Pharmaceuticals, Inc., 509 U.S. 579–601, 1993.)

It is worth noting that a meta-study conducted by Dixon and Gill (2002) prior to the Daubert Amendment, which used a sample of three-hundred and ninety-nine federal district court opinions to quantify "types of expert evidence challenged; criteria used to evaluate expert evidence; reasons expert evidence is excluded; proportion of challenged evidence excluded; types of challenged evidence excluded," discovered that in addition to the five original Daubert requirements, and five additional factors listed by the U.S. House of Representatives Committee on the Judiciary in the Daubert Amendment to Rule

702 (2015), judges, plaintiffs, and defendants called into question the following additional factors:

- Clarity and coherence of expert's explanation of theory, methods, and procedures
- Breadth of facts, data, or studies underlying analysis
- Reliance on verifiable evidence
- Use of facts or data reasonably relied on by experts in the field
- Consistency of theory or findings with other studies, principles, or experts in a particular field
- Statistical significance of findings
- Existence of real-world data to support theory
- Court-appointed neutral expert's evaluation of evidence
- Reputation of the expert

Under the Daubert standard, the original factors that may be considered in determining whether a methodology is valid are: (1) whether the theory or technique in question can be and has been tested; (2) whether it has been subjected to peer review and publication; (3) its known or potential error rate; (4) the existence and maintenance of standards controlling its operation; and (5) whether it has attracted widespread acceptance within a relevant scientific community (Daubert v. Merrell Dow Pharmaceuticals, 1993).

It is also interesting that the Committee felt it necessary to point out that both before and after Daubert, courts have typically looked at other factors which should be considered relevant in determining whether "expert testimony is sufficiently reliable" to allow admissibility. These factors include:

(1) Whether an expert's testimony regards research that was done solely for the purpose of a court case

(2) Whether the expert has over-generalized findings to the point where erroneous conclusions are being drawn

(3) Whether the expert has considered alternative explanations

(4) Whether the expert is being as cautious with conclusions drawn for the court case, as he or she would in regular practice, and

(5) Whether the expert's field of expertise is known to reach reliable conclusions about matters in the area being tried by the court (U.S. House of Representatives Committee on the Judiciary, 2015)

This means that while Daubert requirements and Committee factors listed have been identified as issues that should be considered when determining the reliability, and therefore admissibility of expert testimony, the Rule as amended gives great latitude to the courts in examining other factors in its determination. In the end however, power remains in the hands of the court to determine which factors are most relevant to a particular case, but even when admitted, expert testimony can always be challenged by either side in the proceedings if doubts arise as to the reliability or validity of testimony being presented; this should give bomb technicians pause.

At this point it also seems prudent to make a distinction, at least for the purpose of this discussion, between *analysis* and *assessment*. In most cases, where exploitation of potential IED circuitry is concerned, electronics analysis requires specialized training and equipment, and is based on well-established scientific principles and methods, and uses instrumentation to provide data that can be validated, and used evidentiarily. Assessment of potential IED circuitry on the other hand, may be conducted under field conditions, at an incident site, in a laboratory, or at any other location the device may be encountered. Assessment of potential IED circuitry usually requires no additional training beyond familiarization with basic IED construction, or graduation from a bomb disposal school, and usually requires no specialized equipment. In essence, assessment of IED circuitry is usually visually based, with the assessor looking at the device or image of the device, or perhaps and x-ray. In reviewing images of the device, whether a still image, video feed, or x-ray, the assessor is interpreting what is being seen, and applying any past experience, knowledge, or training they may have to make determinations about the viability of a device, its functionality, and any hazards it may present.

In the first case, where an analysis of the electronics in question has been conducted by an individual who has received specialized training, and used specialized equipment to gather data and make determinations, a judge will likely be able to decide rather easily whether evidence provided by a forensic analyst should be admitted and provided to a jury based on the Daubert standard. There is probably little doubt that such testimony would stand up to the scrutiny of a Daubert inquiry. The findings from an assessment of IED circuitry however, is not only likely to prompt a Daubert inquiry, but the reliability and veracity of the knowledge and experience of the proffered expert presenting testimony would likely need to be established as well.

Bomb technicians would be well advised to consider that courts are increasingly demanding more proof that tools, techniques, and procedures are based on well documented scientific principles. Even if a bomb technician believes their testimony to be based on scientific principles and methods, rather than simply experience, they remain subject to a Daubert inquiry, and where once the bomb disposal profession was considered a "dark art," with its tools, techniques, and procedures shrouded from public view, an increase in the world-wide use of IEDs in recent decades has shined a light on the subject, and created a proliferation of information about technical aspects of IEDs that was once only available to investigators, bomb technicians, and forensic examiners.

To say the information on IEDs and counter-IED technologies is voluminous is an understatement, as a quick search on Google Scholar for a period ranging from 2003 to present (June 2022) of the term "improvised explosive device exploitation," returned 17,500 peer-reviewed articles. In short, anyone with access to the Internet, has as much, if not more, access to technical information on IEDs than a bomb technician learns during initial training at a bomb disposal school.

Measuring Error

Measuring error can be difficult, and is often controversial, especially to those being scrutinized for potential error. The need for correctness seems to be built into the human psyche, as is evidenced by *confirmation bias*, or the condition in which, when free to choose information sources, people will seek out sources that support their position, rather than sources that offer an alternative perspective (Taber and Lodge, 2006). Since it is probably unrealistic to expect that all error can be eliminated, it is fair to ask how much error is acceptable, and under what circumstances? Of course the answer to this question is situationally dependent. For some professions however, like architectural engineering, neurosurgery, and bomb disposal, most people will probably agree that the answer should be more restrictive than in some other professions, because even small errors in these professions can have catastrophic consequences.

The catastrophic nature of potential error in some professions is one reason why it is necessary to measure error, but another is to understand, in the aggregate, what implications error might have within a system. Take for example forensic science, where according to Saks and Koehler (2005), the two leading causes of wrongful convictions are testing error, meaning that the results of forensic analysis tests were inaccurate, and the other being false or misleading forensic testimony, which is self-explanatory. Even though outlined and expanded upon by Daubert and Federal Rules of Evidence Rule 702, what is considered acceptable error is not fixed, or even quantified. Instead, what is considered acceptable is usually defined by the triers of fact such as the court, or the consumers of information produced by examiners, technicians, or scientists.

Investigators will often point to use of the *scientific method* to bolster confidence in their conclusions, while forensic scientists and laboratory technicians refer to the establishment and use of protocols and procedures, as well as accreditations and certifications to support the accuracy of findings. The reality of the situation however, is that it is impossible to eliminate all error. As noted by the famous scientist Richard Feynman, "Scientific knowledge is a body of statements of varying degrees of certainty -- some most unsure, some nearly sure, but none absolutely certain." (Feynman and Leighton, 2001)

Without delving too deeply into minutia, terms that collectively help laypeople and the courts better understand what is meant by *measurement error*, are terms like *accuracy*, *precision*, and *percentage-of-error* (Heidaryan, 2019). Fortunately, if forensic laboratories are using high quality, properly functioning, and well calibrated equipment, accuracy and precision are built into the test equipment itself. This is not to say that the precision or accuracy of a particular piece of equipment will always produce a 100% error-free measurement, as most tools have inherent strengths and weaknesses. What it should do however, is produce measurements within established community accepted tolerances. Rarely though, will these results be 100% accurate in the absolute sense.

In most cases, *precision*, or how consistently the device delivers the same value for the same measurement, and *accuracy*, how close to the measured value is to the "real" value, will depend on how well a tool was designed and assembled. The variability in wrist-watches highlights just how different accuracy and precision are from timepiece to timepiece, even though all watches are designed to provide the same data. For an individual brand and model of watch, error rates can only be improved by improving how, and with what care, the watch is manufactured; this is true for any instrument. Because there will always be some degree of inherent measurement error, or percentage of error, one can only calculate how far a given reading or measurement deviates from a range of known measurements. In the final analysis, it requires human judgement to determine whether the measurements produced by a tool are useful, which brings us back to the courts, as the consumer of forensic science analysis and data.

According to The American Society of Crime Lab Directors Lab Accreditation Board (https://www.ascld.org), there are three "classes" of error:

- Class 3: An error determined to have a minimal effect, that is unlikely to recur, and does not affect the fundamental reliability of the laboratory's work
- Class 2: An error that is more serious than Class 3, but not persistent enough to cause immediate concern over the lab's overall work

- Class 1: A serious error. The nature and cause of the error call into question the reliability of the laboratory's work.

The fact that the Lab Accreditation Board discriminates between three classes of error highlights why human judgement is critical in defining what is or is not an acceptable error rate, and in determining what can be put forth as evidence in court. FRE 702, and its state equivalents, governs the admissibility of expert testimony, including forensic analyses. In addition to the original guidelines for admissibility established in FRE 702, the 2000 Amendment to Rule 702 added the following requirements:

- the testimony is based on sufficient facts or data
- the testimony is the product of reliable principles and methods, and
- the expert has reliably applied the principles and methods to the facts of the case.

According to Koehler (2018), this means that forensic science expert testimony, unlike most other forms of evidence, is inadmissible unless the evidentiary proponent can demonstrate that it is reliable, even though Rule 702 did not spell out what it means for expert testimony to be reliable; that is up to the court to decide. However, Daubert and the Advisory Notes to Rule 702, do offer the courts suggestions on factors that might be considered to help determine reliability. These include:

1. Whether the expert's theory or method has been tested,
2. Whether the theory or method has been subject to peer review and publication,
3. The method's error rate,
4. Whether the method is a standard one with controls, and
5. Whether the theory or method has been generally accepted in the scientific community.

As Koehler (2018) notes, while these factors are considered in the legal arena, they are "fundamentally scientific in nature," and "judges should look to the broader scientific community for guidance when deciding whether proffered scientific evidence is sufficiently reliable to justify its admissibility at trial." The author goes on to say however, that the forensics community might not be the best scientific community to provide this guidance, because of its close ties to law enforcement.

Koehler (2018) also points out that the larger, non-forensics scientific community would likely offer a very different perspective on the extent to which forensic science claims stand up to empirical testing, as it is, or at least should be, a disinterested party. Two seminal reports, the 2009 National Academy of Sciences (NAS) Report, and the 2016 President's Council on Science and Technology (PCAST) Report, also support this contention. The 2009 NAS report repeatedly states that there is little scientific data to demonstrate the reliability or accuracy of the methods used in many of the forensic sciences, and concludes, "little rigorous systematic research has been done to validate the basic premises and techniques" of most forensic disciplines, and these disciplines "have yet to establish either the validity of their approach or the accuracy of their conclusions."

The 2009 NAS report also states, "A key task… for the analyst applying a scientific method is to conduct a particular analysis to identify as many sources of error as possible, to control or eliminate as many as possible, and to estimate the magnitude of remaining errors so that the conclusions drawn from the study are valid." (National Research Council, 2009, p.111) In summarizing the report, Du (2017), states "What applies to physics and chemistry applies to forensic science," and concludes that errors should, to the greatest extent possible, be quantified. The PCAST report goes even further, giving the courts specific guidance for assessing the scientific reliability and validity of proffered forensic science evidence, and weighs in on how to determine whether a principle, method, or purported fact is scientifically reliable and valid.

The PCAST report also underscores the importance of testing forensic claims and methods, and states that such tests are “an absolute requirement” for any claim of scientific reliability or validity. However, not everyone agrees with the conclusions reached by the NAS or PCAST reports. With respect to the PCAST report, the Department of Justice (DOJ) concluded that PCAST had overstepped its role as a science and technology advisory council by making recommendations about the courtroom use of forensic science, noting that since its release, defense attorneys often cite PCAST’s conclusion that forensic methods are unreliable, or have not been properly validated. The DOJ went as far as to state, “while we appreciate PCAST’s contribution to the field of scientific inquiry, the DOJ will not be adopting the recommendations related to the admissibility of forensic science evidence.” (Hunt, 2017).

Unfortunately, there are far too many examples of forensic scientists failing to demonstrate scientific reliability and validity of proffered evidence. One noted example, which is germane to this study, is when an American lawyer named Brandon Mayfield was wrongfully accused of committing the Madrid Train Bombings in 2004, which killed 192 people. Despite Mayfield being in the United States at the time of the bombing, and no other evidence linking him to the crime, Mayfield was arrested after three FBI fingerprint experts concluded that his fingerprint matched a fingerprint found on a bag of detonators found at the crime scene. Shortly after Mayfield’s arrest, Spanish Police notified the FBI that an Algerian man named Daoud Ouhnane had been confirmed as the source of the print. The FBI subsequently withdrew their identification of Mayfield as the bomber and released him from custody (Ribeiro, Tangen, and McKimmie, 2019).

Koehler (2017) identifies other examples where forensic science has fallen short with respect to reliability, and highlights examples such as the identification of statistical errors in the FBI's DNA database; a moratorium on bite mark evidence in Texas; massive crime lab scandals in Massachusetts; and an acknowledgment by the Justice Department and FBI that microscopic hair testimony was exaggerated in more than 95% of cases. However, some of the forensic disciplines are beginning to examine error rates even though to date, as far as this researcher was able to determine, no forensic science discipline has published well-established error rates, simply because too few studies have been conducted. In fact, a recent study by Murrie, Gardner, Kelley, and Dror, (2019) identified that, irrespective of the lack of known error rates, forensic examiners gave unrealistically low estimates of error rates in their own disciplines. The authors went on to say that of the examiners studied, the vast majority could not identify a single source for estimated error rates.

Koehler (2017) contends that forensic science leadership should take much of the responsibility for a lack of belief in, or visibility into error rates within their own organization and the broader forensic science community, claiming that leaders in the field of forensic science tend not to "create and promote a scientific culture within the profession in which the study, measurement, and reporting of error is an integral part of the work performed." The author supports this contention by citing the words of Professors Michael Saks and David Faigman, who state that many of the forensic sciences have devolved into "nonsciences," whose "primary claims for validity rest on anecdotal experience and proclamations of success over time." It is also interesting to note that in Daubert, the Court expressly states that error rates should be considered as a factor to determine if a scientific method is sufficiently reliable to be admissible, and yet, according to most legal scholars, it has rarely been used to exclude exaggerated or unproven forensic science evidence.

So what constitutes an acceptable error rate? Again, that appears to depend on who is using the information, but that may not remain the case in the future, as the judicial system begins to demand more visibility into just how such rates are determined.

Research into Cognition in the Bomb Disposal Community

While the population for this study is the bomb technician, and the primary focus is diagnostic reasoning and cognitive approaches that lead to success in problem-solving, little literature has been generated by the research community into the bomb technician population itself, or cognitive abilities within that community. Given the nature of the community, which tends to be secretive anyway, and the nature of the job performed, which tends to be solitary, this is not incredibly surprising. Regardless, a few studies related to this topic do exist, and those will be addressed in chronological order.

The first study this author was able to uncover, acknowledging full well that other earlier studies on bomb disposal operators may exist, was conducted by Cooper (1982), in cooperation with the British Royal Army Ordnance Corps. This study focused primarily on psychometric measures, and sought to establish whether personality traits exist that can predict an individual's ability to perform well in stressful situations, and under stressful conditions. Three psychometric inventories were used for this study, and included the 16PF lnventory, Clinical Analysis Questionnaire (CAQ), and the Dynamic

Personality Inventory (DPl). According to Cooper (1982) these inventories measured the following characteristics:

16PF: 16 bipolar source trait personality factors

- Factor A - Reserved and critical vs. warm-hearted and easygoing
- Factor B - Low intelligence vs. high intelligence
- Factor C - High ego strength vs. low ego strength
- Factor E - Submissiveness vs. dominance
- Factor F - Somber vs. enthusiastic
- Factor G - Low superego vs. high superego
- Factor H - Timid v adventurous
- Factor I - Toughminded vs. tender
- Factor L - Trusting vs. suspicious
- Factor M - Practical vs. imaginative
- Factor N - Artlessness vs. shrewdness
- Factor O - Untroubled adequacy vs. guilt proneness
- Factor Q1 - Conservatism vs. radicalism
- Factor Q2 - Group inherent vs. self-sufficient
- Factor Q3 - Low self-sentiment vs. high self-sentiment
- Factor Q4 - Low ergic tension vs. high ergic tension

CAQ – A clinical pathology questionnaire consisting of 12 scales

- 01 – Hypochondriasis
- 02 – Tendency toward Suicide
- 03 - Brooding Discontent
- 04 - Anxious Depression
- 05 - High Energy Euphoria
- 06 – High Guilt and Resentment
- 07 - Bored Depression
- Pa – Paranoia
- Pp - Psychopathic Deviation
- Sc – Schizophrenia
- As – Psychasthenia
- Ps - Psychosis

DPI: 33 bipolar scales of social/interactive and intra-psychical dimensions of the personality

- H - Acceptance of Social Values vs. Rejection of Accepted Values
- Wp – Passivity vs. Activity
- Ws - Seclusion, Withdrawal and Introspection vs. Avoidance of Seclusion
- O - Self-Indulgence and Sociability vs. Use of Denial as Defense
- OA - Impulsiveness vs. Non-impulsiveness

- Od - Emotional Dependence on Others vs. Difficulty in Forming Warm Personal Relationships
- Om - Individuality vs. Need for Security
- Ov - Dominance and Competitiveness in Relationships vs. Shyness in Relationships
- Oi - Spontaneous in Relationships vs. Inhibition and Overcontrol
- Ou - Conventional vs. Unconventional in Behavior and Habits
- Ah - Possessive vs. Lack of Concern with Possessions
- Ad - Obsessive-Compulsive vs. Disregard for Precision and Detail
- Ac - Conservative in Relation to Problems vs. Tendency to Disregard Tradition and Unorthodox in Approach to Problems
- Aa - Submissive to Authority vs. Rejection of Authority
- As - Tolerant vs. Authoritarian
- Ai - Emotionally Insular vs. Liberal Outlook in Relationships
- P - Self-Confident and Assertive vs. Lack of Self-Confidence
- Pn - Narcissism vs. Masochism or Reaction as a Defense against Self-love
- Pe - Exhibitionism vs. Self-Effacing
- Pa - Psychological Drive and Ambition vs. Inadequate Drive
- Ph - Independence vs. Need for Security
- Pf - Self-Confidence and Intelligence vs. Shyness
- Pi - Adventurous vs. Dislike of Physical Risk
- S - Acceptance of Sexual Impulses vs. Suppression of Impulses
- T1 - Positive Feelings and Expressions vs. Unwanted and Unloved Feelings
- C1 - Creative and Artistic vs. Lack of Creativity
- M - Tendency Toward Masculinity in Style of Behavior
- F- Show Feminine Identifications, Social Roles (High Score, Over-cautious vs. Low Score, Tolerance to Conditions of Stress)
- MF - Emotional Maturity vs. Anxiety
- SA - Gregarious vs. Shy
- C - Need to Give Affection vs. Cold and Schizoid, Difficulty in Maintaining Emotional Ties
- EP – Ego Defensiveness vs. Tendency to Give in Easily
- E1– Initiative vs. Indecisive

Cooper (1982) used a t-tests for independent samples to calculate significance of differences between what he classified as successful bomb disposal experts, meaning those who had performed with distinction in Northern Ireland, and a control group of bomb technicians of no notable distinctions. For two of the three inventories, the 16PF and CAQ, no significant differences could be found between the two groups. For the DPI however, nine significant differences were noted, prompting Cooper to suggest, that while there may be no difference between bomb technicians in pathological/clinical and individual personality traits, there may be differences in interpersonal and social behaviors and orientations, even though a closer examination of the data revealed relatively consistent social behavioral patterns.

The results of Cooper's study (Cooper, 1982), can be reduced to the following:

- Data suggests that successful bomb disposal technicians seem to have low-level affiliation and affection motivation, as identified by H, Od, and T1 factors on the Dynamic Personality Inventory (DPl)
- Successful bomb disposal technicians also appear to have difficulty in forming and maintaining close personal relationships, as identified by C, Pn, and T1 factors on the Dynamic Personality Inventory (DPl)
- The data also suggests that successful bomb disposal technicians have a tendency toward nonconformity, meaning that they rely less on conventional values and judgments than did the control group. This was determined by differences in Ac, H, Od factors

Finally, Cooper (1982), suggests that successful bomb technicians appear to be "social isolates preferring to work on their own and with 'things' as opposed to people." He also suggests that this tendency toward self-isolation may account for some level of unconventionality, and enables the successful bomb disposal expert to treat each bomb encountered with a high degree of flexibility.

One area that seems to be of particular interest to researchers on cognition and the bomb disposal community has to do with attrition rates during bomb disposal training. As part of a study by Hogan and Quigley (1983), the researchers examined both cognitive and non-cognitive factors that might be attributing to the high attrition rates of U.S. Navy Divers undergoing a 42-week Explosive Ordnance Disposal (EOD) training program at Indian Head Maryland.

The researcher’s used several survey instruments during their study, but on Holland's Self-Directed-Search (SDS), a vocational preference measure, researchers discovered that EOD divers ranked highest in categories related to Realistic, Investigative, and Social interests. According to Holland (1972), this profile is similar to those of engineers and technician in other disciplines, or even accomplished athletes. According to the authors, such persons are practical and technically oriented, as well as having concrete mindsets. In addition, the authors state that these individuals are well-coordinated and curious, as well as helpful in social situations. Based on their findings, Hogan and Quigley (1983) went so far as to say that “persons who deviate markedly from this profile, (i.e., persons with Artistic, Conventional, and Enterprising interests) will be unhappy during EOD training and at risk for attrition.”

Hogan and Quigley (1983) also used the California Psychological Inventory, or CPI (Gough, 1975) as one of their study instruments. According to the authors, at the time their research was conducted, the CPI was considered, “one of the most fully validated measures of normal personality ever developed.” The CPI suggests that the high scores received by EOD students for Social Presence, Self-Acceptance, and Psychological Mindedness, as well as their low scores in factors like Responsibility, Socialization, and Communality, indicate that EOD students tend to be curious, well-adjusted, self-assured, and unconventional. According to Hogan and Quigley (1983), similar profiles can be found in thrill-seeking professions such as “race car drivers, pilots, and professional athletes.”

Following this study, and a study by Hogan, Hogan, and Briggs (1984) looking into physical factors that might contribute to attrition rates during Explosive Ordnance

Disposal (EOD), Hogan and Hogan (1985) conducted a confirmatory study into the cognitive factors related to attrition that were examined by Hogan and Quigley (1983). During the Hogan and Hogan study (Hogan and Hogan, 1985), the researchers again looked into several of the more traditional approaches to personnel assessment and selection for jobs that required higher levels of cognitive abilities and technical skills, but the researchers primary focus for this particular study, was the Armed Service Vocational Aptitude Battery, or ASVAB, the only military measure of cognition being used at the time for admission into EOD school.

According to Hogan and Hogan (1985), a potential EOD School candidate at the time of the study, was required to meet minimum scores on both the verbal and quantitative sections of the ASVAB. At face value, this would seem reasonable given that EOD classroom training and practical area testing is academically rigorous. Irrespective of this, researchers found that even though the ASVAB was the sole cognitive measure being used for EOD selection, data suggested little correlation between ASVAB scores and training performance or completion (Alf and Gordon, 1957; Hall and Freda, 1982; Hogan, 1984; Hogan and Briggs, 1984).

During the time that the Hogan and Hogan study was being completed (Hogan and Hogan, 1985), the U.S. Navy had an EOD Apprenticeship Program through which a potential candidate could become an Explosive Ordnance Disposal Technician by completing several Divisions at EOD School, returning to the fleet to work with an EOD unit for several years, much like on-the-job-training, then return to EOD School to complete the course of training required to become a fully qualified Explosive Ordnance Disposal Technician. Hogan and Hogan (1985) found that even for the EOD

Apprenticeship Program, the ASVAB did not significantly predict cognitive performance. Similar results were found in relation to dive training, which is a requirement for Navy EOD Technicians, but not the Air Force, Army, or Marine Corps.

In addition to looking at ASVAB scores, Hogan and Hogan (1985) used the Self-Directed Search (SDS) to see if EOD candidates vocational interests were an indicator of potential success in EOD training. The SDS (Holland, 1972) vocational interests are categorized into six occupational themes or types, and these were compared to tasks common to tasks performed by EOD technicians. The researchers found that candidates likely to succeed in EOD training had very distinguishable interests as determined by the SDS-Realistic Scale and even though EOD technicians who were participants tended toward introversion, they were also well-adjusted, self-confident, and tended to be risk-takers. The researchers also concluded that respondents who successfully graduated EOD School and appeared successful in the field, also liked working on technical problems, but those who were uninterested in technology did not perform well during EOD training.

Hogan and Hogan (1985) also used the Hogan Personality Inventory (Hogan, 1982; Hogan, 1985), or HPI, to assesses six factors associated with personality, as well as status and popularity amongst peers. The researchers found that the HPI successfully predicted EOD School training success among Army, Navy, Air Force, and Marine Corps EOD candidates (Hogan, 1984; Hogan and Briggs, 1984). More specifically, the authors found that the Prudence scale of the HPI, which measures conscientiousness vs. irresponsibility, seemed to be the most predictive indicator, looking at factors like flexibility, cautiousness, and impulse control.

In 1983, at the same time Hogan and Quigley were conducting their research (Hogan and Quigley, 1983), Hallam (1983) was examining other potential factors that might affect successful performance as a bomb technician, primarily fear and courage. Hallam's study population consisted of 200 enlisted, non-commissioned, and commissioned officer bomb-disposal operators from the British Royal Ordnance Corps who had served in Northern Ireland (Hallam, 1983). At the time when these duties were most critical, and over thirty thousand explosive devices were dealt with by bomb disposal operators in Northern Ireland over a 10-year period, members of the Royal Ordnance Corps could be assigned to bomb disposal duties in a non-volunteer status, and underwent no formal selection process. Before they received bomb disposal training to perform these duties however, they were given a battery of psychometric tests, underwent a psychiatric interview, and had to pass a series of military interviews (Rachman, 1990).

According to Hallam (1983), only 10% of the more than two-hundred candidates who underwent these tests were rejected, and only 5% for psychiatric reasons. From this, the Royal Ordnance Corps, and Hallam, concluded that "soldiers, officers, and noncommissioned officers, are capable of carrying out this difficult and dangerous work providing they are given specialized training in addition to their normal training courses." (Rachman, 1990) The psychometric data Hallam analyzed also suggested that these bomb disposal operators had, with only a few exceptions, highly stable personalities, and were highly competent individuals. Rachman (1990) also points out that these bomb disposal operators scored higher on the portions of the psychometric tests suggesting psychological health, than their civilian counterparts. Additionally, no psychological abnormalities or antisocial tendencies were indicated.

Unsurprisingly, Rachman (1983), found clear evidence that the specialized training received in bomb disposal increased the skill and confidence level of those becoming bomb disposal operators. The author states, “after completing it, the novices (i.e., those who had not yet carried out a tour of duty as a bomb-disposal operator) expressed approximately 80% of the confidence of the experienced operators.” It was also discovered during Rachman’s later research (Rachman, 1990) that, unlike dealing with hoax devices and suspicious packages that turned out not to be bombs, dealing with an actual device greatly increased the confidence levels of novice bomb disposal operators. Rachman (1990) states, “once the inexperienced operators successfully completed one bomb-disposal task, their confidence and feelings of competence rose close to the level of the experienced operators.”

After researchers like Hallam (1983), Rachman (1983, 1990), began looking at factors like fear and courage, and other factors like personality traits and interests (Hogan, 1984; Hogan and Briggs, 1984; Hogan and Hogan, 1985), researchers turned to examining behaviors like sensation seeking as a motivation for pursing bomb disposal as an occupation. Glicksohn and Bozna (2000) took just such an approach with their research, attempting to develop a personality profile that would help recruitment personnel find appropriate candidates for the bomb disposal profession.

Zuckerman (1994) and Goma-i-Freixanet (1995) postulated some time earlier that certain professions, such as fire-fighting, law enforcement, and special operations, drew individuals who are sensation seekers to those occupations. By natural extension, Glicksohn and Bozna (2000) believed this might also be true for the high-risk bomb disposal profession, where practitioners routinely faced calculated physical risk in the performance of their duties. Another interesting aspect of the research being conducted in the Glicksohn and Bozna study, is that they hypothesized, based on the research conducted by Cooper (1982), that bomb technicians would be different from personnel in other high-risk professions, in that while both groups should score high on a thrill-and-adventure-seeking (TAS) scale, the bomb technicians would exhibit field-independent cognitive styles, meaning that they preferred to work independently, as opposed to being part of a group (Glicksohn and Bozna, 2000).

These results are in contrast to the control group of anti-terror operatives used in the Glicksohn and Bozna study, who were found to be field-dependent cognitively, which is in keeping with the findings of McDonald, Norton and Hodgson, who conducted research into training success in the special forces (McDonald, Norton and Hodgson, 1990). Bomb technicians field-independence was also assessed by Glicksohn and Bozna to be higher than norms published by Witkin et al. (1971), with bomb technicians feeling "no need to exhibit physical self-confidence, nor teamwork skills, rather a skillful and detached cognitive style, of a field-independent nature." (Glicksohn and Bozna, 2000)

In 2006, a study conducted by Bundy (Bundy and Simms, 2007) investigated the extent to which individual learning style preferences and intelligence strengths were common to bomb technicians as a profession, because it had long been postulated in the bomb disposal community that there was a particular cognitive type that seemed to be drawn to the bomb disposal profession. The results of this study seemed to indicate that this hypothesis was not unfounded, as overall, out of the "ten demographic variables, eight intelligence strengths, and 17 learning style preferences," that were examined in a 100 bomb technician sample from 12 countries, only six percent of dependent and independent variables showed statistically significant differences between participants. In short, this data seemed to suggest that 94% of the bomb disposal community was exhibiting the same learning style preferences and intelligence strengths.

To see if the results of the Bundy study (Bundy and Simms, 2007) might be of use in reducing attrition rates at EOD School among US Army EOD candidates, Bundy and Shearer (2012) conducted a study for the U.S. Army Ordnance Corps to ascertain if it were possible to develop a graduation prediction scale based on learning style preferences and intelligence strengths. To investigate this question, Bundy and Shearer (2012) used two self-report instruments that were administered to 983 candidates who had been admitted to the Army EOD training program. At the end of the training, program administrators reported back to the researchers on graduates and non-graduates. Graduates were those that passed the training and were assigned to EOD duties, and non-graduates were those individuals deemed to have been terminated from training for academic reasons (i.e., failures). The final sample for this study consisted of 671 students, 422 of which were counted as Graduates, and 249 who were counted as Non-Graduates. An additional 312 candidates were dismissed for non-academic reasons such as disciplinary or medical issues, or the program failed to report their final status. Regardless, the study found that a number of cognitive factors, as measured by the instrument scales, were found to have significant correlation to graduation status (Bundy and Shearer, 2012), suggesting that the creation of a relatively accurate graduation prediction scale is possible. To date however, no field trials of such a scale has been attempted.

Diagnostic Reasoning in the Medical Community

To this author, understanding what takes place cognitively in the minds of bomb technicians has been a some thirty-plus year endeavor, and one that began while personally a member of the bomb disposal community. The thought has always been, from an intellectual perspective, that if researchers, administrators, trainers, and even bomb technicians themselves were collectively able to identify and understand the cognitive processes and procedures that occurred mentally within the brains of operators, the potential might exist to not only reduce accidental death and injury among practitioners in the bomb disposal field, but improve assessment and selection of the best candidates to become bomb technicians, and improve training and professional development of those who have chosen to make bomb disposal their vocation.

To any informed reader, this would clearly be seen as a naïve and lofty goal. In addition to bomb disposal being a highly specialized field, with relatively few practitioners, it also tends to be a closed community, meaning its members are reluctant to allow examination by outsiders. Even as an insider to this community, being a former bomb technician, this author faced reluctance by community members to be "put under a microscope." Additionally, as demonstrated in previous sections, almost no research has been conducted on cognition within the bomb technician community. This lack of foundational research in the bomb disposal community forced this author to turn to other communities for a research model that could be applied to, and have relevance for bomb disposal. It is within this context that this author began looking for research models from other disciplines to inform the subject under consideration for this research effort.

As stated in Chapter 1, the ability for a bomb technician to identify the pieces and parts of an improvised explosive device, assess the hazards associated with those pieces and parts, and then formulate a plan to neutralize or disarm that device, is a critical aspect of the bomb technicians job. To be able to do this, on a cognitive level, requires that a bomb technician call on prior knowledge, select tools and procedures, and create and implement courses of action. Often this process is seamless and results in successful outcomes, but sometimes it is not, and can have catastrophic consequences not only for the bomb technician, but others as well.

Upon reviewing the literature, there appeared to be few other professions that require a similar level of both practical and technical knowledge, a requirement to analyze unconstrained information quickly and accurately, and requires practitioners to implement actions and plans, that if done incorrectly, might result in critical failures with lethal consequences. Adding in a requirement that any community under consideration must also have undertaken development a body of knowledge related to cognition within that community through structured, peer-reviewed research, it became apparent that the medical community, and more specifically the medical diagnostics community, was the only logical choice.

Although its genesis is likely to have started much earlier, most authors agree that psychological research into diagnostic reasoning began in earnest in the 1950s, and another 20 years had to pass for diagnostic reasoning to become an area of empirical research in medicine (Barrows and Bennett, 1972; Bourne and Dominowski, 1972; Elstein, Kagan, Shulman, Jason, and Loupe, 1972). According to Schmidt, Norman, and Boshuizen (1990), this early research into diagnostic reasoning focused on cognitive tools for accessing memory like recall, introspection, and reflection data, and theories posited focused on structured models of how individual pieces of information relate to one another. According to Schmidt, Norman, and Boshuizen (1990), as well as Bordage and Lemieux (1991), and Custers, Regehr, and Norman (1996), the semantic and analytical reasoning models developed during this period formed the basis for many diagnostic processes. However, data from later research suggests that semantic and analytical models based on recall, introspection, and reflection do not adequately explain the nature of diagnostic reasoning (Elstein, 1999; Norman and Brooks, 1997) and can produce blind spots with respect to implicit, or unconscious/subconscious reasoning processes.

Lucchiari, Folgieri, and Pravettoni (2014) also suggest that decision-making in medicine is usually based on some form of diagnostic process, even if subconsciously, and that even if using a formal conscious process, the task of diagnostics is not easy, because the diagnostician must act as both information collector and information processor, using disparate sources of information, which may include disparate elements like a patient's medical history, current signs and symptoms, and the results of any tests ordered, to formulate a hypothesis upon which to base clinical treatment. The ability to perform accurate and reliable diagnostics is such a highly regarded skill that most medical school curricula now contains coursework directly addressing diagnostic processes and procedures, even though, according to Bloch, Hofer, Feller, and Hodel (2003), simply knowing and understanding diagnostic processes, or even being able to access relevant information about a particular disease, is not sufficient on its own to produce an accurate diagnosis.

Several researchers point out that accurate diagnostics may depend on intuition rather than analysis (Croskerry, 2013; Gigerenzer and Gaissmaier, 2011). For instance, Gabbay and Le May (2010) posit that physicians develop treatment strategies based on more subtle indicators, and quickly infer judgment based on incomplete information. Yet other researchers (Lucchiari and Pravettoni, 2012; Lucchiari and Pravettoni, 2013) advocate for a cognitively balanced model, where clinical decisions emerge from a "functional balance between analysis and intuition" (Lucchiari, Folgieri, and Pravettoni, 2014). This approach allows diagnosticians to address each case individually, and formulate an approach that fits the needs of that particular case.

In their research into the role of strategy in diagnostic reasoning, Bloch, Hofer, Feller, and Hodel (2003) found that highly successful diagnosticians use a combination of knowledge and practice to improve and perfect diagnostic success, and the types and amount of information gathered by test subjects who had correct diagnoses differed little from those who had incorrect diagnoses. The authors further concluded that data collected seemed to suggest that diagnostic accuracy was affected more by information gathered during examinations, and a diagnosticians level of training, than in having a systematic approach to performing the diagnostic process.

As noted by Mongtomery (2005), physicians draw on not only their prior training and knowledge, but scientific information, clinical experience, and diagnostic skills to perform their job well. However, medical science is constantly evolving, and new advances in biology and chemistry, as well as the development of new technologies and technological advances, means that, as stated by Montgomery (2005), "physicians still work in situations of inescapable uncertainty." The author also contends that this uncertainty has become both professionalized and ritualized, and is often ignored by physicians and patients alike, with both practitioner and patient just accepting that there are far too many new developments in the medical field, with new protocols and procedures, and new medications hitting the market every day, for the medical provider to feel comfortable with their use, or even be aware of them all.

To repeat an old adage, “When faced with not knowing what to do, you do what you know.” This is as true in medicine as it is in bomb disposal, where practitioners in both communities must learn not only what to do in known situations, where complete or near-complete information is available, but what to do when information is incomplete, unavailable, or even conflicting. But how do you training people to deal with uncertainty, and make effective decisions in an environment where information may be incomplete or misleading, and an inaccurate assessment or diagnosis can lead to ineffective, damaging, or even catastrophic outcomes?

In both the medical community and bomb disposal, students learn the basics of their profession during initial training, where they learn not only what information to consider relevant when problem-solving, but how to think about certain types of problems. One they leave the classroom however, or even an apprenticeship or residency, it is incumbent on the new practitioner to be able to make inferences based on the cognitive and intellectual skills gained during training, and apply these skills when faced with uncertain situations. In many cases, this is a new experience for the practitioner, and their critical thinking skills are un- or under-developed, and they may find it difficult to apply recently acquired skills and information to new circumstances (Kaddoura, 2011;

Kuiper, Pesut, and Kautz, 2009; Lunney, 2010; Silva et al., 2011; Turk, Tugrul, and Sahbaz, 2013; Yildirim & Ozkahraman, 2011).

Assessing the ability to perform diagnostic reasoning, which according to Jahn and Braatz (2014) can be defined as "the retrieval of knowledge about symptoms and their likely causes to generate and update diagnostic hypotheses," is a critical part of assessing overall clinical judgement, and along with analyzing critical thinking tasks, which might include looking at the use or misuse of terminology, identifying false assumptions, and challenging beliefs and assumptions, or requiring articulation of arguments for conclusions drawn, these become powerful tools in understanding the cognitive processes used by medical practitioners (Bandman and Bandman, 1998; Johansen and O'Brien, 2016; Paans, Sermeus, Nieweg, and van der Schans, 2010). Although it is impossible to directly observe diagnostic reasoning, because the process occurs within the mind (Westra, 2001), it is possible to see the tangible effects of diagnostic reasoning through indirect measures such as the assessment of error rates and patient outcomes.

Researchers in cognitive psychology continue to investigate the approaches people take while solving problems, and a number of theories have emerged that may help researchers understand the process of diagnostic reasoning in the medical profession (Eva, 2005; Flavell, 1976; Kahneman, Slovic, S., Slovic, P., and Tversky, 1982; Norman, 2009; Norman and Eva, 2010; Schmidt, Norman, and Boshuizen, 1990; Tversky and Kahneman, 1985). Unfortunately, one of the clear conclusions is that it is extremely difficult to teach general problem-solving strategies, and that even if a practitioner is skillful at one type of problem-solving, they may not be successful in another (Coderre, Mandin, Harasym, and Fick, 2003; Elstein, Shulman, and Sprafka, 1978; Eva, 2003; Eva, Neville, and Norman, 1998; Mandin, Jones, Woloschuk, and Harasym, 1997; Norman, Tugwell, Feightner, Muzzin, and Jacoby, 1985).

The seeming importance to the scientific community of understanding human decision-making cannot be overstated, as two Nobel prizes have been awarded in human decision-making, one to Herbert Simon in 1978, and the other to Daniel Kahneman in 2002, and cognitive psychologists have been working diligently since the 1970s to understand the fundamental processes that underpin cognition (Groopman and Prichard, 2007; Montgomery, 2005). And while new models for reasoning and decision-making are emerging all the time, the most prominent fall within one of two camps: the first being that decision-making tends to be more intuitive than analytical, and the other being that decision-making is more analytical than intuitive. Collectively, these who approaches are known as *dual process theory*, with the intuitive approach subsuming other modalities such as inductive reasoning, Gestalt theory, thin slicing, and heuristics; and analytical decision-making subsuming normative reasoning, hypothetico-deductive reasoning; bounded rationality, and Bayesian reasoning (Croskerry, 2009).

Reader should be advised however, that a great deal of disagreement still exists between Intuitive and Analytical decision-making advocates. Moreso in the degree to which each are used in the decision-making process, as opposed to the exclusivity of each. Regardless, the dual process theory of decision-making is widely embraced by the healthcare community, and is commonly used as a model for teaching decision theory, as it has important implications for understanding how diagnostic failures occur. According to Graber (2005), 75% of diagnostic error is due to flawed diagnostic reasoning on the part of the physician, and Croskerry, Abbass, and Wu (2008) have identified over 40 cognitive and affective biases that may impact clinical reasoning. According to Croskerry (2008), decision-making in a clinical setting is difficult not only because of the subject matter, but the processes involved as well. Hammond (1996) calls these complexities “irreducible uncertainties” that can exacerbate diagnostic failure.

It is now widely accepted that for any individual, in any given circumstance, decision-making will fall somewhere along the dual process theory continuum between intuitive, unconscious decision-making, and a deliberate, analytical approach (St. Evans, 2008). Which process is used will be situationally dependent according to Simon (1990), because in some circumstances, where the decision maker has less information or experience, an analytical approach may be more appropriate, and in others where the decision make has a great deal of training and experience, an intuitive approach may be more appropriate. Hammond (1996) posits that a blend of the two approaches is likely to be most often used, and that a “continuous oscillation” occurs between the two modes.

Additionally, where it was once believed that in any given field, an expert practitioner would have better reasoning skills than a novice in that domain, this does not appear to be wholly accurate (Norman and Eva, 2010). Instead, it appears that the amount of training and experience (i.e., knowledge) a practitioner possesses is what makes the difference, rather than just having general problem-solving skills (Elstein et al., 1978). It also appears, according to Eva, Hatala, LeBlanc, and Brooks (2007), that how this knowledge is arranged and stored in a person’s memory can facilitate use during the problem-solving process. Another way to think of this is that expert physicians are better able to connect-the-dots than novices, because of prior knowledge and experience when problem-solving, especially when faced with unfamiliar or novel situations (Boshuizen and Schmidt, 1992; Patel, 1994).

According to Ilgen, et al (2012), based on education and training received, observations during residencies, case reviews, or clinical rotations, novices build up and integrate substantial amounts of information into memory, and form associative links between signs and symptoms and conditions. These memories, and experience gained from actual patient encounters, form "unique clusters of information for each diagnosis." This collection of material is turned into a library of sorts according to Schmidt, Norman, and Boshuizen (1990), where information can be called on when needed, either consciously or subconsciously, to perform decision-making functions and generate hypotheses.

Brooks, Norman, and Allen (1991), as well as Coderre, Mandin, Harasym, and Fick (2003) say that this type of information retrieval is akin to pattern matching, and is seen as the primary mode of reasoning in expert diagnosticians. This type of automatic, nonanalytical reasoning, which calls on stored memory and pattern recognition, has now been labeled System 1 or Type 1 thinking (Croskerry, 2009; Evans, 1984; Evans, 2008; Ilgen et al, 2012; Kahneman, 2011; Stanovich and West, 2000). By contrast, if a purposeful, analytic approach is required that calls for deductive reasoning to be able to match signs and symptoms to conditions, it is said that System 2 or Type 2 thinking is being employed (Croskerry, 2009; Evans, 1984; Evans, 2008; Ilgen et al, 2012; Kahneman, 2011; Stanovich and West, 2000). It should be noted that while Type 1 thinking is much more intuitive, and seen as evidence of, or a trait in expert diagnosticians, it is also prone to error (Eva and Cunnington, 2006).

In reality, both Type 1 and Type 2 thinking are used in most situation where diagnostic reasoning is required. This is known as *dual processing*, and according to scholars on the subject (e.g., Ark, Brooks, and Eva, 2006; Eva, Hatala, LeBlanc, and Brooks, 2007; Ilgen et al, 2012; Mamede, Schmidt, and Penaforte, 2008; Mamede, Schmidt, Rikers, Penaforte, and Coelho-Filho, 2008; Moulton, Regehr, Lingard, Merritt, and MacRae, 2010; Norman, 2009; Norman and Eva, 2010), affords novice and expert practitioners alike, the best chance of overall diagnostic success.

According to Croskerry (2014), Type 1 and Type 2 decision-making, also referred to as Type 1 and Type 2 thinking or decision-making, are now the two most widely accepted forms of thinking or decision-making. Using functional MRI, Goel and Dolan (2003) demonstrated that Type 1 thinking is localized to the ventral medial prefrontal cortex of the brain, and Type 2 thinking is associated with the right inferior prefrontal cortex. Similarly, Masicampo and Baumeister (2008) demonstrated a physiological basis that separates Type 1 and Type 2 thinking, in that Type (System) 2 thinking requires more energy.

Type 1 decision-making is an intuitive method by which the decision maker makes fast, autonomous decisions, and it is the same process that individuals use in making most decisions throughout their day. Kahnemann (2011) contends that this is a “mindless” process based on associations, meaning that certain objects and patterns elicit certain responses based on past experience and interactions. The author points out that routine activities like driving a car from known Point A to known Point B, unless being performed by a new driver, takes very little thought. However, if a driver, even an experienced driver, is asked to conduct a task that is performed infrequently, such as parallel parking, Type 2 decision-making is engaged, where judgement and reasoning are necessary to perform an action, such as successfully maneuvering the car into the parking space.

Croskerry (2014) notes that much of Type 1 decision-making is based on heuristics, or "rules of thumb." This type of decision-making is often referred to as "making an educated guess" or "using common sense," but whatever the term applied, this type of thinking reduces the cognitive burden created by analytical decision-making. Croskerry (2014) also contends that this type of decision-making is useful in situations where there is a great deal of uncertainty, or incomplete information, filling in the knowledge gaps with a "best guess" information. Lakoff, Johnson, and Sowa (1999) suggest that 95% of decision-making time is spent in Type 1 decision-making, which would suggest that this is one reason, according to the authors, that people rely so heavily on intuition, or "gut instinct."

Type 1 decision-making has a down-side however, and that is that Type 1 decision-making carries inherent biases toward information and situations familiar to the decision maker, which means that unfamiliar information may be overlooked or dismissed before being considered. This in turn, may result in faulty decisions, which in the cases of medical or bomb disposal decision-making, may have disastrous consequences. This is not to say that Type 2 decision-making, although deliberate and analytical, is without issues. For one thing, according to Croskerry (2014), it is generally slower and more resource intensive, and if not conducted properly, can result in diagnostic failure.

Croskerry (2014) also suggests that this type of reasoning may not be the best approach in emergency situations where fast decision-making is required, or trying to assimilate too much information too quickly may lead to "analysis paralysis." It would seem prudent however, at least to this author, that if Type 1 decision-making is required for emergency situations, then the education and experience of the decision maker needs to be at the highest level possible.

Cognitive and Affective Bias in Decision-making

It might seem peculiar to some that anyone would consider discussing a topic like diagnostic reasoning without discussing cognitive and affective biases, but for others, it seems peculiar that such a discussion is even warranted (Orasanu, Calderwood, and Zsambok, 1993). As recently as the 1980s, discussing cognitive bias was rare in all but a few disciplines like medicine and clinical diagnostics, and in some disciplines, like the forensic sciences, it was almost non-existent (Perkins, 1985). It wasn't until the 1970s that some of the more simplistic rational models of decision-making were even challenged (Tversky and Kahneman, 1971; Tversky and Kahneman, 1974a), and the heuristics and biases approach to human judgment even considered.

The recognition that cause-and-effect exists, if only intuitively, has played a prominent role in the survival of many species, and none more so than humans. If an animal eats a particular type of brightly colored berry, and it causes illness or death, and the eater is not able to recognize, or work out a connection between eating the berry (cause), and illness or death (effect), this is problematic for not only the individual, but for the species. If however, the eater makes a connection between the two, and avoids that type of berry in the future, the benefits are self-evident. To extend this further however, if individuals of a species begin to recognize that plants with brightly colored berries, or an alkaline taste are poisonous, they may avoid all brightly colored berries or plants with an alkaline taste. In this way, species start to collect a body of knowledge about the world in which they live. When new plants that match the established criteria as poisonous are then encountered by an individual or individuals within that species, the plant is usually avoided. If however, there are factors that require overriding these norms, such as drought conditions, that individual may cautiously eat the plant to establish if it is in fact poisonous. The point being that humans, along with a great many other species, perform diagnostic reasoning without much conscious thought, but a defining characteristic of decisions made through diagnostic reasoning, is that depending on the depth and breadth of prior knowledge and experience, or preconceived notions regarding the subject under consideration, the conclusions reached can be faulty. These preconceived notions based on prior knowledge and experience are the underpinning for bias.

Numerous researchers (e.g., Graber, Franklin, and Gordon, 2005; Croskerry, Abbass, and Wu, 2010; Zwaan, et al, 2010; and Croskerry, 2014) contend the way we process information, and perceive the world, affect the way we make decisions. If a diagnostician, regardless of the discipline, has insufficient knowledge regarding a topic being considered, i.e., a *declarative shortcoming*, or the process being used for reasoning is truncated, inefficient, or incomplete, i.e., a *procedural shortcoming*, it will dramatically affect the outcome and accuracy of conclusions reached. There also seems to be no shortage to the ways in which we are able deceive ourselves into making wrong decisions. This contention is supported by Croskerry (2014), who states, “no group, society or culture suffers a shortage of diagnosticians; however, their main instrument of diagnosis, the brain, operates under an inherent restraining characteristic – bias." Both Jenicek (2010) and Dobelli (2015) list over 100 types of cognitive bias that people face daily, and Croskerry (2014) states, "Bias is so widespread that we need to consider it as a normal operating characteristic of the brain."

While it would be convenient to think that certain types of individuals, or at least certain professions, were immune to bias, allowing them to make accurate decisions with unfailing clarity, such is not the case. This of course does not prevent people from making claims of, or even believing in their own infallibility when it comes to being subject to bias (Pronin, Lin, and Ross, 2002). However, the truth remains that no evidence exists, or even suggests any one profession is more prone to, or even less prone to cognitive or affective biases than any other. Disciplines that build their processes on the scientific discipline appear just as prone to bias as the social sciences, and the impact of cognitive bias in some professions, such as medicine, is beginning to be studied at great length simply because of the implications it has for those professions (Croskerry, 2014). It seems unreasonable, at least to this author, to think then, that the bomb disposal community would be immune from such bias in its decision-making processes.

The medical profession seems particularly susceptible to bias during the diagnostic process, because not only must the knowledge and experience of the medical professional be taken into consideration, but that of the patient as well. As Croskerry (2014) notes, this includes, on both sides, making connections regarding signs and symptoms that may be colored by a frame of understanding ranging from scientific, evidence-based knowledge to faith-based beliefs and superstitions. However, both perspectives are vulnerable to seeing patterns where none exist, or relationships, i.e., correlation and causation, simply because signs and symptoms may have physical or temporal proximation. Unfortunately, an ability to make an accurate assessment, or diagnosis of the circuitry used in a potential explosive device may suffer from these same vulnerabilities. Not only must the knowledge and experience of the bomb technician be considered, but the knowledge and experience of the bomb builder may also affect the "sameness" of one device to another.

Dror (2015) points out that the forensic sciences are also subject to bias in analysis, data interpretation, and decision-making, especially where judgements are based on human perception. And while the forensic sciences are, for the most part, taking steps to eliminate, or at least minimize bias in its declarative statements and analytic processes, there are many hard-liners in the profession that still claim its infallibility (Ashbaugh, 1994; Coble, 2015; Dror, 2015 Dror and Hampikian, 2011; Dror and Rosenthal, 2008). Bias can be introduced in two major areas with respect to investigative work, whether being performed by forensic scientists, medical examiners, bomb technicians, arson and explosion investigators, or anyone else involved in the collection and preservation of evidence, or its analysis. These two areas are at the incident site or crime scene itself, or in the laboratory.

At the incident or crime scene, investigators and technicians busily go about collecting and preserving evidence, usually based on either some learned protocol or procedure instantiated by their organization, or through experience gained over years of conducting investigative fieldwork. According to Dror (2015), this causes many investigators and technicians to believe that they are simply gathering evidence at the scene, and this precludes the introduction of bias. As the author states, many decisions that can be affected by bias actually take place at an incident site or crime scene, from determining where to look for evidence, selecting what evidence will be collected, and how that evidence will be packaged/preserved for disposition to a laboratory or evidence locker. The author states that the processes and procedures used during initial evidence collection are more than just the mere gathering of evidence, because once the scene has been returned to normalcy, it is unlikely that additional evidence can be retrieved later because of spoilage or destruction, and bias can be introduced simply by the context through which investigators view the scene, even prior to arrival on-site. For example, an investigator is likely to approach and treat a scene very differently if they believe they are being dispatched to a gas explosion as opposed to a bombing, or a drug lab as opposed to an improvised explosives lab. Again, the preconceived notions arrived at beforehand are not based on the scene itself, but beliefs about what they are about to encounter, so perceptions, interpretations, and judgement of the investigator are more subject to bias when they arrive at the crime scene.

The forensics community makes a great deal of the fact that much of its analysis is conducted under laboratory conditions, and seems to imply that because standard processes and procedures are used, the potential for bias is eliminated. As Dror, et al (2011) states however, a great many analytical forensic techniques are perception-based, such as tool mark comparison, fingerprint identification, and handwriting analysis to name a few, and that the initial perception of the evidence can be greatly influenced by a number of physical and physiological factors, leaving room for misinterpretation of the data, and cognitive bias. Dror, et al (2015) points out that the variable nature of physical and biological materials, and physical and cognitive differences between examiners, can cause two examiners to look at the same sample, and draw two totally different conclusions, even if the two examiners have received identical training. Even more remarkable however, is an apparent lack of reliability in some forensic techniques. Studies have shown the same examiner can look at the same evidence at different times, and reach totally different conclusions, indicating that bias, especially conformation bias, may have been introduced in some way, as many examiners feel allegiance to prosecutors and investigators, rather than the defense counsel (Coble, 2015; Dror and Hampikian, 2011; Dror and Rosenthal, 2008).

The good news is that researchers, scientists, and even lay people are beginning to accept that cognitive and affective bias are a normal part of brain function, and are looking for ways to counter its effects, and that fundamentally, critical thinking is the best way to reduce or eliminate bias (West, Toplak, and Stanovich, 2008). It is likely to be a long journey toward creating bias-free investigative and research findings, but perhaps with diligence, it can be achieved.

Diagnostic Accuracy, Success Rates, and Expertise

The last bit of discussion in this literature review is perhaps the most nebulous, because when researchers, administrators, and educators investigate subjects like diagnostic reasoning, the goal, whether spoken or not, is to find some mechanism by which to improve diagnostic accuracy and reduce error rates, and improve clinical problem-solving (Eva, Neville, and Norman, 1998). Enigmatically however, research data suggests an unexpected consistency, which is that no content-independent process has been found that can differentiate an expert's diagnostic findings from a novices. In other words, both successful and unsuccessful diagnosticians, whether expert or novice, use the same hypothetico-deductive reasoning as part of their problem-solving process (Elstein, Shulman, and Sprafka, 1978; Neufeld, Norman, Barrows, and Feightner, 1981). However, a process seen in expert diagnosticians that is not seen in novices involves pattern recognition (Gilhooly, 1990; Schmidt, Norman, and Boshuizen, 1990). According to Coderre, Mandin, Harasym, and Fick (2003), novice problem solvers will progress through various stages of knowledge acquisition, structuring, and retrieval as they work toward becoming an expert diagnostician, but all eventually lead to the accumulation of body of knowledge regarding problems that need to be solved in their domain of expertise. In medicine, these are termed *illness scripts*. These illness scripts allow practitioners to recognize various illnesses by comparing them to their internal library of known illnesses, and provide treatment accordingly. This type of pattern matching, given the complexity and time required to accumulate such a body of knowledge, is likely not available to novice practitioners.

According to Coderre, Mandin, Harasym, and Fick (2003), it appears there are three diagnostic reasoning strategies typically used by diagnosticians: deductive reasoning, which is used by experienced diagnosticians to include or exclude diagnoses when faced with a problem outside their area of expertise; inductive reasoning, which is used when pattern recognition is not possible; and pattern-recognition, which is typically only used by experts. If deductive reasoning is used, the diagnostician generates a hypothesis, and his or her general knowledge about diseases and conditions is compared to the signs and symptoms of the patient under consideration. Information gathering usually includes specific information about the patient, such as family history, laboratory data, current signs and symptoms, and so on. Based on similarities between the clinicians existing knowledge, a hypotheses is accepted to the exclusion of other hypotheses, a diagnosis made, and a treatment plan formulated. Of note is the fact that all three of these strategies depend on prior knowledge and accumulated experience as the basis for drawing conclusions.

There continues to be interest in, and a growing body of knowledge on diagnostic error. A quick search on Google Scholar for articles since 2018 on diagnostic error, a search site that uses algorithms to seek out scholarly peer-reviewed articles on the web, returned a total of 445,000 relevant articles. The search parameters excluded patents and citations, focusing on journal articles and books. According to Norman and Eva (2010) a great deal of the literature on this topic suggests that most diagnostic errors are cognitive, and are usually the result of one or more cognitive biases, and that these errors can be directly linked to Type 1, non-analytical thinking, which relies heavily on pattern recognition. However, Norman and Eva's own research (Norman and Eva, 2010) suggests that there is little evidence that Type 1 thinking can be associated with diagnostic error, and studies of dual process theory show that experts are as likely to commit errors when they are attempting to be systematic and analytical (i.e., using Type 2 thinking) as those using Type 1 thinking. In short, diagnostic error can occur regardless of the thinking system used.

Norman (2009) posits that because Type 1 thinking functions through the subconscious retrieval of exemplars (i.e., pattern matching), diagnostic error can occur if matching occurs based on some irrelevant similarity. Norman (2009) also suggests that this type of bias is likely inherent in Type 1 thinking because decisions using Type 1 thinking are made without the benefit of introspection. This is not to suggest however, that Type 1 thinking is "bad" or more error-prone than Type 2, analytical thinking, as the study of benefits and uses of heuristics by psychologists dates back to the 1970s and the theory of *bounded rationality* (Hamm, 2004). Other studies (Wilson and Schooler 1991; Dijksterhuis, Bos, Nordgren, and Van Baaren, 2006) have shown that analytical approaches are often inferior to Type 1 thinking, and that experts in many fields, when faced with several apparently similar choices, will instinctively recognize an appropriate course of action, albeit subconsciously (Klein, 1999). Burns (2004) ties this ability to expertise, demonstrating that being able to subconsciously make fast, accurate decision using Type 1 thinking in any given domain, relates to a high level of overall ability in that domain.

Unfortunately, even though it is often easy to identify when diagnostic error has occurred, determining how that error occurred is much more difficult. Regardless, researchers have found that a number of error types are identifiable. In a meta-analysis on diagnostic error conducted by Graber, Franklin, and Gordon (2005), the authors identified that poor attitudes on the part of clinicians played a relatively minor role in diagnostic error, even though patients weighted attitudinal trait like apathy and inattentiveness, or even taking shortcuts, more heavily than other causes of error. Interestingly however, Berner and Graber (2008) identified that overconfidence may be a contributory factor to diagnostic error. In their review of diagnostic error cases, they discovered that, not uncommonly, 94% of doctors who experienced diagnostic error rated themselves in the top half of their profession and could not recall having made more than cursory diagnostic errors (Mele, 1997).

The study conducted by Graber (2008) also supports the idea that cognitive errors (biases) are much more common that errors caused by gaps in knowledge. This appears to be a common finding among numerous other studies (Croskerry, 2000; Croskerry, 2002; Croskerry, 2003a; Croskerry, 2003b; Elstein and Schwarz; 2002; Mamede, Schmidt, and Rikers, 2007; Redelmeier, 2005). In his research, Croskerry (2003b) identifies a number of the more prominent biases encountered in diagnostic reasoning, but some of the more common are *availability* -- selecting a diagnosis that is easy to recall; *base rate neglect* – pursuing an unusual diagnosis because it is more interesting, even though a common disease is more likely; *representativeness* – only considering typical variants of diseases, even though other variants exist; *confirmation bias* – only seeking data that supports ones diagnosis, not refutes it; and *premature closure* – the tendency to select a diagnosis before all relevant data has been gathered.

As stated earlier, retroactively trying to determine the cause of diagnostic error is often difficult. Wears and Nemeth (2007) contend that any attempt to uncover past causes may themselves fall victim to *hindsight bias*, or the tendency to recognize causality in clues that may not have been evident to the diagnostician at the time of the original diagnosis (i.e., things seem much more evident than they actually were). According to Norman and Eva (2010), another serious issue with using cognitive bias as a sole basis for the cause of diagnostic error, is that this is antithetical to psychological literature on the subject. This is supported by Gigerenzer and Goldstein (1996), who suggest that heuristics and biases are good mental strategies for quick decision-making when faced with uncertainty and ambiguity, but can be unreliable, even at the best of times, and can often result in poor decisions.

Dual process theory, with its two types of reasoning strategies, Type 1 being non-analytical and Type 2 being analytical, offers some explanation as to why cognitive bias is likely never the sole cause of diagnostic error. Norman and Eva (2010) suggest that since Type 1, non-analytical reasoning, is tantamount to an information retrieval and matching system based on past experience, it will in all likelihood be directly influenced by how new situations are presented, and how closely those presentations match prior cases, which can lead to error. Wilson and Schooler (1991) suggest that Type 2 thinking (i.e., analytical reasoning) places too heavy a cognitive burden on working memory, and slows down the analytical process.

Norman and Eva (2010) also suggest that there may be no basis for associating bias error rates solely with one diagnostic process or another. The authors also suggest that *availability* and *representativeness* biases may be directly linked to hypothesis generation, which is fundamentally non-analytic. Conversely, data gathering is a very conscious and deliberate process, but can be influenced directly by search for and finding confirmatory information (Barrows, Norman, Neufeld, and Feightner, 1982). Taking all of this into consideration, it is difficult, at least for this author, to see many circumstances where a clinician, or a bomb technician for that matter, might rely solely on one type of reasoning or another. Additionally, deficits in knowledge and experience will undoubtedly impact a diagnosticians ability to process newly acquired information, so they are inextricably linked.

But what of expertise and years of experience required to accumulate the domain-specific knowledge that makes one a specialist in a given field? One of the major issues with using expertise as a criteria is that even in the field of knowledge management, researchers struggle with identifying and understanding what constitutes expertise (Nelson, Nadkarni, Narayanan, and Ghods, 2000). Broadly speaking, an expert has been defined as someone who is capable of superior performance within a specific domain of knowledge or activity, and that an expert's knowledge, skills, and abilities consist of both a cognitive element and a technical element (Johnson, Zualkernan, and Garber, 1987; Keyes, 1990; Nonaka, 1994; Alavi and Leidner, 2001). Brehmer (1980) suggests however, that expertise is not only dependent on domain knowledge, but requires a familiarity and understanding of the context within which that knowledge will be used, and other factors that can influence the usefulness of that knowledge. Research conducted by Bradley, Paul, and Seeman (2006) seem to support this contention, suggesting that experience alone is not an indicator of expertise, since for experience to be useful, an ability to correctly structure those experiences, and relate them cognitively to other information and experience, must be present.

Whether talking about bomb disposal or medicine, expert knowledge is complex. It is easy for a novice that has graduated from a recent course of study to recognize and use basic principles and knowledge from that discipline to solve simple problems within that domain, but an expert will depend on knowledge and relationships to conduct problem-solving that a novice may not recognize or only vaguely understands. Experts also differ from non-experts in that experts tend to build complex mental models of problems that may contain many sub-elements or models, but novices view individual elements of complex problems as mental models of their own, without a structure to link these elements together in a meaningful way (Rumelhart and Norman, 1976; Larkin, McDermott, Simon, and Simon, 1980; Chi, Feltovich, and Glaser, 1981; Sheetz, 2002; Bradley, Paul, and Seeman, 2006).

Looking at a series of meta-analyses of research on elicitation of expert and novice knowledge, Bradley, Paul, and Seeman (2006) found that general cognitive ability is a much more valid predictor of performance on entry-level jobs than domain-specific knowledge, and that training and experience ranked fairly low (Hunter, 1983a; Hunter, 1983b; Hunter and Hunter, 1984; Hunter, 1985). In a study involving 16,058 workers in jobs with a low level of task complexity, where workers had little experience (<5 years), McDaniel, Schmidt, and Hunter (1988) found that experience was the most valid predictor of job performance, but as job complexity increased, the validity of experience decreased; the same was true for workers with higher levels of experience, where the validity of experience decreased as experience increased. Other studies (Gutenberg, Arvey, Osburn, and Jeanneret, 1983; Snow and Lohman, 1984) support these findings, demonstrating that the importance of cognitive ability increases with job complexity, and for complex jobs, years of experience is less of a predictor of expertise than a combination of experience and cognitive ability.

To illustrate just how tenuous factors like expertise can be in performing diagnostics and problem-solving, it seems prudent to close out this literature review with the findings from research conducted by Arzy, Brezis, Khoury, Simon, and Ben-Hur (2009) titled *Misleading one detail: a preventable mode of diagnostic error?* As the name suggests, these researchers, in an attempt to better understand cognitive bias and the potential for prevention of diagnostic error, looked at how the addition of one misleading detail in a patient's case history can lead diagnosticians to an incorrect diagnoses. These researchers surveyed 51 physicians in a large teaching hospital, presenting each with 10 clinical vignettes, but unbeknownst to the diagnosticians, each case contained a single misleading detail. The doctors were then asked to offer a diagnosis for each case, identifying any condition or conditions leading to the presentation. Remarkably, the addition of one misleading detail led to an incorrect diagnosis in 90% of the cases, and even if doctors were warned that erroneous information might be present, the accuracy rate did not increase. However, if misleading details were omitted, the accuracy rate increased by 60%, with misdiagnoses only occurring 30% of the time.

It is not incredibly difficult to see how inaccurate information might inadvertently be introduced into, or considered in the diagnostic process. For example, a patient might lie about a symptom, or associate an unrelated condition to their current malady. It is also not unheard of for misinterpretation of laboratory results, or misreading of imagery to occur, or for there to simply be a mix-ups in patient histories. Fundamentally this means that a misleading detail could be entered at any step in the diagnostic process, and drastically bias diagnosis and treatment, and as identified by Arzy, Brezis, Khoury, Simon, and Ben-Hur (2009), and others (Tversky and Kahneman, 1974b; Graber, Franklin, and Gordon, 2005), even an awareness that misleading details may be present, does not significantly reduce their potential impact.

The implications for diagnostic error, modes of thinking, bias, and one misleading detail are as significant for the bomb disposal community as they are for the medical community. Error in the bomb disposal community can have catastrophic consequences; Type 1 and Type 2 thinking are likely used on every call; using gut-instinct and rules-of-thumb are a norm in the bomb disposal community, rather than the exception; and the potential introduction of erroneous, unrelated, or misleading information into the decision-making and problem-solving process during an incident response are a given. It is time that researchers and bomb technicians themselves take a deeper look into these issues, and understand at an operational level, how they may be impacting the bomb disposal community.

CHAPTER III

METHODOLOGY

Description of the Methodology

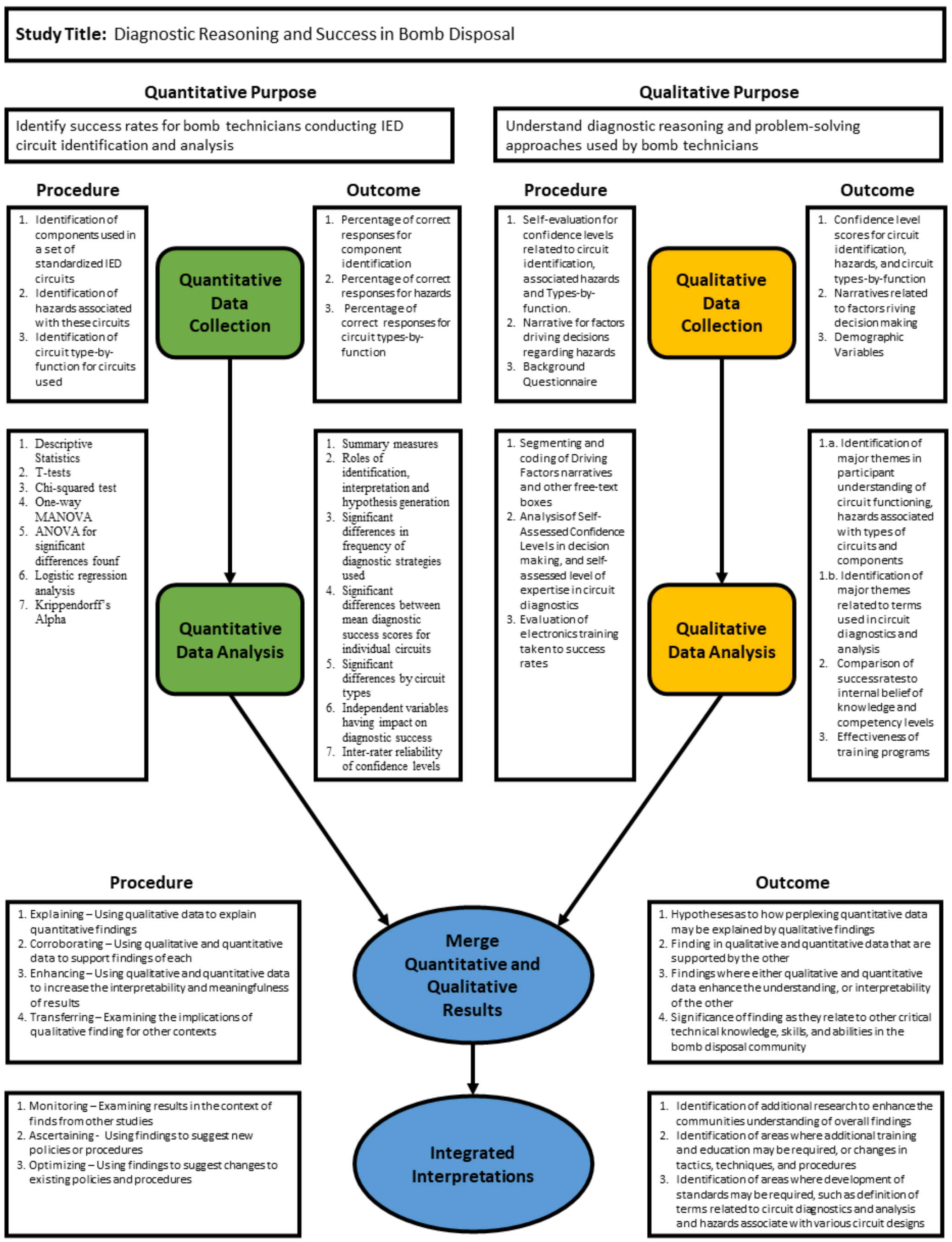
This study utilized a convergent mixed-methods design with a pragmatistic worldview. For those who are more familiar with quantitative or qualitative research methodologies, the term mixed-methods may require a brief explanation. According to (Creswell (2014) and Creswell and Clark (2017), mixed-methods research, often simply referred to as MMR, is defined as research that brings together aspects of both quantitative and qualitative research for data collection and analysis, and integrates the findings from each into a coherent interpretation of the findings that uses the analytical strengths of both approaches. Fetters and Freshwater (2015) contend that by integrating quantitative and qualitative data, researcher are able to gain insight into the subject under study that might not be accessible to researchers using quantitative or qualitative techniques independently. And while the use of mixed-methods research is not without controversy (Biesta, 2010; Morgan, 2007; Clark and Ivankova, 2015; Shannon- Baker, 2016), MMR has gained popularity in many social science disciplines such as education, and the social, natural, and health sciences (Curry and Nunez-Smith, 2014; Maxwell, 2016; Plano Clark, 2010; Moseholm and Fetters, 2017; Stange and Zyzanski, 1989; Tashakkori and Teddlie, 2009).

The use of the term pragmatistic worldview may also require a degree of explanation. According to Morgan (2007), a worldview is “all-encompassing ways of experiencing and thinking about the world, including beliefs about morals, values, and aesthetics,” and treats a worldview as being synonymous with a paradigms, or that individual’s “shared understanding of reality.” A pragmatic, or pragmatistic approach to research simply implies that the research does not focus on the more traditional ontological (philosophically, the nature of a thing) or epistemological (the theory of knowledge about a thing) differences between approaches, but rather focuses on the fundamental characteristic of an approach to conduct research. In doing so, the researcher is able to combine the complementary aspects of both quantitative and qualitative approaches, and reap the ontological and epistemological benefits of each (Shannon-Baker, 2016).

Finally, the use of the term *convergent* in discussing mixed-methods research simply implies that quantitative and qualitative data is merged during analysis, and approaches for merging this data, which usually occurs during data analysis, are described by numerous researchers and research scholars (e.g., Bazeley, 2012; Castro, Kellison, Boyd, and Kopak, 2010; Creswell and Clark, 2017; Curry and Nunez-Smith, 2014; Onwuegbuzie, Slate, Leech, and Collins, 2009; Plano Clark, Garrett, and Leslie-Pelecky, 2010). Figure 1 provides a procedural diagram of the convergent mixed-method approach used for this study.

Figure 1

Procedural diagram for research into diagnostic reasoning and success in bomb disposal. Diagram based on procedural diagram template designs provided in Fetters (2019).



Sample and Population

For this cross-sectional quantitative study, a convenience sample of current and former bomb technicians from across the globe was used. Participants were recruited using social media and connections through bomb technician associations and professional organizations. The following criteria was used for selection: 1) being a current or former bomb technician, which is defined as having had render safe authority and responsibility within a government sanctioned agency or organization; 2) being aged 18 years or older; and 3) being able to read and comprehend English at a technical level.

A conscious decision was made to allow not only current and former military bomb technicians who have been trained through a formal government-sponsored bomb disposal school, but those who have only received on-the-job-training as well, acknowledging that these bomb technicians exist, with many having served admirably over their careers. The age requirement for participation was likely unnecessary for US participants, but was a consideration for non-U.S. bomb technicians. Thus for legal purposes of obtaining consent to participate, the U.S. standard was used. Finally, although suboptimal, a self-declared proficiency in the English language was required, as it is beyond the scope of this study, and the ability of this researcher, to make translations available for multiple languages.

Initial recruitment for participation in the study was conducted through social media posts, and direct requests to potential participants via email lists provided by such organizations as the International Association of Bomb Technicians and Investigators, the U.S. Bomb Technician Association, the National Bomb Squad Commanders Advisory Board, and the NATO EOD Centre of Excellence. Requests were also made to publications such as the Counter-IED Journal, and The Detonator, for placement of a short recruitment notice for study participants, over several consecutive issues.

Instrumentation

Using a web-based platform, study participants were presented with images of seventeen exemplar improvised explosive device circuits selected by an expert panel. A top image of each circuit was provided, which allowed study participants to see types of components being used. Each circuit was hosted on its own webpage, along with a web-based form to collect data. Data collected from these forms was used to determine the diagnostic reasoning approaches used by study participants, as well as diagnostic success rates achieved.

After registering for the study and providing demographic information, participants were given a link to a practice circuit, which they could use to familiarize themselves with form layout and function. After completing the practice circuit, they moved sequentially through the seventeen exemplar circuits. While it was possible to skip a circuit without completing the analysis form for that circuit, this was not readily apparent to the participant, so participants were unconsciously encouraged to complete each circuit's analysis form before moving to the next. Study participants were also allowed to go back and change responses if desired, but again, this was not readily apparent, or encouraged. Finally, study participants were also able to leave and return to the study as needed, and all answers for completed circuit analysis forms were saved automatically upon submission, so when a subject returned, they were able to see, and even change previous responses.

Each participant was also assigned a unique access code to the study, which means that only they were able to respond to, or see their own responses. Even if an individual were to accidentally stumble upon a webpage associated with the study, they were unable to see the circuits, or associated questions. Web addresses were automatically logged for all participants, and all responses, and changes to responses, were logged in a database, and timestamped for further analysis. This ensured fidelity of the data collected.

The form for each circuit was divided into the following eight sections:

Section 1: Components

This section contained a list of common electronic components that may be found in IEDs. They are in list form, with a checkbox beside each (see Figure 2). For this section, the task for study participants was to identify all circuit components. For example, if a light sensing circuit is pictured, a study participant would check the box next to the *Light Dependent Resistor (LDR)*, the *Light-Emitting Diode (LED)*, and the *Resistor*, to receive a “correct” score on their diagnosis. There is also an *Additional Components* section with a fillable free-text field for identification of component(s) that may not be on the checkbox list (see Figure 3). A study participant would use the *Additional Components* box to key in the name of the component they felt had been omitted, but are visible on the circuit.

Figure 2

Components Checkbox List

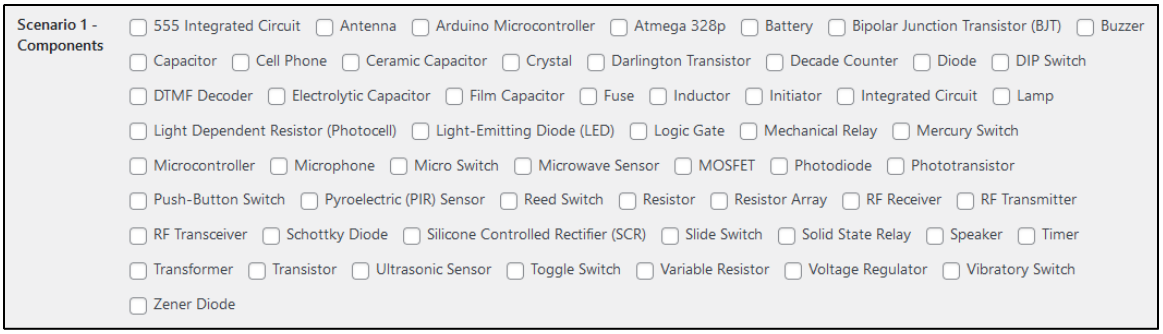
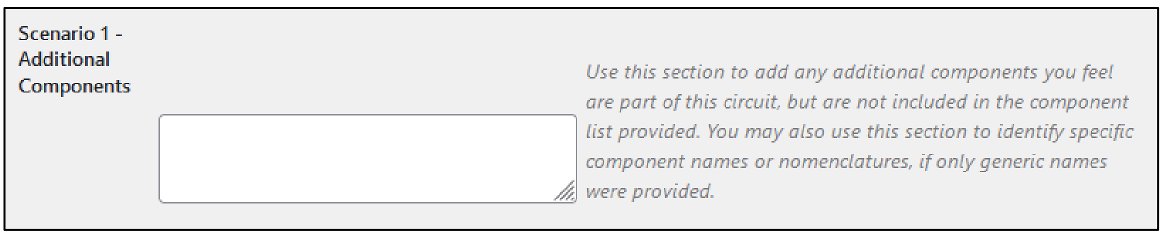


Figure 3

Additional Components Free-Text Field

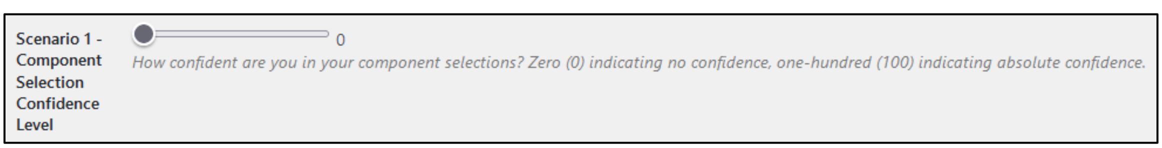


Section 2: Confidence Level for Components Identified

In this section, study participants were asked to rate their confidence level for the selections made. This was not a scored section, this information was analyzed, and provided insights into cognitive factors affecting diagnostics (see Figure 4).

Figure 4

Confidence Level Slider for Components



Section 3: Associated Hazards

This section was used to determine what potential hazards are associated with the circuit depicted, meaning, if there are precautions that should be observed by the bomb technician, for example, not tilting the circuit, or a "tilt hazard," the Tilt checkbox would be checked. Study participants were provided with a list of hazards, and were asked to check all that apply to receive a "correct" score on their diagnosis (see Figure 5). There was also an *Additional Hazards* section with a fillable free-text field for identification of hazards that may not be on the checkbox list (see Figure 6).

Figure 5

Associated Hazards Checkbox List

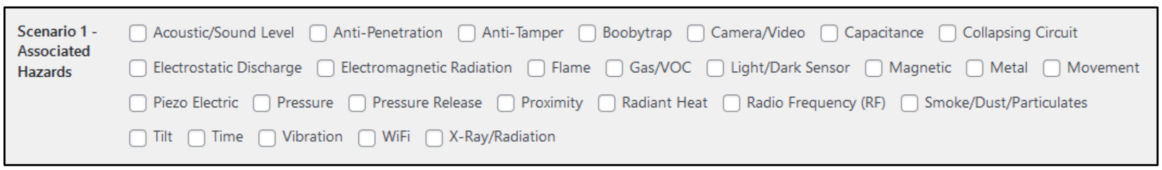
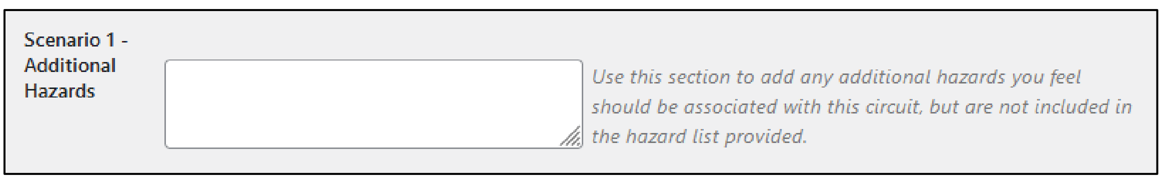


Figure 6

Additional Hazards Free-Text Field

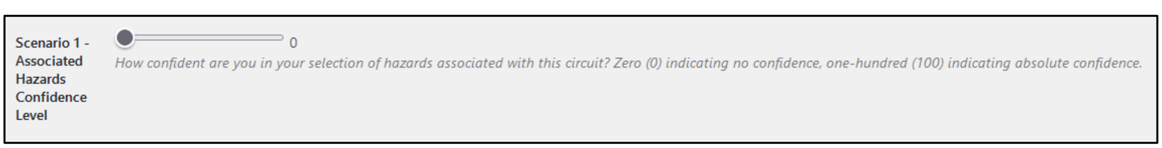


Section 4: Confidence Level for Associated Hazards

In this section, study participants were asked to rate their confidence level for the selections made. While not scored, this information was analyzed, and provided insights into cognitive factors affecting diagnostics (see Figure 7).

Figure 7

Confidence Level Slider for Associated Hazards

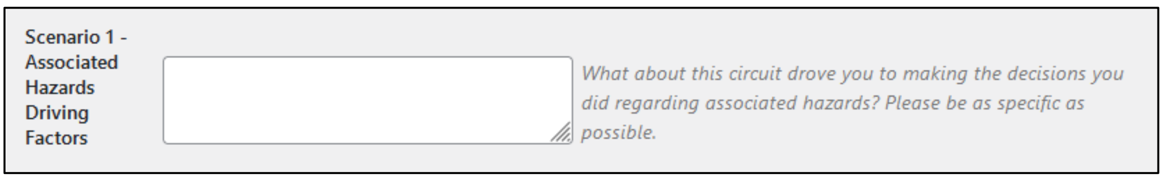


Section 5: Driving Factors for Associated Hazards

This section asked study participants to identify factors that led them to the conclusions reached regarding associated hazards. This may be a single component, combination of components, or even just a "gut feeling." This was not a scored section, but will be analyzed, and may provide insight into the diagnostic approach(s) used. See Figure 8.

Figure 8

Free-Text Field for Associated Hazards Driving Factors

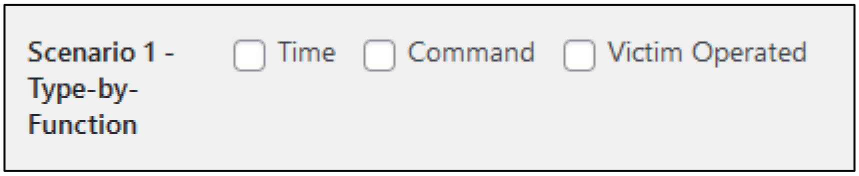


Section 6: Circuit Type-by-Function

For this section, there were three labeled checkboxes. Study participants needed to determine if the overall function of the circuit depicted is Command, Time, or Victim Operated, or some combination of these types (see Figure 9). For example, if a circuit is identified as being radio-controlled, a study participant would check the box next to Command. However, if the circuit has both a mercury switch and an RF receiver, they should select both Victim Operated and Command as type-by-function, to receive a "correct" score on their diagnosis, because they will likely have no way of determining if one of these components is simply used for arming or safe-separation, or if both are used for firing.

Figure 9

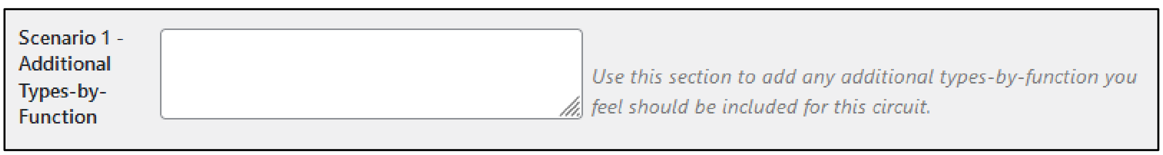
Circuit Type-By-Function Checkbox List



There was also an *Additional Type-by-Function* section with a fillable free-text field for identification of types-by-function that a study participant might feel needed to be added to the checkbox list (see Figure 10).

Figure 10

Additional Type-By-Function Free-Text Entry Field

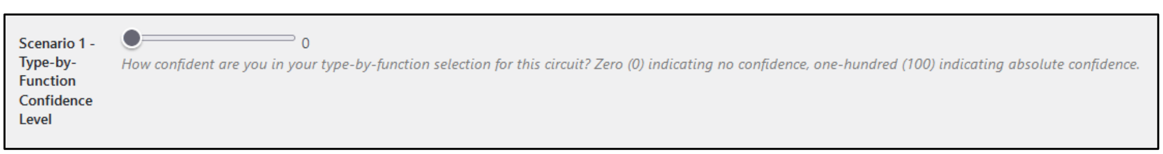


Section 7: Confidence Level for Circuit Type-by-Function

In this section, study participants were asked to rate their confidence level for the selections made. While not scored, this information was analyzed, and provided insights into cognitive factors affecting diagnostics. See Figure 11.

Figure 11

Confidence Level Slider for Circuit Type-By-Function

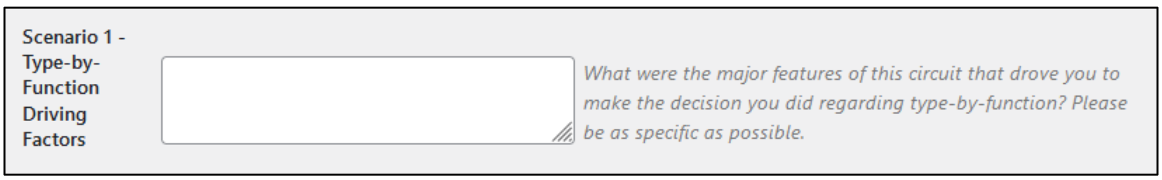


Section 8: Driving Factors for Circuit Type-by-Function

This section asked study participants to identify factors that led them to the conclusions reached regarding circuit type-by-function. This may be a single component, combination of components, the overall circuit configuration, or just a "gut feeling." This was not a scored section, but was analyzed, and provided insight into the diagnostic approach(s) used (see Figure 12).

Figure 12

Free-Text Field for Circuit Type-By-Function Driving Factors



Based on responses for each circuit, two types of scores were generated: 1) assessment of diagnostic selections, and 2) assessment of cognitive processes.

Assessment of diagnostic selections. Dichotomous scoring was used for sections that have either right or wrong answers, such as the Component Identification, Associated Hazards, and Type-by-Function sections. A score of 1 was given for the correct diagnosis, and a score of 0 for an incorrect answer. Because an "Additional" free-text field was provided for each, along with a free-text field for *Driving Factors*, an expert panel would make a determination as to the correctness or incorrectness of non-checkbox responses. If the panel deems the response correct, it was given a score of 1.

Assessment of cognitive processes. Once scores were generated for Component Identification, Associated Hazards, and Type-by-Function sections, they were examined relative to Confidence Levels and Driving Factors to determine whether analytical- or intuitive reasoning was more dominant, or even used equally. Confidence Levels and Driving Factors were analyzed individually, and provided additional insights.

Content Validation

The content for this study was validated by an expert panel consisting of subject matter experts (SMEs) in improvised explosive device (IED) response and IED exploitation. While four of the SMEs are representatives from the US counter-IED community, two are non-US, ensuring a broader, global perspective was considered. It is also important to note that three of the panelists are active, or currently serving bomb technicians; two are retired bomb technicians, but still working in relevant counter-IED positions; and one subject matter expert (SME) came from the IED exploitation community and has advanced education and training in electronics and electrical engineering. These six panelists have all volunteered their time to participate as panelists, and their guidance was instrumental to ensuring the circuits presented to study participants were representative of IED circuitry that may be encountered by bomb technicians globally and are at an appropriate level to test the general bomb technician communities' level of IED circuitry knowledge.

After acceptance as panelists, experts were sent a link and password to access Phase I web-based forms. Panelists were also provided a unique identifier so Personally Identifiable Information (PII) would be disassociated with individual panelists. Over a six-week period, experts selected for the panel were provided access to a web-based collection of 50 potential circuits for use in this study. Each panelist was asked to evaluate the appropriateness of circuits in the collection, meaning were the circuits selected technically accurate and at the right complexity level, i.e., not too easy for a bomb technician to analyze, but also not impossible, and the expert's perception regarding the appropriateness of individual circuits was collected using an online form. A 10-point Likert scale ranging from 1 to 10 was used by panelists to evaluate individual circuit complexity, with 1 being very easy to diagnose, and 10 being very difficult.

Experts were also provided lists of suggested components, associated hazards, and circuit types-by-function. These are the lists that, after Expert Panel refinement, were included in the participant forms for analysis of individual circuits. Using checkboxes, panelists were asked to check (select) all items that should be included for respective sections and leave unchecked (blank) all items that should not be included (omitted). A free-form text field was also provided to allow panelists to suggest possible items for addition or suggest ways to improve possible response options.

The results of this phase of Expert Panel input was used to identify and create the content of the final study data gathering instrument. This content was further analyzed in Phase II of Expert Panel input, and the circuits selected were added to the data collection website.

Circuit Components

In the Circuit Components section, panelists were provided a list of 61 electronic components or modules of potential use in IED circuitry (see Appendix A). The list was originally developed by this author and represents a collection of components and modules found in publications like the United Nations Mine Action Service (2017), Improvised Explosive Device Lexicon, and other bomb technician training materials. Space was also provided in this section for panelists to make comments and suggest components not originally included by this author. Table 1 provides a complete list of component selections made by panelist for inclusion in the final study data collection instrument.

Table 1

Components Selected by Panelists

	Panelist 1	Panelist 2	Panelist 3	Panelist 4	Panelist 5	Panelist 6
555 Integrated Circuit	X	X	X	X	X	X
Accelerometer				X		X
Antenna	X	X	X	X	X	X
Arduino Microcontroller	X	X	X	X	X	X
ATmega328P				X	X	X
Barometric Pressure Sensor				X		X
Bipolar Junction Transistor	X			X	X	X
Buzzer	X	X			X	X
Capacitor	X	X	X	X	X	X
Ceramic Capacitor	X			X	X	X
Crystal				X	X	X
Darlington Transistor	X			X	X	
Diode	X	X		X	X	X
DIP Switch	X	X	X	X		X
DTMF Decoder	X	X		X	X	
Electrolytic Capacitor			X	X	X	X
Espressif Microcontroller				X	X	
Film Capacitor				X	X	X
Force Sensitive Resistor				X		X
Fuse		X		X		X
Inductor				X	X	X
Integrated Circuit (IC)	X		X	X	X	X
Lamp	X	X		X	X	X
Laser Diode				X		X
Light Dependent Resistor	X	X	X	X	X	X
Light-Emitting Diode	X	X	X	X	X	X
Logic Gate	X			X	X	
Mechanical Relay	X	X	X	X	X	X
Mercury Switch	X	X	X	X	X	X
Microcontroller	X	X		X	X	X

	Panelist 1	Panelist 2	Panelist 3	Panelist 4	Panelist 5	Panelist 6
Microphone			X	X	X	X
Micro Switch	X	X	X	X	X	X
Microwave Sensor				X	X	X
MOSFET	X	X		X	X	X
Opto-Coupler				X	X	
Photodiode	X	X		X	X	X
Phototransistor	X	X	X	X	X	
Push-Button Switch	X	X	X	X	X	X
Pyroelectric Sensor			X	X	X	X
Raspberry Pi Microcontroller				X		X
Reed Switch	X	X	X	X	X	X
Resistor		X	X	X	X	X
Resistor Array				X	X	X
RF Receiver	X	X	X	X	X	X
RF Transmitter	X	X		X	X	X
RF Transceiver		X	X	X	X	X
Saw Resonator				X	X	
Schottky Diode				X	X	X
Silicone Controlled Rectifier	X	X	X	X	X	X
Slide Switch	X	X	X	X	X	X
Solid State Relay	X	X		X	X	
Speaker	X				X	X
Strain Gauge				X		
Thermistor				X	X	
Transformer	X	X		X	X	
Transistor	X	X		X	X	X
TRIAC				X	X	
Ultrasonic Sensor		X	X	X	X	X
Variable Resistor	X	X		X	X	X
Vibratory Switch	X	X	X	X	X	X
Zener Diode				X	X	X

Note: Only components that were selected by at least on panelist are included in Table 1.

Overall, each component on the original list of 61 received at least one vote for inclusion. However, only 24.6% received votes from all 6 panelists. Another 23% received votes from 5 panelists (83%), and another 14.8% received votes from 4 panelist

(67%). All other components received 50% of panelist votes or less, with the Strain Gauge only receiving one vote.

There were several components recommended for addition by panelists. These included:

- LASER Sensor (TX/RX)
- Active IR Module (TX/RX)
- Microwave Sensor
- RADAR TX/RX
- Pressure Switch
- Ultrasonic Sensor
- X-ray Sensitive Switch
- X-ray Sensitive Components
- Passive Infrared (PIR) Sensor
- EMF
- Mechanical Time
- Chemical Time
- Electronic Time
- RFID
- NFC
- AI
- PIC microcontroller
- STM Microcontroller
- AVR Microcontroller
- Varactor Diode
- Adafruit Circuit Playground
- Water/Hydro Sensor
- Motor (servo, stepper)
- Solenoid
- Membrane Switch
- Axis Sensor (rather than Accelerometer)
- Piezo or Piezo Crystal (rather than Crystal)
- Pyroelectric (add PIR)
- Tilt Switch
- Magnetic switch or Magnetic Reed Switch (rather than Reed Switch)

After collection of the original round of feedback from panelists, the following questions were asked:

1. What should the cutoff be for keeping a component on the list? Should all 6 panelists (100%) have to agree to keep something on the list? 83%? 67%? 50%? What do you think would provide the greatest analytical value?
2. Are there components recommended for addition that need to be added? Please let me know if you feel strongly about any particular additions or name changes (e.g., Reed Switch to Magnetic Reed Switch).

3. Do we go general or specific? If we go general, and only keep components that received a vote from 5-of-6 panelists, our list will only consist of 29 components. If we push that down to components that received 4-of-6 panelists, we are down to 38 components.
4. How do you feel about going general, but including a subsection of the Component Section that allows someone to go deeper if they want to? Is this the same thing as going specific, and having a more detailed component list? Will techs take the easy way out, and choose the generic component, even though they know the difference between a generic diode and a Schottky or Varactor diode?
5. Do you think having a text box, and asking them to identify specific components if they know them is a potential solution to getting more detail, or are we back to the easy-way-out scenario, or does it even truly matter with respect to their diagnostic process?

Panelist responded to these questions, and collectively the following decisions were made regarding the Components list:

1. If 50% of panelists agree on a component name, it should be included.
2. It is not necessary to add additional components to the list.
3. Generic component names should be use for the study, with a free-form textbox made available for study participants to provide greater specificity if desired.
4. Names of components will be reviewed for US-centric labeling, and non-US panelists will provide alternative labeling to be included.

Based on this feedback, the final list included 50 components, which are identified in Table 2. Number of panelists, and percentage of panelists selecting these components are also included in this table.

Table 2

Final List of Components Based on Panelist Feedback

	Number of Panelists Selecting (*N*=6)	Percentage of Panelists Selecting
555 Integrated Circuit	6	100%
Antenna	6	100%
Arduino Microcontroller	6	100%
ATmega328P	3	50%
Bipolar Junction Transistor	4	67%
Buzzer	4	67%
Capacitor	6	100%
Ceramic Capacitor	4	67%
Crystal	3	50%
Darlington Transistor	3	50%
Diode	5	83%
DIP Switch	5	83%
DTMF Decoder	4	67%
Electrolytic Capacitor	4	67%
Film Capacitor	3	50%
Fuse	3	50%
Inductor	3	50%
Integrated Circuit (IC)	5	83%
Lamp	5	83%
Light Dependent Resistor	6	100%
Light-Emitting Diode	6	100%
Logic Gate	3	50%
Mechanical Relay	6	100%
Mercury Switch	6	100%
Microcontroller	5	83%
Microphone	3	50%
Micro Switch	6	100%
Microwave Sensor	3	50%
MOSFET	5	83%
Photodiode	5	83%

	Number of Panelists Selecting (*N*=6)	Percentage of Panelists Selecting
Phototransistor	5	83%
Push-Button Switch	6	100%
Pyroelectric Sensor	4	67%
Reed Switch	6	100%
Resistor	5	83%
Resistor Array	3	50%
RF Receiver	6	100%
RF Transmitter	5	83%
RF Transceiver	5	83%
Schottky Diode	3	50%
Silicone Controlled Rectifier	6	100%
Slide Switch	6	100%
Solid State Relay	4	67%
Speaker	3	50%
Transformer	4	67%
Transistor	5	83%
Ultrasonic Sensor	5	83%
Variable Resistor	5	83%
Vibratory Switch	6	100%
Zener Diode	3	50%

Associated Hazards

In the Associated Hazards section, panelists were provided a list of 32 hazards that a bomb technician might face if a given component or module were present in the IED circuitry (see Appendix B). For example, if a mercury-switch is incorporated in a circuit, a “tilt hazard” may be present, and not tilting the device (or circuit) is a safety precaution that should be observed by the bomb technician. In this instance, if panelists felt this was a precaution, or hazard that study participants should know, it was included in their selection list.

All panelists agreed on 34.4% of potential associated hazards, and 83% of panelists agreed on another 21.9% of proposed hazards. Pushing down to 4-of-6 panelists, added another 5 hazards to the list, or another 15.6%. Only 9 hazards (28.1%) fell at or below the 50% mark. Table 3 identifies hazards selected by individual panelists.

It was also suggested that there be more generic versions of some hazards, such as Light, Heat, RF, Device Movement, IR, Pressure, X-ray, Chemical, etc., recognizing that some of these had already been included.

The follow-up questions for panelists related to Associated Hazards closely align with those asked for Components, such as:

1) What should the cutoff be for keeping an associated hazard on the list?
2) Are there hazards recommended that need to be added?
3) Do we go general or specific?

Panelist responded to these questions, and much like responses made for Components, collectively the following decisions were made regarding Associated Hazards:

1. If 50% of panelists agree that a hazard should be on the list, it was included.
2. No additional hazards need be added.
3. Generic hazards are preferred for the study, rather than hazards specific to an individual component.
4. A free-form textbox was made available for study participants to add additional hazards.
5. Names of components were reviewed for US-centric labeling, and non-US panelists were provided alternative labeling they felt should be included.

Based on this feedback, the final list consisted of 27 hazards. These hazards are identified in Table 4, which also identifies number and percentage of panelists selecting that hazard.

Table 3

Associated Hazards Selected by Panelists

	Panelist 1	Panelist 2	Panelist 3	Panelist 4	Panelist 5	Panelist 6
Acceleration				X	X	
Acoustic/Sound Level		X	X	X	X	X
Anti-Penetration	X	X	X	X	X	X
Anti-Tamper	X	X	X	X	X	X
Bluetooth				X	X	
Boobytrap	X	X	X	X	X	X
Camera/Video		X		X	X	X
Capacitance	X	X		X	X	X
Collapsing Circuit	X	X	X	X	X	X
Light/Dark Sensor	X	X	X	X	X	X
Electrostatic Discharge (ESD)		X	X	X	X	X
Electromagnetic Radiation (EMR)	X			X	X	X
Flame	X			X	X	
Flash				X	X	
Gas/Volatile Organic Compounds			X	X	X	
Magnetic	X	X		X	X	X
Metal		X	X	X	X	
Moisture					X	
Movement	X	X	X	X	X	X
Object/Facial Recognition				X	X	
Piezo Electric	X			X	X	X
Pressure	X		X	X	X	X
Pressure Release	X	X	X	X	X	X
Proximity		X	X	X	X	X
Radiant Heat				X	X	X
Radio Frequency (RF)	X	X	X	X	X	X
Smoke/Dust/Etc.				X	X	X
Tilt	X	X	X	X	X	X
Time	X	X	X	X	X	X
Vibration	X	X	X	X	X	X
Wi-Fi		X	X	X	X	
X-Ray/Radiation		X	X	X	X	X

Table 4

Final List of Associated Hazards Selected by Panelists

	Number of Panelists Selecting (*N*=6)	Percentage of Panelists Selecting
Acoustic/Sound Level	5	83%
Anti-Penetration	6	100%
Anti-Tamper	6	100%
Boobytrap	6	100%
Camera/Video	4	67%
Capacitance	5	83%
Collapsing Circuit	6	100%
Light/Dark Sensor	6	100%
Electrostatic Discharge	5	83%
Electromagnetic Radiation	4	67%
Flame	3	50%
Gas/VOC	3	50%
Magnetic	5	83%
Metal	4	67%
Movement	6	100%
Piezo Electric	4	67%
Pressure	5	83%
Pressure Release	6	100%
Proximity	5	83%
Radiant Heat	3	50%
Radio Frequency (RF)	6	100%
Smoke/Dust/Particulates	3	50%
Tilt	6	100%
Time	6	100%
Vibration	6	100%
Wi-Fi	4	67%
X-Ray/Radiation	5	83%

There were several other potential hazards recommended for addition. These include:

- Deceleration
- Light Sensor
- LASER
- Barometric
- Weight
- Signature
- Frequency
- Battery Decay
- Chem./Bio.
- Light Sensing (rather than flash)
- Thermal Shift (rather than radiant heat)

Circuit Type-by-Function

For the Type-by-Function section, panelists were provided a list of three (3) categories, which were Time, Command, and Victim Operated. All panelists agreed that these were the primary categories of Type-by-Function and should be included in the study data collection instrument (see Table 5). Several panelists suggested further subdividing Command into Remote Control Command and Command Wire, and Time into Electronic Time, Mechanical Time, and Chemical Time. There was also some discussion regarding adding a Projected category, but ultimately the group decided to stay with the original three categories of Time, Command, and Victim Operated. A free-form text box was included to allow study participants to add new categories if they feel necessary.

Table 5

Circuit Type-By-Function Selected by Panelists

	Panelist 1	Panelist 2	Panelist 3	Panelist 4	Panelist 5	Panelist 6
Command	X	X	X	X	X	X
Time	X	X	X	X	X	X
Victim Operated	X	X	X	X	X	X

Difficulty Ratings

In the next section of the panelist consensus building form, panelists were given 50 circuits of varying levels of complexity (see Appendix C), as well as schematics of each circuit. Panelists were asked to rate how difficult they felt these circuits would be for a bomb technician to diagnose if presented with an image of the circuit that showed all components used in that circuit. Using this approach is intended to simulate how a bomb technician might originally encounter a circuit in the field, either through personal inspection of a device, or through the lens of a robot camera or spotting scope. The rating scale provided panelists was from one (1) to ten (10), with 1 representing an easy circuit to diagnose, and 10 representing a very difficult circuit to diagnose. A list of circuits and panelist ratings are available in Table 6, and Table 7 provided Descriptive Statistics for these ratings.

Table 6

Circuit Difficulty Ratings Assigned by Panelists

	Panelist 1	Panelist 2	Panelist 3	Panelist 4	Panelist 5	Panelist 6
SCR Kitchen Timer	1	1	1	3	3	1
Collapsing Circuit	1	2	1	5	3	2
Indonesian Light SCR	1	1	1	5	4	2
Balanced SCR	1	2	2	5	5	1
Adjustable Light Sensor	1	2	3	5	4	1
Transistor Trap Det Dual	2	2	3	3	5	2
Urdu Watch Timer	1	1	3	8	3	2
Casio Anti-Lift	1	2	4	6	5	2
Dual SCR	1	2	5	6	3	3
Battery Removal	1	2	2	10	5	1
Command Wire	1	2	8	5	3	2
Single Wire Cmd Det	1	3	5	7	3	2
Decade Counter	4	2	5	2	5	4
Monostable 555 Timer	2	4	3	4	5	4
Casio LDR/Pressure	2	2	4	8	5	2
Collapsing Ct w/Capac.	2	2	7	7	3	2
Cellphone Optocoupler	1	2	8	6	5	3
FRS LDR Light Anti-Lift	3	2	4	8	5	3
Microcontroller LDR	3	4	4	6	5	3
NRF24L01 PIR	2	3	5	5	4	6
Tip122 Radio Squelch	6	1	2	9	3	4
Casio Breakwire	2	5	6	6	5	3
FRS Breakwire	2	2	7	8	5	3
Radio Squelch	6	2	1	9	5	4
MOSFET RC Timer	1	4	7	9	4	3

	Panelist 1	Panelist 2	Panelist 3	Panelist 4	Panelist 5	Panelist 6
Nokia 3310 Op-Amp	1	3	6	10	3	5
Microcontrol Ultrasonic	9	4	6	3	3	3
Cwc7 Rcvr/RC Tmr SCR	4	2	5	9	3	6
Microcontroller PIR	2	6	8	6	4	4
Urdu Touch Switch	5	3	6	8	5	3
Reed Pro Micro	4	5	3	9	6	4
ATmega328P DTMF	6	4	2	6	6	7
AtTiny Mail Device	5	4	4	8	6	4
Esp8266 RCIED	2	2	7	9	7	5
Active IR Pro Micro	6	3	3	7	8	5
Urdu Water Level	6	5	5	8	5	4
Iraq Timer CEXC	3	3	8	9	4	7
Iraq Timer Pic16	3	3	8	9	4	7
LDR Logic Gate	6	4	9	8	5	3
NRF24L01 RCIED	3	6	7	9	4	6
RC Armed MOSFET	4	4	8	9	5	5
Active IR Counter	9	3	6	7	7	4
Lora 328p	6	5	3	10	5	8
Wire Disconnect	5	3	8	9	3	9
ATmega328P NO/NC	8	5	7	8	6	6
Astable 4020	5	7	8	6	7	8
Accelerometer with LDR	6	6	8	10	8	4
Odessa Device	6	6	8	9	6	7
Wi-Fi Mac Device	9	8	7	9	5	5
Squelch Counter	7	7	9	10	6	8

Note: Circuits were rated from 1-10, 1 meaning easy, and 10 very difficult.

If readers conduct their own analysis of data in Tables 6 and 7, they will see a fairly wide spread for mean panelist ratings, with the mean being commonly referred to as the average (Salkind and Frey, 2021). The analysis conducted by this author identified mean rating scores for individual panelists ranging from 3.36 to 7.2, which is a fairly wide spread for a 10-point scale. Also, in looking at Range (Triola, 2018), it can be seen that most panelist's ratings had an 8-point separation, with ratings from 1 to 9 being the most common. Panelist 5 however, only had a 5-point spread, with ratings ranging from 3 to 8.

These findings do not suggest that Panelist 5 is an outlier however, since this panelist's average rating was as similar to other panelists ratings as those of Panelist 4, who had an average rating of 7.2. The reason for this variance is unclear and could possibly be a function of training or experience, as someone who has trained with a particular type of circuit, or encountered it in the field, may be much more likely to know whether the circuit is easier, or more difficult than others to diagnose. While this remains unclear at present, demographic data collected and analyzed during the study may aid in suggesting if these variables correlate to particular types of circuits.

In examining the data more closely, natural stratifications began to appear with respect to how difficult panelists perceived circuits to be, or at least how difficult they might be to study participants. Breaking these ratings down into quartiles aligned with difficulty scores, the following clusters appear that approximate categories with labels such as Very Easy, Easy, Difficult, and Very Difficult.

Table 7

Descriptive Statistics – Difficulty Rating

	Panelist 1	Panelist 2	Panelist 3	Panelist 4	Panelist 5	Panelist 6
Mean	3.58	3.36	5.2	7.2	4.72	4.04
Standard Error	0.3489	0.2454	0.3417	0.2983	0.1896	0.2941
Median	3	3	5	8	5	4
Mode	1	2	8	9	5	4
Standard Deviation	2.4668	1.7351	2.4159	2.1092	1.3407	2.0796
Sample Variance	6.0853	3.0106	5.8367	4.4490	1.7976	4.3249
Kurtosis	-0.6329	-0.0654	-1.1982	-0.4259	-0.0805	-0.4519
Skewness	0.6605	0.8072	-0.2080	-0.6416	0.4859	0.5828
Range	8	7	8	8	5	8
Minimum	1	1	1	2	3	1
Maximum	9	8	9	10	8	9
Sum	179	168	260	360	236	202
Count	50	50	50	50	50	50
Confidence Level (95%)	0.7011	0.4931	0.6866	0.5994	0.3810	0.5910

Top-10 Circuits

In the final stage of Phase I of the Expert Panel Consensus Process, panelists were asked to select their “Top-10” choices from the 50 circuits list, that they believed bomb technicians should be able to identify, with the caveat that these selections ranged from easy to very difficult. Table 8 provides the Top-10 Circuits selected by each panelist and demonstrates that 29 of the 50 circuits provided for consideration, received at least 1 vote for inclusion in the study, which means that 21 of the circuits provided would be eliminated immediately as potential candidates. It was this researcher’s hope however, that there would be a higher level of consensus with respect to the 29 circuits selected by at least one panelist for inclusion, but there was not; an explanation follows.

Analysis of the data reveals that only one circuit, the Adjustable Light Sensor, was selected by all panelists. It received a 2.6 average rating by panelists with respect to difficulty, but wasn't rated by panelists overall, as the easiest circuit that study participants should be able to identify. Cumulative circuit difficulty rating data demonstrates that the SCR Kitchen Timer was rated as the easiest circuit by panelists, with an average difficulty rating of 1.67, but only 4-of-6 raters (67%) agreed that the SCR Kitchen Timer should be in the study. The Decade Counter also received 4-of-6 votes for inclusion, with an average difficulty rating of 3.67, which would place it into the *Easy*, not *Very Easy* quartile.

In addition to the SCR Kitchen Timer and Decade Counter, only four (4) more circuits were selected by at least 3-of-6 panelists (50%). These included the Battery Removal, Cellphone Optocoupler, Collapsing Circuit, and Microcontroller-Based PIR Circuit. Of the remaining 22 circuits, 11 received two (2) panelist votes each, and 11 received a vote from at least one (1) panelist.

In an attempt to assure there were no hidden or unobservable variables that might make the types of circuits being used unreliable as part of the study instrument, a Cronbach's Alpha was run, and while it is impossible to rule out some latent variables affecting the results (i.e., votes), the Cronbach's Alpha was 0.77, which is within an acceptable range for Cronbach's Alpha of greater than or equal to 0.7, to 1.0 (Hasnain, Onishi, and Elstein, 2004). Individual panelist Alphas were also conducted, and all were within acceptable range.

Three additional correlation tests were also run to see if the results from the Difficulty Ratings and Top-10 choices correlated across panelists, and correlation was suggested by each test (see Tables 9-12). The Pearson Correlation Coefficient returned a score of 0.91; the Spearman Correlation Coefficient was 0.95; and the Kendall

Table 8

Top-10 Circuit Selected by Individual Panelists

	Panelis t 1	Panelist 2	Panelis t 3	Panelist 4	Panelist 5	Panelis t 6
Adjustable Light Sensor	X	X	X	X	X	X
Decade Counter		X	X		X	X
SCR Kitchen Timer	X	X	X			X
Battery Removal	X	X	X			
Cellphone Optocoupler	X			X		X
Collapsing Circuit		X	X		X	
Microcontroller-Based PIR	X		X			X
Active IR Counter				X		X
ATmega328P DTMF			X		X	
Collapsing Circuit w/Cap		X		X		
Command Wire	X				X	
CWC7 RCVR RC Timer					X	X
Indonesian Light SCR	X		X			
Iraq Timer CEXC	X				X	
NRF24L0X RCIED					X	X
Radio Squelch		X	X			
Microcontroller Ultrasonic				X		X
Wire Disconnect Boobytrap		X			X	
AtTiny Mail Device			X			
Balanced SCR				X		
Casio Break-Wire					X	
Casio Anti-Lift		X				
Casio Pressure	X					
LDR Logic Gate				X		
Lora 328p						X
MOSFET RC Timer	X					
Nokia 3310 Op-Amp				X		
NRF24L01 PIR				X		
Urdu Touch Switch		X				

Correlation Coefficient was 0.86. For these coefficients, the closer the coefficient is to 1.0, the closer the results are to “complete correlation,” with 0 suggesting “no correlation" (Herzog, Francis, and Clarke, 2019; Salkind and Frey, 2021; Triola, 2018). This does not suggest however, that the circuits presented are at the right difficulty level, or even appropriate for this study, because in running a Bland-Altman interrater reliability test on panelist difficulty ratings, the score suggests that there is an extremely low interrater reliability, and implies panelists disagreed with each other's assessments.

Table 9

Pearson's Coefficient T-Test

	Value
Alpha	0.05
Tails	2
Correlation	0.9086
Standard Error	0.0603
t	15.0748
p-value	0
lower	0.7874
upper	1.0298

Table 10

Pearson's Coefficient Fisher

	Value
Rho	0
Alpha	0.05
Tails	2
Correlation	0.1429
Standard Error	0.0603
z	10.4180
p-value	2.0519
lower	0.8437
upper	0.9474

Table 11

Spearman's Coefficient Test

	Value
Alpha	0.05
Tails	2
Rho	0.9505
t-stat	21.1925
p-value	0

Table 12

Kendall's Coefficient Test

	Value
Alpha	0.05
Tails	2
tau	0.86482
Standard Error	0.10953
z	7.89559
z-crit	1.95996
p-value	2.9
lower	0.65014
upper	1

Given the lack of consensus on circuits to be included, this researcher felt it prudent to provide a visualization to panelists of a juxtaposition between the four Difficulty quartiles, and Top-10 selections. Panelists were then asked to consider the following options as a path for moving on to Phase II of the consensus process:

1. Use the circuits provided in the original offering, and pick 3 or 4 circuits from each of the quartiles, Very Easy, Easy, Difficult, and Very Difficult.
2. Include all of the circuits that received at least one vote, which would mean including 29 circuits in the study.
3. Include the top 18 circuits, meaning all that received at least 2 votes.
4. Include all circuits that received at least 3 votes, which reduces the number of circuits to 7, and would eliminate the Very Difficult quartile altogether.

The final two options presented to panelists for consideration were much more drastic, and involved eliminating the circuits already represented for consideration, and in essence, starting the circuit selection process over. The study continued using the components, hazards, and types-by-function agreed upon by panelists but would either:

1) Require each panelist to submit circuits of their own choosing that they felt were representative of circuits that the community should be able to effectively analyze/assess/diagnose, or
2) Ask the Terrorist Explosive Device Analytical Center (TEDAC) to provide real-world circuits from their database of unclassified circuits, and have panelists vote on a list for inclusion in the study.

Fortunately, the majority of panelists agreed that it was not necessary to start the circuit selection process over, even though almost all acknowledged that in a perfect world, pulling real-world examples would have been the most desirable option.

Panelists also agreed that 29 circuits, representing all of the circuits that received at least one panelist vote, was far too many, and 7, representing those that received at least three votes, was far too few. Additionally, all panelists agreed that having representative circuits from each quartile was important, so having between 12 and 16 circuits was probably the right number to have good circuit representation at the right levels. Based on this feedback, and in reviewing the data, the 4 circuits from each quartile with the highest number of votes was selected for inclusion in the study. These results can be seen in Table 13, or as a simplified alphabetical list, in Appendix D.

Table 13

List of Final Circuits

Circuit Name	Quartile	Number of Panelist Votes
Adjustable Light Sensor	Very Easy	6
SCR Kitchen Timer	Very Easy	4
Collapsing Circuit	Very Easy	3
Battery Removal	Very Easy	3
Monostable 555 Variable Timer	Easy	4
Cellphone Optocoupler	Easy	3
Capacitor-Based Collapsing Circuit	Easy	2
Radio Squelch	Easy	2
Microcontroller-Based PIR	Difficult	3
Microcontroller-Based Ultrasonic	Difficult	2
DIY CWC-7 Receiver Dual SCR	Difficult	2
ATmega328P DTMF	Difficult	2
Iraq Timer CEXC	Very Difficult	2
NRF24L01 RCIED	Very Difficult	2
Active IR Counter	Very Difficult	2
Wire Disconnect Boobytrap	Very Difficult	2

Data Collection

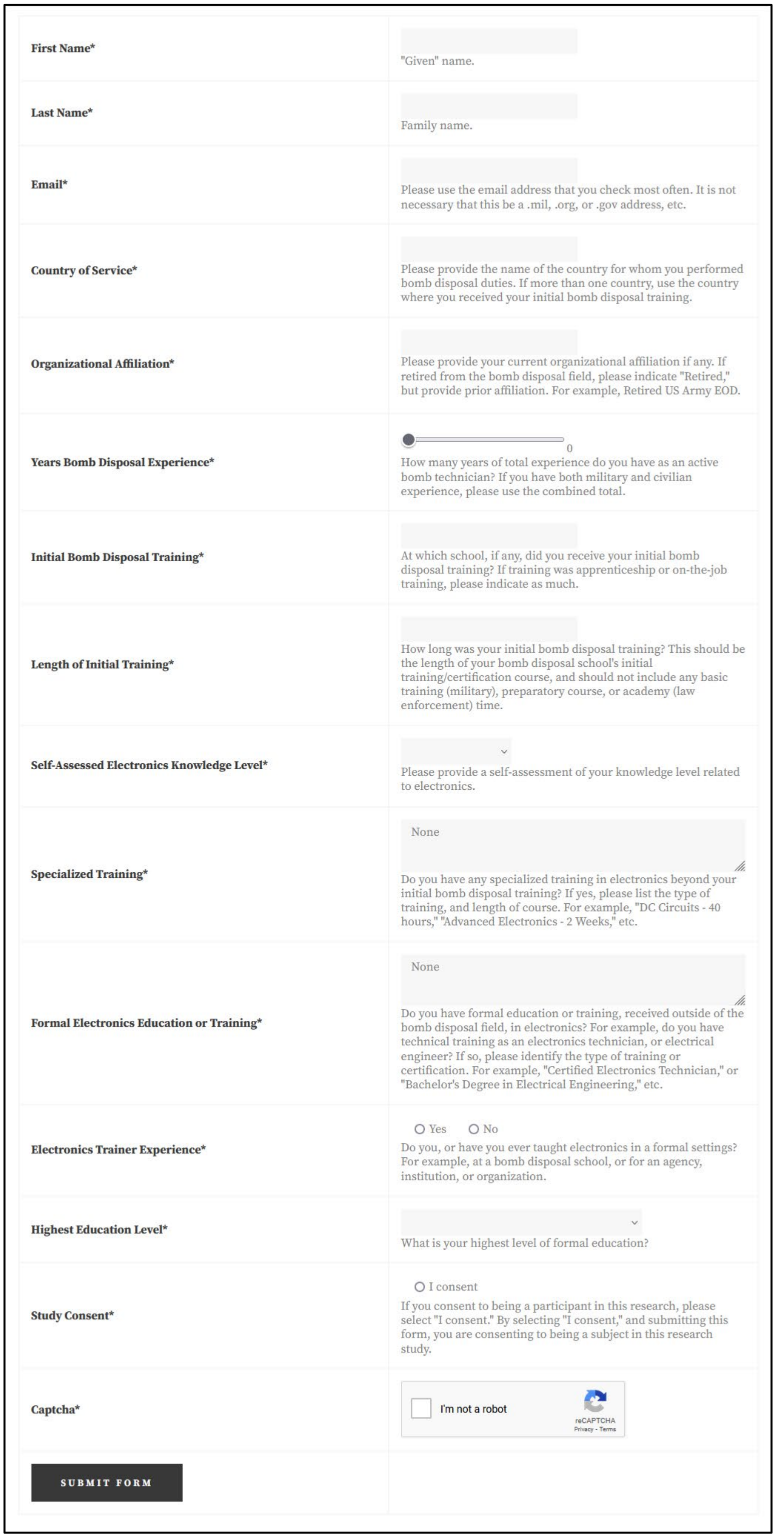
As stated earlier, data was collected using a web-based data collection instrument hosted on a commercial server. The website used to inform study participants about the study, the parameters for participation, and the sign-up form itself, were all built by this author specifically for the study. In addition, the web-based forms used for data collection, and the database used to store input from those forms, is also hosted on the commercial server used to host the website for this study.

Demographic information was collected for potential study participants to ensure potential candidates were, or had at one point during their career, been a bomb technician, and to capture information necessary to assess potential correlations between dependent and independent variables. Figure 13 is a screen-capture of this input form.

Once eligibility for participation in the study was established, study participants were sent an email verifying acceptance into the study, and provided an individualized access code linking their input from forms to a secure database. Figure 14 provides shows an example of an acceptance email with access code and personal information redacted.

Figure 13

Study Participation Request Form



First Name*	"Given" name.
Last Name*	Family name.
Email*	Please use the email address that you check most often. It is not necessary that this be a .mil, .org, or .gov address, etc.
Country of Service*	Please provide the name of the country for whom you performed bomb disposal duties. If more than one country, use the country where you received your initial bomb disposal training.
Organizational Affiliation*	Please provide your current organizational affiliation if any. If retired from the bomb disposal field, please indicate "Retired," but provide prior affiliation. For example, Retired US Army EOD.
Years Bomb Disposal Experience*	0 How many years of total experience do you have as an active bomb technician? If you have both military and civilian experience, please use the combined total.
Initial Bomb Disposal Training*	At which school, if any, did you receive your initial bomb disposal training? If training was apprenticeship or on-the-job training, please indicate as much.
Length of Initial Training*	How long was your initial bomb disposal training? This should be the length of your bomb disposal school's initial training/certification course, and should not include any basic training (military), preparatory course, or academy (law enforcement) time.
Self-Assessed Electronics Knowledge Level*	Please provide a self-assessment of your knowledge level related to electronics.
Specialized Training*	None Do you have any specialized training in electronics beyond your initial bomb disposal training? If yes, please list the type of training, and length of course. For example, "DC Circuits - 40 hours," "Advanced Electronics - 2 Weeks," etc.
Formal Electronics Education or Training*	None Do you have formal education or training, received outside of the bomb disposal field, in electronics? For example, do you have technical training as an electronics technician, or electrical engineer? If so, please identify the type of training or certification. For example, "Certified Electronics Technician," or "Bachelor's Degree in Electrical Engineering," etc.
Electronics Trainer Experience*	○ Yes ○ No Do you, or have you ever taught electronics in a formal settings? For example, at a bomb disposal school, or for an agency, institution, or organization.
Highest Education Level*	What is your highest level of formal education?
Study Consent*	○ I consent If you consent to being a participant in this research, please select "I consent." By selecting "I consent," and submitting this form, you are consenting to being a subject in this research study.
Captcha*	I'm not a robot reCAPTCHA Privacy - Terms
SUBMIT FORM	

Figure 14

Sample Email Providing Individualized Access Code

From: Bundy, Ed
Sent: Saturday, January 22, 2022 10:55 AM
To: [redacted]@[redacted].gov
Subject: Acceptance into the Diagnostic Reasoning Study

[redacted],

Thanks for your willingness to participate in my study, and you can follow the link below to access the study site. The first page you come to will be a practice scenario just to familiarize you with the study layout, but it should be pretty self-explanatory. If you have any questions however, please do not hesitate to drop me an email, and I will get back to you as quickly as possible.

Unique Individual User
Link: [redacted] (https://mfwbb.tech/Research_Portal/?page_id=148&pid=[redacted])

Please be aware that the link provided is unique to you, so don't share it with other potential study participants. You should retain this email so you can access the site again easily, but just be aware, if you have to leave the site for some reason, the last information submitted will be saved, and you can basically take up right where you left off. Re-entering the site takes you to the beginning of the questionnaire again however, but that gives you the opportunity to review and change anything if you want to.

Good luck, and thanks again for participating!

Respectfully,

Ed

****
Edwin A. Bundy, Ph.D., CIPBI
Graduate Student, School of Forensic Sciences
Arson and Explosives Investigation Program
Reply To: edwin.bundy@okstate.edu or [redacted]

The purpose of education is not just an accumulation of knowledge. It is to replace a closed mind with an open one.
****

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Data Analysis

For the purposes of this analysis, the following assumptions were made with respect to responses:

- Failure to identify a component included by the expert panel, or the inclusion of components omitted by the expert panel, constitutes misidentification, or an identification error.
- Not including hazards identified by the expert panel, or including hazards omitted by the expert panel, constitutes an association error.
- Not matching a circuit type-by-function identified by the expert panel constitutes a misdiagnosis, or hypothesis error.

Analysis was performed in several stages. First, all responses were evaluated to determine the total number of correct diagnoses, and the number of correct diagnoses with identification and association errors. Results were reviewed for homo- or heterogeneity, and if heterogeneity is exhibited, an attempt was made to identify natural stratifications, and separate participants into logical groupings for additional analysis.

In the next stage, each circuit type-by-function response was examined further to determine the number of correct and incorrect diagnoses, and for the numbers of identification- and association errors made. T-tests were used to compare any groups of participants with respect to diagnostic scores, and error types. This allowed for an assessment of the relative roles of identification, interpretation and hypothesis generation in the diagnostic process, and a comparison of any groups with regard to the nature of their reasoning processes.

Construct validity was determined by examining significant differences in the use of diagnostic strategies by study participants, and their ability to arrive at a correct analysis. A chi-squared test was used to determine significant differences in frequencies of use in diagnostic strategies between study participants. The chi-squared test was repeated for each circuit. To reduce the possibility of a Type 1 error, the level of significance was set at 0.01 for the chi-squared test, and 0.05 for all other statistical tests.

A one-way MANOVA was used to determine if there are significant differences between study participants' (independent variable) mean diagnostic success scores (dependent variable) for individual circuits. If a significant difference was found, an ANOVA was used to determine which circuits exhibited significant differences between participants.

A logistic regression analysis was used to determine which of the independent variables being studied (diagnostic reasoning strategy, experience, and education and training) have an impact on diagnostic success (the dependent variable). This analysis enabled modeling of the odds of making the correct diagnosis in terms of the independent variables. The regression was carried out using a generalized estimating equation approach. This approach enabled modeling of the association between responses from the same respondent.

Krippendorff's Alpha was used to estimate inter-rater reliability for study participant confidence levels related to components identified, associated hazards, and circuit type-by-function. Krippendorff's Alpha was used because it can handle various sample sizes, categories, and numbers of raters.

CHAPTER IV

FINDINGS

To determine the diagnostic reasoning approaches used, and success rates achieved by bomb technicians, the following null hypotheses were tested:

1) There are no significant differences in diagnostic reasoning approaches used by bomb technicians for IED electronic component identification, evaluation of associated hazards, and determination of circuit type-by-function.
2) There are no significant differences in success rates achieved by bomb technicians for IED electronic component identification, evaluation of associated hazards, and determination of circuit type-by-function, based on country of service; organizational affiliation; years of bomb disposal experience; bomb disposal school attended for initial training; length of initial training; self-assessed IED electronics knowledge level; specialized IED electronics training; formal electronics education or training; IED electronics trainer experience; or highest education level achieved.

These null hypotheses were tested by presenting study participants with 18 scenarios using IED firing circuits. Sixteen of the circuits were characterized at one of four different levels as determined by an expert panel: *Very Easy*, *Easy*, *Difficult*, and *Very Difficult*. Two scenarios, the Practice Scenario and Scenario 18, were not rated by the Expert Panel. Of the remaining sixteen scenarios, four were rated by the panel as *Very Easy*, four were rated as *Easy*, four as *Difficult*, and four *Very Difficult*. This researcher would characterize the Practice Scenario as *Difficult*, and Scenario 18 as *Very Difficult*, based on the assessment of other scenario circuits by the panelists.

The results of this study are based on participant responses related to the entire 18-Scenario circuit collection. However, not all study participants completed all scenarios, nor did they complete all subsections of the study instrument for individual scenarios. For example, a participant may only have completed individual scenarios through Scenario 9, but for several of the scenarios, the participant elected, for whatever reason, not to do the *Associated Hazards* or *Circuit Type-by-Function* portions of Scenario 8 and 9, etc. The reasons for non-completion of scenarios or subsections was not collected, but data was analyzed for all scenarios in which one or more subsections was completed, with the analysis being based on number of participants completing that subsection. As such, the reader should not assume a population of all respondents (n=228) when looking at data for scenarios or subsections of this study.

The layout of this chapter will be straightforward. *Demographics* will be covered first, describing the population with respect to dependent variables, which includes country of service; organizational affiliation; years of bomb disposal experience; bomb disposal school attended for initial training; length of initial training; self-assessed IED electronics knowledge level; specialized IED electronics training; formal electronics education or training; IED electronics trainer experience; and highest education level achieved. Next, the findings related to independent variables (i.e., component identification, evaluation of associated hazards, and determination of circuit type-by-function), will be identified. Then the reader will be presented with findings on each independent variable (i.e., component identification, evaluation of associated hazards, and determination of circuit type-by-function), as they relate to dependent variables (i.e., country of service; organizational affiliation; years of bomb disposal experience; bomb disposal school attended for initial training; length of initial training; self-assessed IED electronics knowledge level; specialized IED electronics training; formal electronics education or training; IED electronics trainer experience; and highest education level achieved).

Demographics

In total, 348 qualified participants signed up for the study; however, only 228 participants completed at least one subsection of a scenario, which was sufficient to count in the analysis of the data for that section of the survey instrument. Please see Chapter 3 for more detail on the web-based data collection methodology and survey instrument.

The diminution of participants was spread across the 18 scenarios, but there did not appear to be a specific point during the study at which any significant number of participants dropped out. Even though participants were encouraged to complete as many of the scenarios as possible, unfortunately, many reached a point where they felt continuing was of no value to themselves or the study. This conclusion is supported by the following sentiment expressed by one study participant:

> *Much harder than I thought and I found myself interested and engaged up until question 10. Those were a little above my pay grade. So questions 10 and up are not completed. I could name a few components but figured there is no point.*

Table 14 identifies participant numbers for each scenario, to include the Practice Scenario, and dependent variables.

Table 14

Participant Numbers by Scenario And Dependent Variable

	Component Identification	Associated Hazards	Circuit Type-by-Function
Practice Scenario	221	227	217
Scenario 1	215	215	228
Scenario 2	207	204	201
Scenario 3	199	196	197
Scenario 4	181	180	173
Scenario 5	171	166	163
Scenario 6	166	161	165
Scenario 7	155	153	149
Scenario 8	150	148	148
Scenario 9	145	143	141
Scenario 10	138	136	133
Scenario 11	133	133	133
Scenario 12	131	125	127
Scenario 13	127	123	124
Scenario 14	126	123	122
Scenario 15	125	116	116
Scenario 16	121	113	114
Scenario 17	121	121	117

Country of Service

In total, study participants represented bomb technicians from 17 different countries. As can be seen in Table 15, the majority of participants were from the U.S. (n=117), with other English speaking countries (n=33) having more representation than all countries where English was not the primary language spoken combined (n=16).

Table 15

Number of Participants By Country of Service

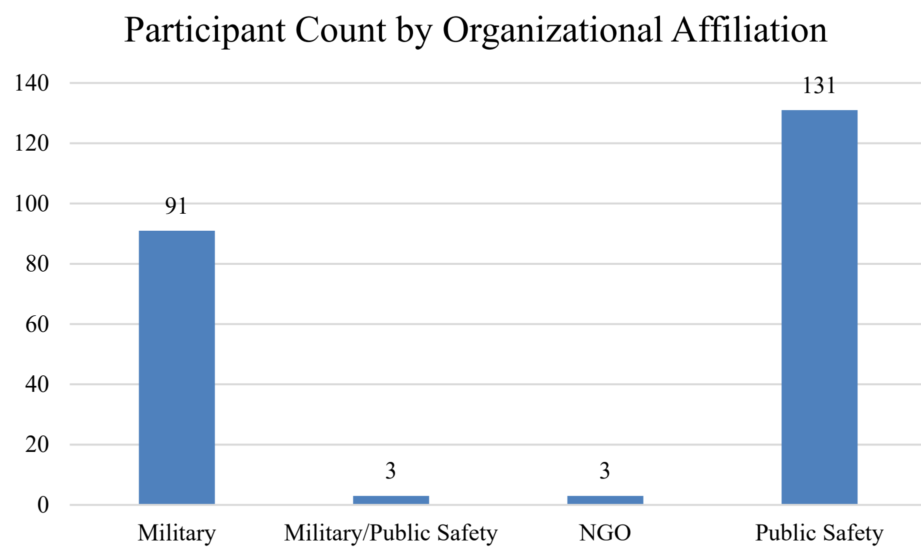
Country of Service	Number of Participants
Argentina	1
Australia	12
Austria	1
Brazil	3
Canada	14
Colombia	1
Greece	1
Hong Kong	2
Ireland	1
Israel	1
Italy	1
Kenya	1
Nepal	1
Philippines	2
Spain	1
United Kingdom	6
United States	179

Organizational Affiliations

Organizational affiliations were divided into four broad categories, based on the type of organizations to which the bomb technician is/was assigned. Those who performed bomb disposal duties for the military were assigned to the *Military* category; those who performed bomb disposal duties for the public sector were assigned to Public Safety; and those who performed duties for Non-Governmental Organizations (NGOs), like the United Nations, were assigned to the *NGO* category. If a participant is performing/has performed bomb disposal duties for both the military and public safety, they were assigned to a *Military/Public Safety* category. Figure 15 identifies participant count by organizational affiliation.

Figure 15

Participants by Organizational Affiliation

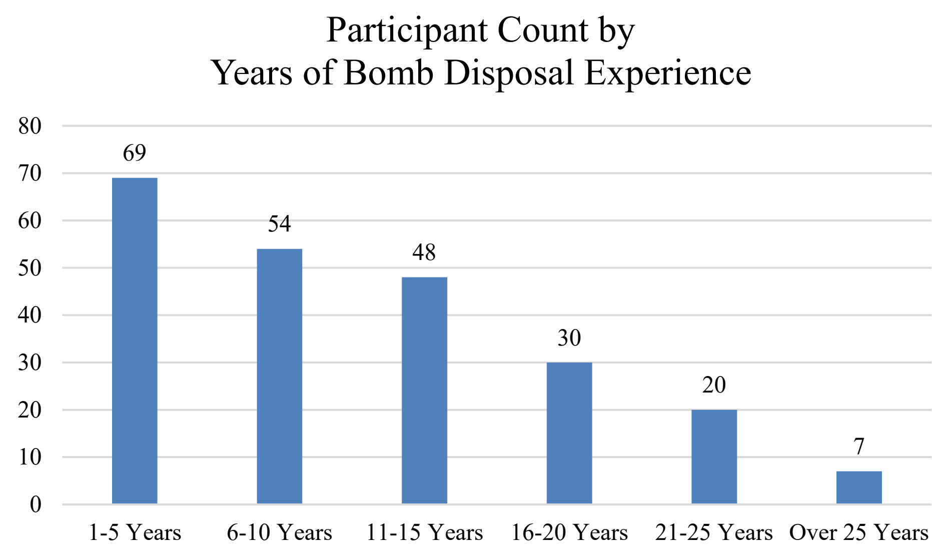


Years of Bomb Disposal Experience

To aid in data analysis, *Years of Bomb Disposal Experience* was binned into 5 year increments such as 1-5 years of experience, 6-10 years of experience, and so forth. The largest number of study participants in any one segment for *Years of Bomb Disposal Experience* (*n*=69), came into the study with 1-5 years of bomb disposal experience. The lowest number (*n*=7), had over 25 years of bomb disposal experience. Figure 16 identifies numbers of participants by years of bomb disposal experience.

Figure 16

Participants by Years Of Bomb Disposal Experience



Bomb Disposal School Attended for Initial Training

Identifying at which bomb disposal school study participants attended was difficult in some respects, with this researcher being unfamiliar with some of the schools declared. In addition, where schools were in non-English speaking countries, a web search was required to translate the name of the school to ensure that some other school was not mischaracterized as a different school, when one participant provided the name in English, and one in their native language. An additional complication arose in cases where study participants attended multiple schools in different sectors. For example, in the U.S., where individuals attended both *Naval School Explosive Ordnance Disposal* (NAVSCOLEOD) in the military, and the Hazardous Devices School (HDS), as a civilian. In these cases, both schools were listed, as were those where the participant declared an apprenticeship, or On-the-Job-Training (OJT). Table 16 identifies initial schools attended by participants, and the number of participants attending each school.

Table 16

Participant Count by Initial Bomb Disposal School Attended

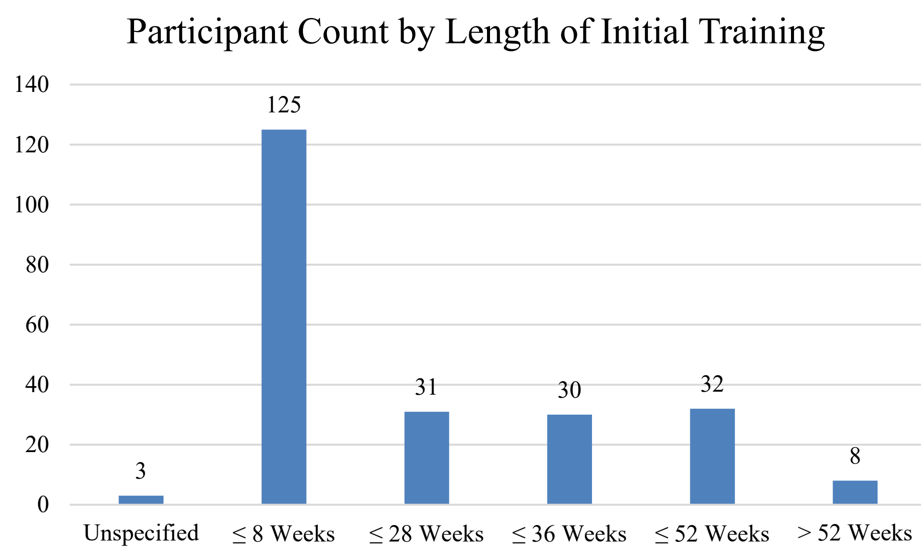
Initial Bomb Disposal Training	Count
Argentine Federal Police	1
Army School Of Ammunition - UK	3
Australian Army	2
Australian Federal Police	3
Austrian EOD School	1
Canadian Forces School of Military Engineering	4
Canadian Police College	10
Defence EOD School - UK	3
EOD Course - Philippines	1
Explosive Artifacts Management Group - Brazil	1
Explosive Ordnance Disposal Bureau, Hong Kong Police Force	2
HDS	102
Hellenic EOD/IEDD School	1
Humanitarian Peace Support School	1
Ireland	1
Israel National Police Bomb Disposal Division School	1
Italian Army	1
Military Police School/OJT/Apprenticeship - Brazil	1
National Police Corps - Spain	1
NAVSCOLEOD	71
NAVSCOLEOD/HDS	2
NAVSCOLEOD/OJT	1
Nepalese Army EOD Holding Unit	1
OJT	4
OJT/HDS	1
Philippine National Police Bomb Disposal School	1
Queensland Police EORT	4
School for Criminal Investigation - Colombia	1
South Australia Police EORT	1
Undeclared	1

Length of Initial Training

Length of initial training varied significantly, from 3 weeks (*n*=2) to 2 years (*n*=2). Irrespective of these rather large disparities, the lengths of initial training appeared to fall naturally into ranges, and it is these ranges that were used to bin study participants. Figure 17 identifies participant count by length of initial bomb disposal training.

Figure 17

Participants by Length Of Initial Bomb Disposal Training



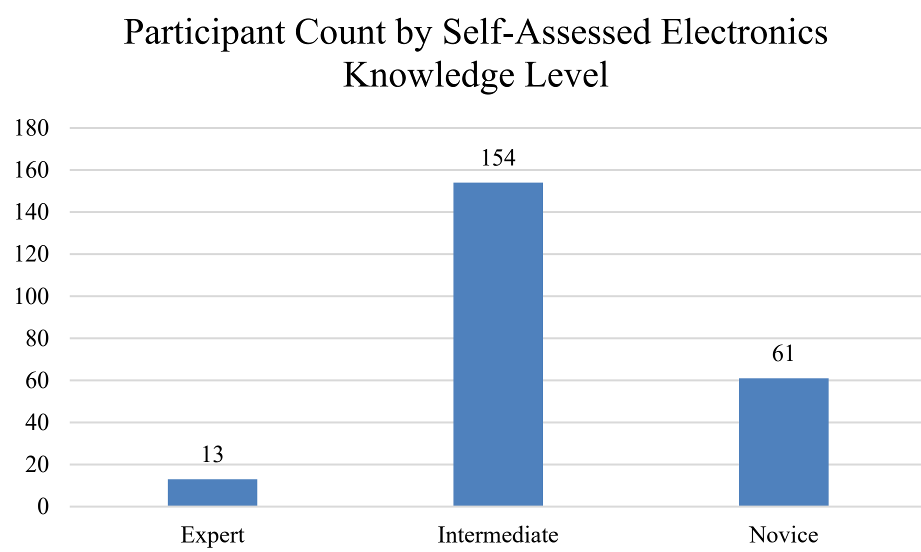
Self-Assessed IED Electronics Knowledge Level

Study participants were asked to assess their own level of knowledge on IED electronics. While three general categories were provided (i.e., *Novice*, *Intermediate*, and *Expert*), no parameters were provided as to what defined these categories. This seemed to induce consternation in some participants after beginning the study, with one respondent who initially identified as *Expert* inquiring, *I've started the study and I was think* [sic] *that intermediate might be a better selection for me. I tinker around with different components and feel that I have a pretty good grasp on different components and fire sets but to say that I am an expert might be reaching a little. What would you consider expert knowledge?*

It is unclear how many other participants might have elected to change their self-assessed knowledge level after beginning the study, but this is one example where that assessment might have changed. Figure 18 identifies numbers of participants who self-assessed as having *Expert*, *Intermediate*, and *Novice* IED electronics knowledge.

Figure 18

Participants by Self-Assessed IED Electronics Knowledge Level



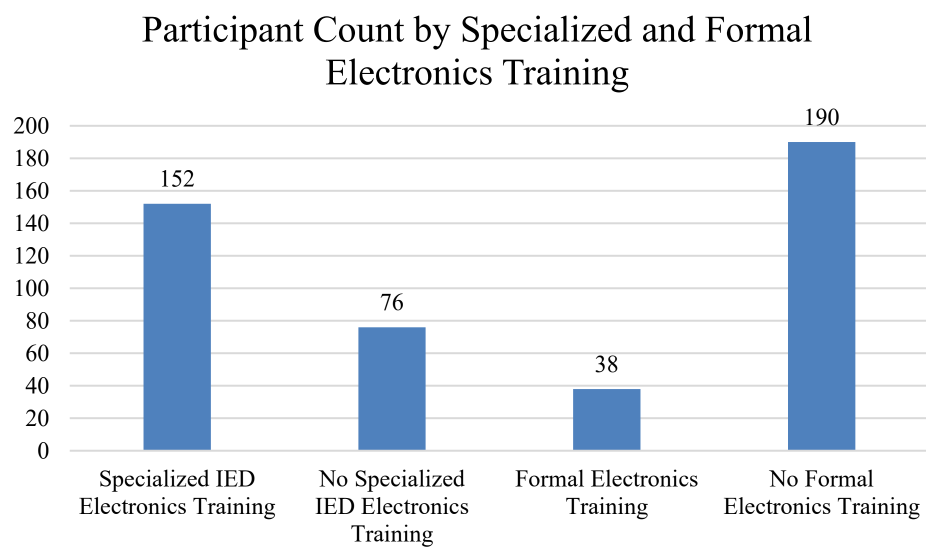
Specialized IED Electronics and Formal Electronics Training

For the purpose of this study, *Specialized IED Electronics Training* connotes any specific course in IED electronics taken beyond a participants initial bomb disposal training. A few participants listed their initial training in this section, which included a text-box to identify the type of training taken, but initial training was not counted in the final numbers. Regardless of whether the specialized training was provided by a government organization, commercial entity, or academic institution, it was counted if it was post initial training.

Formal Electronics Training on the other hand could be counted if obtained before, during, or after initial training. Formal electronics training connotes a course dealing with electronics theory and application not related to IEDs. This might be a degree or certificate program from an academic or technical institution, or a commercial entity offering courses to hobbyists. Some participants noted advanced degrees in electronics engineering, others trade school certifications as electricians, and still others, military certification of occupational skills related to electronics. At least one participant also acknowledged the depth and breadth of relevant training available on the internet, declaring as his formal training, “ >1000 Hours of YouTube consumption,” which may be considered by some to be a valid form of training in this, the Information Age. Figure 19 identifies the number of study participants with, and without *Specialized IED Electronics*, and *Formal Electronics* training.

Figure 19

Participants by Specialized IED Electronics and Formal Electronics Training

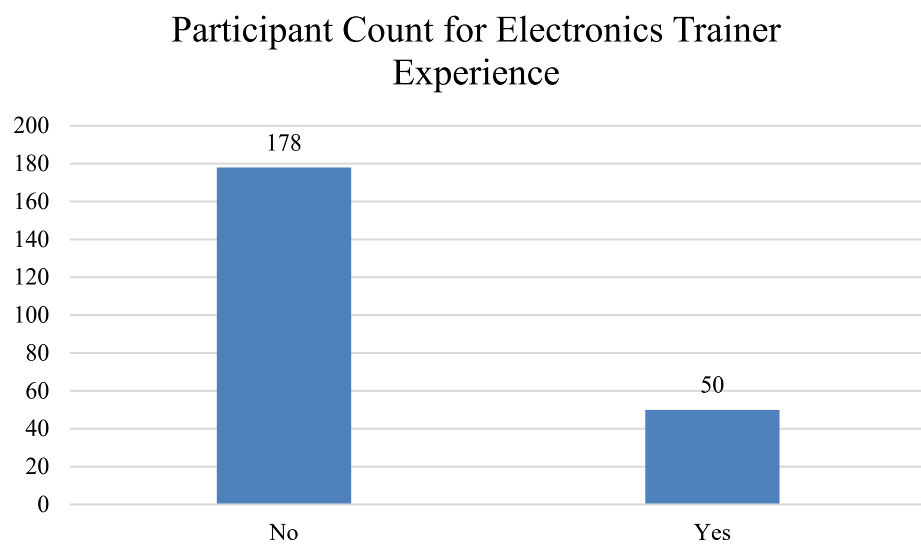


IED Electronics Trainer Experience

This researcher felt it important to capture the number of study participants who themselves, train or have trained other bomb technicians in IED electronics. This information can be used to see if any correlation exists between diagnostic reasoning approaches used by trainers and non-trainers, or if the success rates of trainers might potentially be higher than non-trainers. Figure 20 identifies the number of study participants with and without trainer experience.

Figure 20

Participants by Experience as IED Electronics Trainers

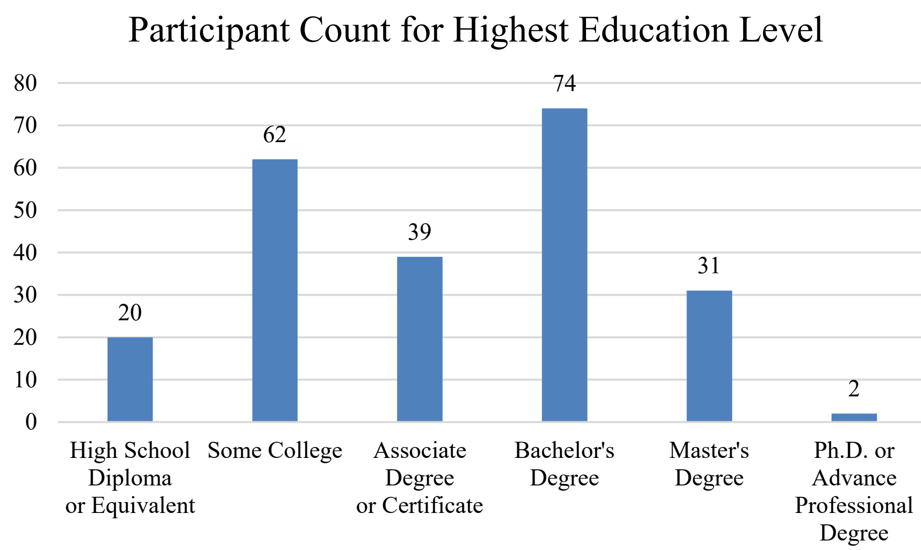


Highest Education Level Achieved

Highest Education Level Achieved is binned into what are considered standard categories of educational achievement in the United States. These, and the number of participants falling into these categories can be seen in Figure 21. It is worth noting however, that participants in this study ranged from those with only a high school diploma or equivalent (*n*=20), to those with a Ph.D. or an advanced professional degree such as a Juris Doctorate (*n*=2).

Figure 21

Participants by Highest Education Level Achieved



What does the average participant in this study look like?

Besides being a current or former bomb technician, the "typical" participant in this study is from the United States (*n*=179), and works, or has worked in the public safety sector (*n*=131). The average participant also has 1-5 years of bomb disposal experience (*n*=69), attended initial bomb disposal training at HDS (*n*=102), and their initial training was less than 8 weeks long (*n*=125). In addition, the average participant rated themselves as having an *Intermediate* level of knowledge regarding IED electronics (*n*=154), has had specialized training in IED electronics (*n*=152), but no formal education or training in electronics (*n*=190), and has no experience training other bomb technicians in electronics (*n*=178). Finally, the typical participant in this study also has a bachelor's degree (*n*=74) or some college (*n*=62).

Quantitative Findings

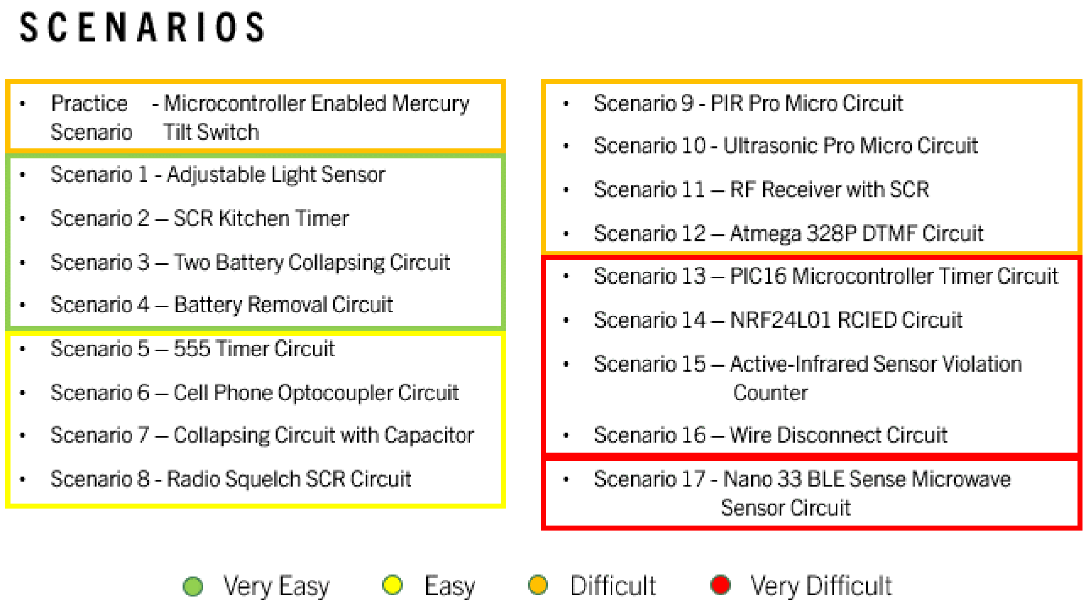
The *Quantitative Findings* section will focus on *Success Rates*, because these are quantifiable, in that there is, for the purposes of this study, a binary quality to the responses obtained, meaning the response was either correct, or incorrect. It is probably worth repeating at this point that the survey instrument material used in this study, to include the circuits and what are considered correct responses for identification of components, hazards associated with individual circuits, and circuit types-by-function, were validated by a panel of IED subject matter experts. As such, the rightness or wrongness of a response are not the opinion of this researcher, but that of panelists.

Where practical, findings related to various scenarios will include a color code to alert the reader to the degree of difficulty assigned to that scenario by the Expert Panel. Figure 22 identifies the scenario numbers along with the name of the circuit, as well as the difficulty level and color code assigned.

It should also be noted that how easy or difficult a circuit is perceived to be is a rather subjective classification. It became obvious early on in work with the Expert Panel that number of components, or even which components were part of a circuit, were not necessarily an indicator of degree of difficulty. For example, the circuit used in Scenario 17, the *Nano 33 BLE Sense Microwave Sensor Circuit*, has no more components, with respect to quantity, than the circuits for Scenario 1 and 2, the *Adjustable Light Sensor Circuit*, or the *SCR Kitchen Timer*, even though the circuits for Scenarios 1 and 2 are considered *Very Easy*, and the circuit for Scenario 17 is considered *Very Difficult*; more on this later.

Figure 22

Scenario Numbers with Circuit Names and Difficulty Color Codes



Average Success Rates by Scenario

Irrespective of what factors may contribute to the ease or difficulty of a circuit, success rates were quantifiable. Table 17 identifies average (i.e., *mean*) success rates by scenario, and Table 18 provides the descriptive statistics for *Success Rates by Scenario*.

Before getting into interpretation of statistical data however, it is probably worthwhile to provide a few definitions of statistical terms for those who are not used to working with statistics. According to Carlberg (2017), the term *mean* is what people normally think of as *the average*, and in simplest terms, it is *the total divided by the count*. The *median* on the other hand, is the *middle number* in a collection of data. For example, a researcher has 13 observations, the 7th observation will be the median, with 6 observations above, and six observations below the median. *Mode* however, refers to *which value occurs most frequently*. In other words, if you have 10 numbers that range between 1 and 10, and 3 occurs more often than any other number, then three will be the mode. It might be that 3 only occurs twice, but if all other numbers only occur once, then 3 is still the mode.

Table 17

Average Success Rates by Scenario

	Component Identification	Associated Hazards	Circuit Type-by-Function
Practice Scenario	1%	4%	52%
Scenario 1	36%	50%	75%
Scenario 2	36%	68%	89%
Scenario 3	53%	2%	18%
Scenario 4	26%	1%	24%
Scenario 5	35%	39%	72%
Scenario 6	5%	11%	35%
Scenario 7	43%	1%	38%
Scenario 8	27%	50%	83%
Scenario 9	28%	0%	49%
Scenario 10	30%	2%	54%
Scenario 11	0%	2%	54%
Scenario 12	4%	18%	37%
Scenario 13	6%	1%	40%
Scenario 14	15%	29%	49%
Scenario 15	1%	4%	53%
Scenario 16	13%	1%	58%
Scenario 17	3%	0%	36%

When looking at statistics regarding how much variability there is in a population, two more terms are important to understand; these are *standard deviation*, and *standard error*. The *standard deviation* refers to how far away from the mean that any given sample will be, so a low standard deviation indicates that sample values will likely be close to the mean, and a high standard deviation indicates that the sample values will likely be farther way from the mean. In other words, the lower the standard deviation, the lower the variability within your population. *Standard error* on the other hand, indicates how well the values for your sample will match a different sample from the same population, so a smaller standard error value is better than a larger standard error value. Generally, the more data points you have, or the more people in your sample size when calculating the mean, the smaller your standard error will usually be. (Carlberg, 2017)

The final term that needs to be covered is *sample variance*, or how spread out if you will, values within the sample are between the mean and any other value. For example, if the mean for a given scenario is 20%, and the sample variance is 5%, then you would expect to find any particular sample taken, to have a value between 15% and 25%. If the individual values in a population are all close to the expected value, the *sample variance* will be small, and close to the mean; if they are dispersed, the *sample variance* will be large, and far away from the mean, and likely each other. Keep in mind that *sample variance* is different from *range*, with *range* providing the numeric difference between the largest, and smallest values in a data set. In other words, *range* provides you with an indication of how far apart the highest and lowest scores are, but have nothing to do with the *mean*, or *average score*.

Table 18

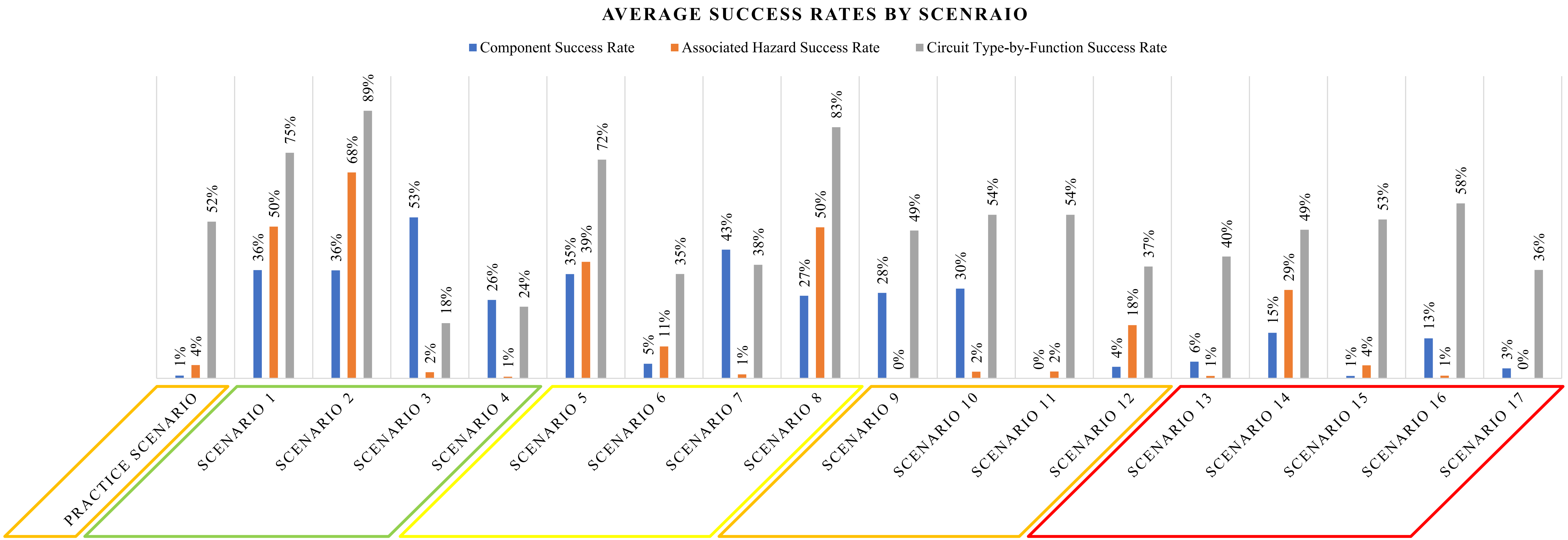
Descriptive Statistics for Average Success Rates by Scenario

	Component Identification	Associated Hazards	Circuit Type-by-Function
Mean	20%	16%	51%
Standard Error	4%	5%	5%
Median	21%	3%	51%
Mode	1%	1%	49%
Standard Deviation	17%	22%	19%
Sample Variance	3%	5%	4%
Range	53%	68%	71%
Minimum	0%	0%	18%
Maximum	53%	68%	89%
Confidence Level (95.0%)	8%	11%	10%

While somewhat duplicative of the data contained in Table 17, it might be helpful to readers to see a graphic representation of the average success rates by scenario. Figure 23 provides such a view.

Figure 23

Average Success Rates by Scenario for Dependent Variables

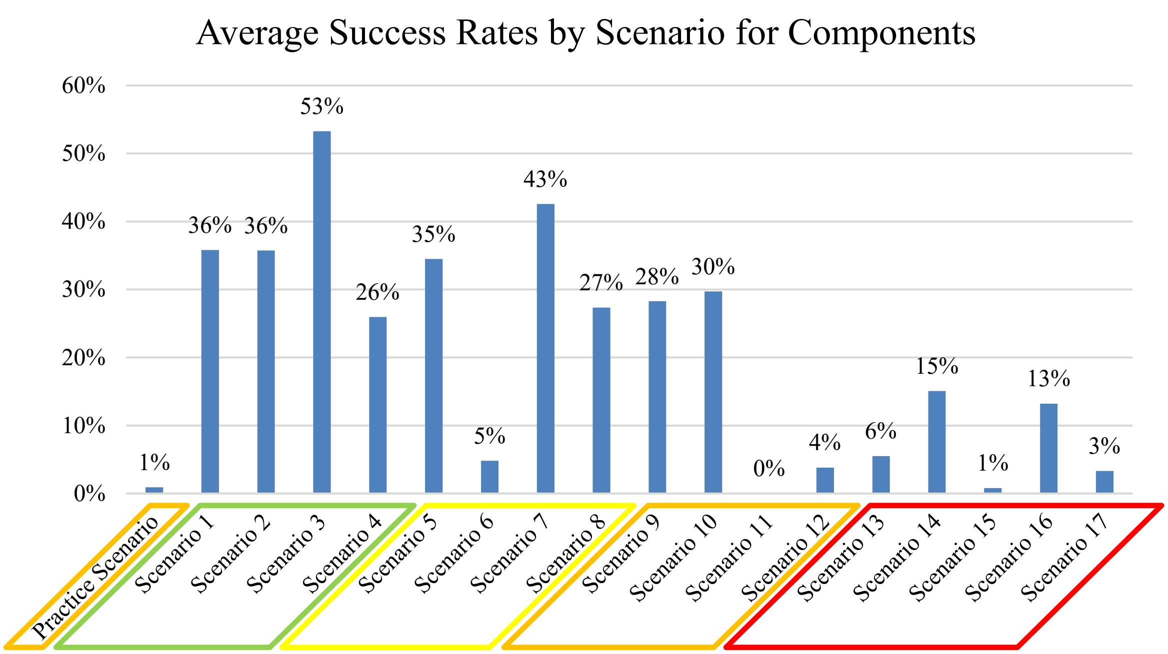


Average Success Rates by Scenario for Component Identification

Figure 24 provide success rates by scenario for components. This will aid in visualization of success rates for individual scenarios. Figures 25 and 26 provide cumulative averages for correct and incorrect component selections, respectively.

Figure 24

Average Success Rates by Scenario for Component Identification



Looking at the statistical data for the dependent variable *Component Identification*, the *mean score* for all scenarios was 20%. The *range* for this variable was 53%, with a *minimum score* of 0%, meaning for at least one scenario, no study participants provided a correct response, and a *maximum score* of 53%, meaning that for at least one scenario, 53% of participant provided a correct response. Tables 19-36 identify percentages of correct and incorrect component selections for each scenario.

It is important to note here that when the label *Correct Components Selected* is used in the following tables, it indicates the percentage of times (i.e., count) that participants selected the same component types for the circuits, as did the Expert Panel. If the reader wants to know the percentage of times that study participants *did not* select the same component types for the circuits as did the Expert Panel, i.e., the *error rate*, simply subtract *Percentage Selecting* from 100%, and the remainder will be *the error rate*.. For example, in Table 19, the Error Rate for identification of the Bipolar Junction Transistor (BJT) would be 86%.

The label *Incorrect Components Selected* may be somewhat counterintuitive, in that it does not indicates that a study participant misidentified that component (i.e., failed to identify that component), rather, they identified a different component as a component in the *Incorrect Components Selected* column. For example, in Table 19 where the 555 Integrated Circuit (IC) shows an average of 38% of participants incorrectly selecting the 555 IC, it means that rather than labeling the actual component correctly in a circuit, for example if it were a PIC microcontroller, or optocoupler, participants *mislabeled* that component as a 555 IC.

Finally, readers are reminded that study participants were not penalized for labeling a component using a generic term for a component when a more specific label was available. For example, if a study participant simply labeled an *electrolytic capacitor* a *capacitor*, they were given credit for a correct response. However, if they used a specific label, for example a *film capacitor*, when the actual capacitor was an *electrolytic capacitor*, the response was counted as incorrect.

Tables 19-36 provide data for correct and incorrect component selections by scenario, while Figures 25-26 provide data for cumulative correct and incorrect data (respectively).

Table 19

Component Selections for Practice Scenario: Microcontroller Enabled Mercury Tilt Switch

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Bipolar Junction Transistor	14%	555 Integrated Circuit	38%
Capacitor	19%	Arduino Microcontroller	1%
Ceramic Capacitor	7%	Darlington Transistor	3%
Light Emitting Diode	81%	Diode	6%
Mercury Switch	96%	Electrolytic Capacitor	1%
Microcontroller	36%	Film Capacitor	1%
MOSFET	52%	Integrated Circuit (IC)	25%
Transistor	40%	Lamp	4%
		Logic Gate	2%
		Micro Switch	1%
		Photodiode	1%
		Reed Switch	1%
		Resistor	11%
		Silicone Controlled Rectifier	37%
		Solid State Relay	5%
		Timer	1%
		Vibratory Switch	3%
		Voltage Regulator	5%

Table 20

Component Selections for Scenario 1: Adjustable Light Sensor

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Light Dependent Resistor	90%	Capacitor	1%
Light-Emitting Diode	95%	Ceramic Capacitor	1%
MOSFET	60%	DIP Switch	1%
Resistor	92%	Integrated Circuit (IC)	3%
Variable Resistor	70%	Silicone Controlled Rectifier	28%
		Solid State Relay	1%
		Transistor	13%
		Voltage Regulator	5%

Table 21

Component Selections for Scenario 2: SCR Kitchen Timer

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Light-Emitting Diode	94%	Bipolar Junction Transistor	4%
Resistor	93%	Buzzer	1%
Silicone Controlled Rectifier	51%	Capacitor	1%
Timer	95%	Ceramic Capacitor	1%
		Darlington Transistor	2%
		Diode	1%
		Integrated Circuit (IC)	2%
		Logic Gate	1%
		MOSFET	6%
		Resistor Array	3%
		Transistor	23%
		Variable Resistor	2%

Table 22

Component Selections for Scenario 3: Two Battery Collapsing Circuit

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Light-Emitting Diode	94%	555 Integrated Circuit	2%
Mechanical Relay	61%	Buzzer	1%
Resistor	91%	Capacitor	1%
		Ceramic Capacitor	1%
		Diode	1%
		DIP Switch	1%
		Electrolytic Capacitor	1%
		Fuse	1%
		Integrated Circuit (IC)	4%
		Lamp	1%
		Microcontroller	1%
		Micro Switch	1%
		Reed Switch	1%
		Resistor Array	1%
		RF Receiver	1%

Table 23

Component Selections for Scenario 4: Battery Removal Circuit

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Capacitor	73%	Bipolar Junction Transistor	1%
Diode	70%	Ceramic Capacitor	4%
Electrolytic Capacitor	21%	Darlington Transistor	1%
Light-Emitting Diode	92%	DIP Switch	1%
MOSFET	48%	Film Capacitor	3%
Resistor	90%	Fuse	1%
		Integrated Circuit (IC)	1%
		Lamp	1%
		Micro Switch	1%
		Push-Button Switch	1%
		Reed Switch	1%
		Resistor Array	7%
		Schottky Diode	4%
		Silicone Controlled Rectifier	36%
		Solid State Relay	2%
		Timer	1%
		Transistor	15%
		Variable Resistor	2%
		Voltage Regulator	1%
		Zener Diode	5%

Table 24

Component Selections for Scenario 5: 555 Timer Circuit

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
555 Integrated Circuit	83%	Arduino Microcontroller	1%
Capacitor	77%	Bipolar Junction Transistor	2%
Electrolytic Capacitor	22%	Ceramic Capacitor	2%
Integrated Circuit (IC)	8%	Darlington Transistor	1%
Light-Emitting Diode	95%	Decade Counter	1%
MOSFET	55%	Diode	2%
Resistor	87%	DIP Switch	1%
		Film Capacitor	4%
		Fuse	1%
		Lamp	1%
		Mechanical Relay	1%
		Microcontroller	6%
		Micro Switch	1%
		Resistor Array	5%
		Silicone Controlled Rectifier	34%
		Solid State Relay	3%
		Timer	5%
		Transistor	9%
		Variable Resistor	1%
		Voltage Regulator	1%
		Zener Diode	1%

Table 25

Component Selections for Scenario 6: Cell Phone Optocoupler Circuit

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Cell Phone	86%	555 Integrated Circuit	3%
Diode	66%	Antenna	5%
Integrated Circuit (IC)	13%	Arduino Microcontroller	1%
Light-Emitting Diode	90%	Buzzer	1%
Mechanical Relay	66%	Capacitor	7%
Resistor	84%	Ceramic Capacitor	1%
Silicone Controlled Rectifier	69%	DIP Switch	1%
		DTMF Decoder	1%
		Fuse	1%
		Inductor	1%
		Lamp	1%
		Microcontroller	4%
		Microphone	1%
		Micro Switch	1%
		MOSFET	14%
		Photodiode	2%
		Phototransistor	20%
		Push-Button Switch	1%
		Reed Switch	1%
		Resistor Array	8%
		RF Receiver	4%
		RF Transmitter	1%
		RF Transceiver	2%
		Schottky Diode	3%
		Solid State Relay	22%
		Speaker	2%
		Timer	2%
		Transistor	33%
		Variable Resistor	1%
		Vibratory Switch	1%
		Voltage Regulator	1%
		Zener Diode	5%

Table 26

Component Selections for Scenario 7: Capacitor-Based Collapsing Circuit

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Capacitor	66%	Antenna	1%
Diode	73%	Arduino Microcontroller	1%
Electrolytic Capacitor	26%	Buzzer	1%
Light-Emitting Diode	92%	Ceramic Capacitor	1%
Mechanical Relay	63%	Decade Counter	1%
Resistor	95%	Film Capacitor	3%
		Fuse	1%
		Integrated Circuit (IC)	1%
		Lamp	1%
		Microcontroller	1%
		Resistor Array	5%
		RF Receiver	1%
		Schottky Diode	4%
		Solid State Relay	23%
		Transistor	1%
		Variable Resistor	1%
		Zener Diode	5%

Table 27

Component Selections for Scenario 8: Radio Squelch SCR Circuit

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Light-Emitting Diode	93%	555 Integrated Circuit	1%
Resistor	90%	Antenna	24%
RF Receiver	37%	Bipolar Junction Transistor	1%
RF Transceiver	47%	Cell Phone	3%
Silicone Controlled Rectifier	66%	Crystal	1%
		Diode	1%
		DTMF Decoder	1%
		Fuse	1%
		Integrated Circuit (IC)	1%
		Lamp	1%
		Microphone	4%
		MOSFET	21%
		Push-Button Switch	1%
		Resistor Array	4%
		RF Transmitter	25%
		Solid State Relay	1%
		Speaker	11%
		Timer	1%
		Transistor	10%
		Variable Resistor	1%

Table 28

Component Selections for Scenario 9: Microcontroller-Based PIR Circuit

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Arduino Microcontroller	74%	555 Integrated Circuit	3%
Diode	63%	ATmega328P	1%
Light-Emitting Diode	95%	Capacitor	3%
Mechanical Relay	72%	Ceramic Capacitor	1%
Microcontroller	12%	Crystal	1%
Pyroelectric Sensor	83%	Electrolytic Capacitor	1%
Resistor	83%	Fuse	1%
		Integrated Circuit (IC)	17%
		Lamp	1%
		Microwave Sensor	1%
		Phototransistor	1%
		Push-Button Switch	1%
		Resistor Array	5%
		RF Receiver	1%
		RF Transmitter	1%
		RF Transceiver	1%
		Schottky Diode	3%
		Solid State Relay	21%
		Timer	2%
		Transistor	1%
		Ultrasonic Sensor	1%
		Variable Resistor	3%
		Vibratory Switch	1%
		Voltage Regulator	1%
		Zener Diode	3%

Table 29

Component Selections for Scenario 10: Microcontroller-Based Ultrasonic Circuit

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Arduino Microcontroller	72%	Antenna	1%
Light-Emitting Diode	95%	ATmega328P	1%
Mechanical Relay	67%	Capacitor	2%
Microcontroller	11%	Ceramic Capacitor	1%
Resistor	88%	Crystal	3%
Ultrasonic Sensor	72%	Diode	2%
		Fuse	1%
		Inductor	1%
		Integrated Circuit (IC)	19%
		Lamp	1%
		Microphone	7%
		Microwave Sensor	2%
		MOSFET	1%
		Reed Switch	1%
		Resistor Array	5%
		RF Receiver	2%
		RF Transmitter	1%
		RF Transceiver	2%
		Schottky Diode	1%
		Solid State Relay	19%
		Speaker	7%
		Timer	2%
		Transformer	1%
		Variable Resistor	1%
		Voltage Regulator	1%
		Zener Diode	1%

Table 30

Component Selections for Scenario 11: RF Receiver With SCR

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Antenna	72%	555 Integrated Circuit	14%
Capacitor	94%	Arduino Microcontroller	15%
Electrolytic Capacitor	26%	ATmega328P	5%
Integrated Circuit (IC)	59%	Bipolar Junction Transistor	7%
Light-Emitting Diode	93%	Ceramic Capacitor	1%
Resistor	77%	Crystal	2%
RF Receiver	53%	Darlington Transistor	2%
Silicone Controlled Rectifier	74%	Decade Counter	2%
Voltage Regulator	7%	Diode	5%
		DIP Switch	2%
		DTMF Decoder	11%
		Film Capacitor	1%
		Fuse	1%
		Inductor	5%
		Lamp	1%
		Logic Gate	2%
		Mechanical Relay	1%
		Microcontroller	34%
		Micro Switch	2%
		MOSFET	45%
		Photodiode	2%
		Phototransistor	4%
		Push-Button Switch	2%
		Resistor Array	20%
		RF Transmitter	2%
		RF Transceiver	6%
		Schottky Diode	1%
		Solid State Relay	2%
		Timer	5%
		Transistor	38%
		Variable Resistor	4%
		Vibratory Switch	1%

Table 31

Component Selections for Scenario 12: Atmega328p DTMF Circuit

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
ATmega328P	25%	555 Integrated Circuit	11%
Crystal	40%	Antenna	5%
Diode	44%	BJT	2%
DTMF Decoder	21%	Capacitor	95%
Electrolytic Capacitor	24%	Cell Phone	89%
Integrated Circuit (IC)	50%	Ceramic Capacitor	5%
Light-Emitting Diode	92%	Darlington Transistor	2%
Mechanical Relay	67%	Decade Counter	7%
Microcontroller	24%	DIP Switch	2%
Resistor	78%	Film Capacitor	1%
Voltage Regulator	7%	Fuse	1%
		Lamp	2%
		Light Dependent Resistor	1%
		Logic Gate	2%
		Microphone	2%
		Micro Switch	1%
		MOSFET	25%
		Photodiode	2%
		Phototransistor	2%
		Resistor Array	18%
		RF Receiver	8%
		RF Transmitter	5%
		RF Transceiver	5%
		Schottky Diode	5%
		Silicone Controlled Rectifier	47%
		Solid State Relay	19%
		Speaker	2%
		Timer	4%
		Transistor	27%
		Variable Resistor	1%
		Vibratory Switch	4%
		Zener Diode	3%

Table 32

Component Selections for Scenario 13: PIC16 Microcontroller Timer Circuit

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Bipolar Junction Transistor	4%	555 Integrated Circuit	20%
Capacitor	92%	Ceramic Capacitor	2%
Diode	69%	Film Capacitor	1%
Electrolytic Capacitor	28%	Fuse	1%
Light-Emitting Diode	94%	Integrated Circuit (IC)	25%
Mechanical Relay	67%	Lamp	1%
Microcontroller	51%	MOSFET	17%
Micro Switch	94%	Push-Button Switch	4%
Resistor	65%	Reed Switch	2%
Transistor	42%	Resistor Array	2%
Voltage Regulator	29%	Schottky Diode	7%
		Silicone Controlled Rectifier	41%
		Solid State Relay	19%
		Timer	3%
		Variable Resistor	1%
		Zener Diode	5%

Table 33

Component Selections for Scenario 14: NRF24L01 RCIED Circuit

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Antenna	75%	555 Integrated Circuit	3%
Arduino Microcontroller	87%	ATmega328P	1%
Bipolar Junction Transistor	5%	Ceramic Capacitor	2%
Capacitor	92%	Crystal	2%
Diode	65%	Darlington Transistor	17%
Electrolytic Capacitor	27%	DTMF Decoder	2%
Light-Emitting Diode	91%	Film Capacitor	1%
Mechanical Relay	64%	Fuse	1%
Microcontroller	87%	Integrated Circuit (IC)	21%
Resistor	78%	Lamp	1%
RF Transceiver	44%	Logic Gate	1%
Transistor	44%	Microwave Sensor	1%
Voltage Regulator	21%	MOSFET	26%
		Photodiode	1%
		Resistor Array	8%
		RF Receiver	29%
		RF Transmitter	3%
		Schottky Diode	7%
		Silicone Controlled Rectifier	42%
		Solid State Relay	20%
		Timer	2%
		Variable Resistor	1%
		Zener Diode	2%

Table 34

Component Selections for Scenario 15: Active-Infrared Sensor Violation Counter

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Bipolar Junction Transistor	19%	555 Integrated Circuit	7%
Capacitor	90%	Antenna	3%
Decade Counter	28%	Arduino Microcontroller	6%
Electrolytic Capacitor	25%	ATmega328P	2%
Integrated Circuit (IC)	67%	Ceramic Capacitor	2%
Light-Emitting Diode	90%	Darlington Transistor	3%
MOSFET	44%	Diode	10%
Photodiode	26%	DIP Switch	1%
Resistor	79%	Film Capacitor	1%
Silicone Controlled Rectifier	55%	Lamp	2%
Transistor	68%	Light Dependent Resistor	7%
Variable Resistor	34%	Logic Gate	6%
Voltage Regulator	34%	Mechanical Relay	1%
		Microcontroller	20%
		Microwave Sensor	2%
		Phototransistor	10%
		Reed Switch	1%
		Resistor Array	13%
		RF Receiver	1%
		RF Transceiver	2%
		Schottky Diode	1%
		Solid State Relay	1%
		Timer	4%
		Transformer	1%
		Vibratory Switch	1%

Table 35

Component Selections for Scenario 16: Wire Disconnect Circuit

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Capacitor	91%	555 Integrated Circuit	9%
Electrolytic Capacitor	28%	Antenna	4%
Integrated Circuit (IC)	66%	Arduino Microcontroller	1%
Light-Emitting Diode	92%	Bipolar Junction Transistor	1%
Logic Gate	30%	Darlington Transistor	1%
Resistor	79%	Decade Counter	4%
Silicone Controlled Rectifier	74%	Diode	1%
Variable Resistor	70%	DIP Switch	1%
		Film Capacitor	1%
		Fuse	1%
		Inductor	1%
		Lamp	4%
		Light Dependent Resistor	7%
		Mercury Switch	1%
		Microcontroller	14%
		Micro Switch	2%
		MOSFET	9%
		Photodiode	19%
		Phototransistor	6%
		Resistor Array	16%
		RF Receiver	1%
		Slide Switch	1%
		Solid State Relay	2%
		Timer	2%
		Transistor	21%
		Vibratory Switch	4%
		Voltage Regulator	3%

Table 36

Component Selections for Scenario 17: Nano 33 BLE Sense Microwave Sensor Circuit

Correct Components Selected	Percent Selecting	Incorrect Components Selected	Percent Selecting
Arduino Microcontroller	70%	555 Integrated Circuit	4%
Light Dependent Resistor	86%	Antenna	3%
Microcontroller	81%	ATmega328P	1%
Microwave Sensor	8%	Bipolar Junction Transistor	1%
Solid State Relay	84%	Capacitor	2%
		Cell Phone	2%
		Ceramic Capacitor	1%
		Crystal	1%
		Darlington Transistor	2%
		Diode	1%
		DIP Switch	1%
		DTMF Decoder	2%
		Electrolytic Capacitor	1%
		Film Capacitor	1%
		Fuse	1%
		Integrated Circuit (IC)	35%
		Light-Emitting Diode	4%
		Mechanical Relay	7%
		Microphone	1%
		Micro Switch	1%
		MOSFET	1%
		Photodiode	2%
		Phototransistor	7%
		Push-Button Switch	3%
		Pyroelectric Sensor	1%
		Resistor	4%
		RF Receiver	2%
		RF Transceiver	9%
		Silicone Controlled Rectifier	1%
		Timer	2%
		Transistor	10%
		Variable Resistor	1%

Figure 25

Cumulative Correct Component Selections by Component Type

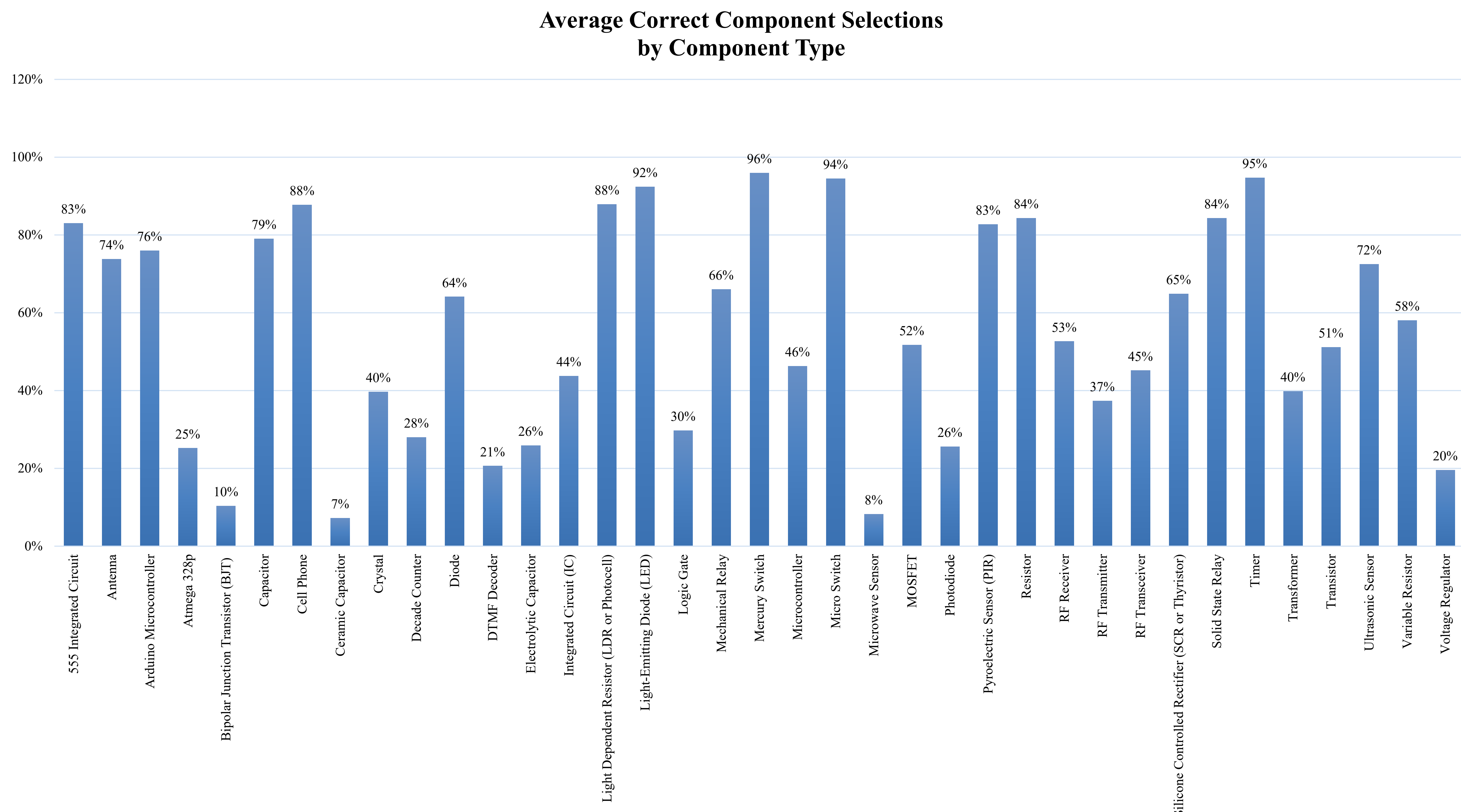
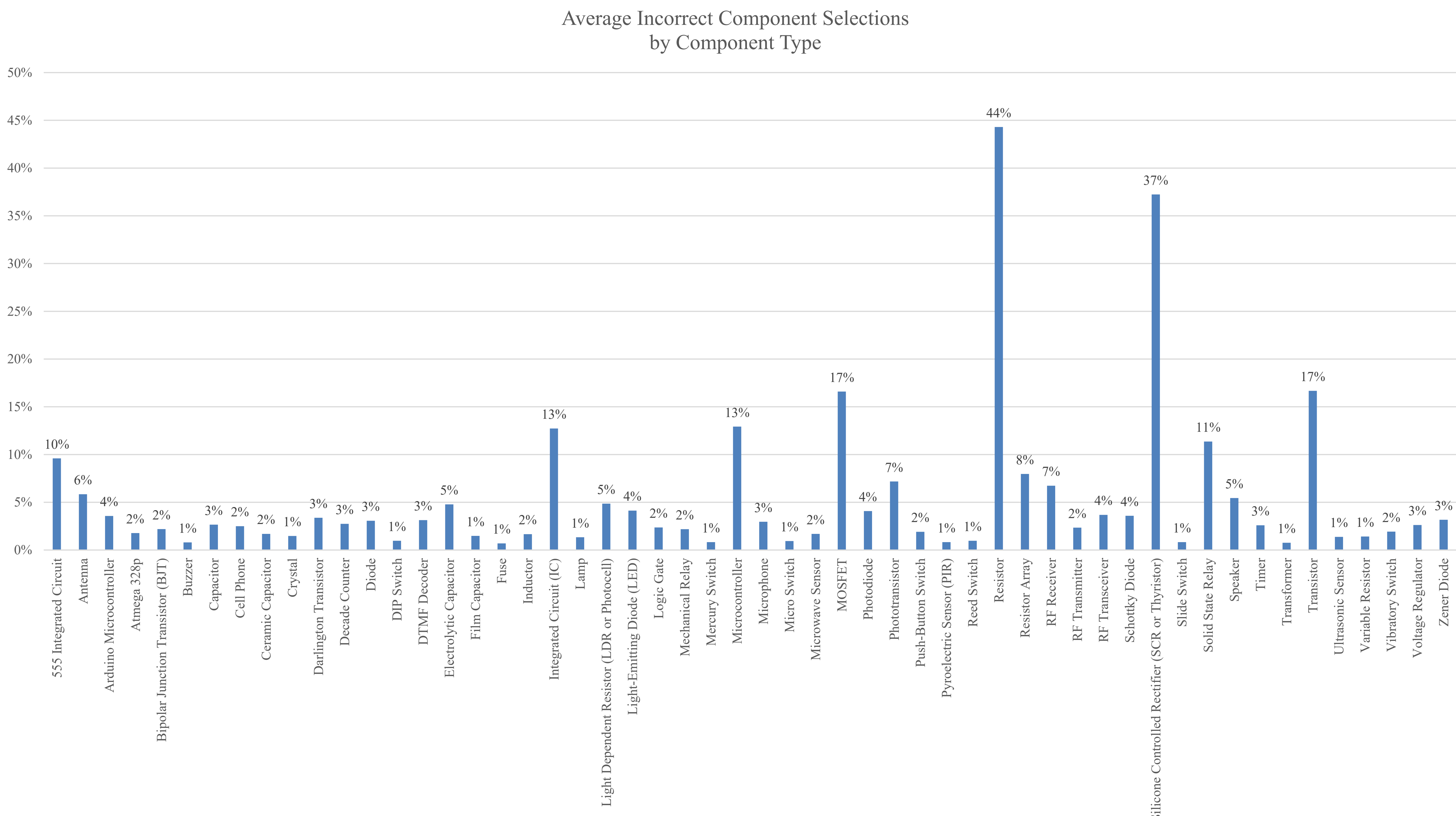


Figure 26

Cumulative Incorrect Component Selections by Component Type



Average Success Rates by Scenario for Associated Hazards

For *Associated Hazards*, the *mean score* for all scenarios was 16%, and the *range* for this variable was 68%. The *minimum score* was 0%, and the *maximum score* was 68%, and Figure 27 depicts the average success rates for associated hazards. Tables 37-54 identify percentages of correct and incorrect hazard selections for each scenario. Figures 28 and 29 provide cumulative averages for correct and incorrect hazards selections, respectively.

Figure 27

Average Success Rates by Scenario For Associated Hazards

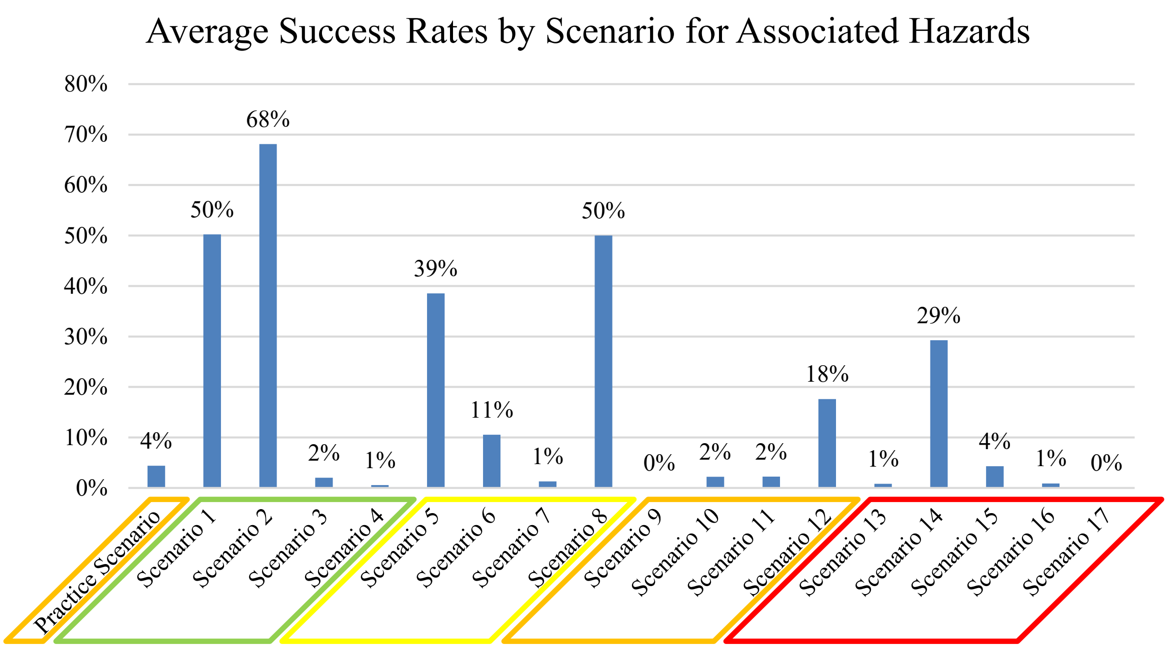


Table 37

Hazard Selections for Practice Scenario: Microcontroller Enabled Mercury Tilt Switch

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Movement	68%	Anti-Penetration	2%
Tilt	83%	Anti-Tamper	47%
		Boobytrap	21%
		Capacitance	4%
		Collapsing Circuit	6%
		Light/Dark Sensor	1%
		Electrostatic Discharge	14%
		Electromagnetic Radiation	10%
		Flame	2%
		Magnetic	4%
		Metal	1%
		Radiant Heat	2%
		Radio Frequency (RF)	5%
		Smoke/Dust/Particulates	1%
		Time	46%
		Vibration	39%

Table 38

Hazard Selections for Scenario 1: Adjustable Light Sensor

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Light/Dark Sensor	98%	Anti-Penetration	9%
		Anti-Tamper	17%
		Boobytrap	16%
		Camera/Video	2%
		Capacitance	2%
		Collapsing Circuit	2%
		Electrostatic Discharge	13%
		Electromagnetic Radiation	9%
		Flame	2%
		Movement	3%
		Proximity	1%
		Radio Frequency (RF)	5%
		Smoke/Dust/Particulates	2%
		Time	7%
		X-Ray/Radiation	10%

Table 39

Hazard Selections for Scenario 2: SCR Kitchen Timer

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Time	100%	Acoustic/Sound Level	1%
		Anti-Tamper	4%
		Boobytrap	4%
		Capacitance	1%
		Collapsing Circuit	1%
		Electrostatic Discharge	15%
		Electromagnetic Radiation	11%
		Flame	1%
		Movement	5%
		Piezo Electric	10%
		Pressure	1%
		Radio Frequency (RF)	4%
		Vibration	7%
		X-Ray/Radiation	1%

Table 40

Hazard Selections for Scenario 3: Two Battery Collapsing Circuit

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Boobytrap	17%	Anti-Penetration	3%
Collapsing Circuit	82%	Anti-Tamper	28%
Time	70%	Capacitance	2%
		Electrostatic Discharge	12%
		Electromagnetic Radiation	10%
		Flame	1%
		Magnetic	6%
		Metal	1%
		Movement	12%
		Pressure Release	1%
		Radio Frequency (RF)	3%
		Tilt	1%
		Vibration	13%
		X-Ray/Radiation	1%

Table 41

Hazard Selections for Scenario 4: Battery Removal Circuit

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Boobytrap	9%	Anti-Tamper	18%
Collapsing Circuit	36%	Capacitance	31%
Time	73%	Electrostatic Discharge	19%
		Electromagnetic Radiation	12%
		Flame	1%
		Metal	1%
		Movement	2%
		Piezo Electric	1%
		Radio Frequency (RF)	4%
		Tilt	1%
		Vibration	2%
		X-Ray/Radiation	1%

Table 42

Hazard Selections for Scenario 5: 555 Timer Circuit

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Time	89%	Anti-Penetration	1%
		Anti-Tamper	9%
		Boobytrap	8%
		Capacitance	23%
		Collapsing Circuit	23%
		Electrostatic Discharge	19%
		Electromagnetic Radiation	14%
		Flame	1%
		Metal	1%
		Movement	4%
		Pressure	1%
		Radio Frequency (RF)	8%
		Vibration	1%
		Wi-Fi	1%
		X-Ray/Radiation	1%

Table 43

Hazard Selections for Scenario 6: Cell Phone Optocoupler Circuit

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Radio Frequency (RF)	71%	Acoustic/Sound Level	19%
		Anti-Penetration	2%
		Anti-Tamper	14%
		Boobytrap	13%
		Camera/Video	12%
		Capacitance	3%
		Collapsing Circuit	18%
		Light/Dark Sensor	10%
		Electrostatic Discharge	17%
		Electromagnetic Radiation	20%
		Flame	1%
		Magnetic	4%
		Metal	1%
		Movement	19%
		Piezo Electric	1%
		Pressure Release	1%
		Proximity	6%
		Radiant Heat	1%
		Tilt	12%
		Time	61%
		Vibration	13%
		Wi-Fi	34%
		X-Ray/Radiation	4%

Table 44

Hazard Selections for Scenario 7: Capacitor-Based Collapsing Circuit

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Anti-Tamper	23%	Acoustic/Sound Level	1%
Boobytrap	12%	Anti-Penetration	1%
Collapsing Circuit	59%	Capacitance	27%
Time	78%	Electrostatic Discharge	15%
		Electromagnetic Radiation	12%
		Flame	1%
		Magnetic	6%
		Metal	1%
		Movement	9%
		Pressure Release	1%
		Radio Frequency (RF)	8%
		Tilt	1%
		Vibration	10%
		Wi-Fi	1%
		X-Ray/Radiation	1%

Table 45

Hazard Selections for Scenario 8: Radio Squelch SCR Circuit

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Radio Frequency (RF)	97%	Acoustic/Sound Level	9%
		Anti-Tamper	1%
		Boobytrap	5%
		Capacitance	1%
		Electrostatic Discharge	21%
		Electromagnetic Radiation	32%
		Flame	1%
		Magnetic	1%
		Metal	1%
		Movement	3%
		Piezo Electric	1%
		Pressure	3%
		Pressure Release	1%
		Proximity	3%
		Time	4%
		Vibration	2%
		Wi-Fi	1%
		X-Ray/Radiation	2%

Table 46

Hazard Selections for Scenario 9: Microcontroller-Based PIR Circuit

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Movement	75%	Acoustic/Sound Level	1%
Radiant Heat	20%	Anti-Penetration	20%
X-Ray/Radiation	39%	Anti-Tamper	34%
		Boobytrap	31%
		Camera/Video	1%
		Capacitance	3%
		Collapsing Circuit	45%
		Light/Dark Sensor	9%
		Electrostatic Discharge	19%
		Electromagnetic Radiation	18%
		Flame	3%
		Magnetic	3%
		Metal	1%
		Proximity	56%
		Radio Frequency (RF)	13%
		Smoke/Dust/Particulates	8%
		Tilt	4%
		Time	41%
		Vibration	10%
		Wi-Fi	4%

Table 47

Hazard Selections for Scenario 10: Microcontroller-Based Ultrasonic Circuit

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Proximity	57%	Acoustic/Sound Level	49%
		Anti-Penetration	17%
		Anti-Tamper	30%
		Boobytrap	27%
		Capacitance	4%
		Collapsing Circuit	39%
		Electrostatic Discharge	16%
		Electromagnetic Radiation	15%
		Flame	1%
		Magnetic	2%
		Metal	1%
		Movement	52%
		Piezo Electric	1%
		Radio Frequency (RF)	13%
		Smoke/Dust/Particulates	6%
		Tilt	7%
		Time	41%
		Vibration	17%
		Wi-Fi	1%
		X-Ray/Radiation	2%

Table 48

Hazard Selections for Scenario 11: RF Receiver With SCR

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Electromagnetic Radiation	25%	Acoustic/Sound Level	1%
Radio Frequency (RF)	89%	Anti-Tamper	5%
		Boobytrap	7%
		Capacitance	13%
		Collapsing Circuit	11%
		Light/Dark Sensor	4%
		Electrostatic Discharge	20%
		Flame	2%
		Gas/VOC	0%
		Magnetic	5%
		Metal	2%
		Movement	4%
		Proximity	6%
		Radiant Heat	2%
		Time	24%
		Vibration	3%
		Wi-Fi	9%
		X-Ray/Radiation	3%

Table 49

Hazard Selections for Scenario 12: Atmega328p DTMF Circuit

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Radio Frequency (RF)	84%	Acoustic/Sound Level	16%
		Anti-Penetration	2%
		Anti-Tamper	22%
		Boobytrap	16%
		Camera/Video	10%
		Capacitance	16%
		Collapsing Circuit	37%
		Light/Dark Sensor	9%
		Electrostatic Discharge	22%
		Electromagnetic Radiation	19%
		Flame	2%
		Magnetic	5%
		Metal	1%
		Movement	19%
		Piezo Electric	6%
		Proximity	6%
		Radiant Heat	1%
		Tilt	13%
		Time	59%
		Vibration	15%
		Wi-Fi	34%
		X-Ray/Radiation	2%

Table 50

Hazard Selections for Scenario 13: PIC16 Microcontroller Timer Circuit

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Boobytrap	42%	Anti-Penetration	7%
Time	46%	Anti-Tamper	52%
		Capacitance	16%
		Collapsing Circuit	30%
		Electrostatic Discharge	20%
		Electromagnetic Radiation	15%
		Flame	2%
		Magnetic	5%
		Metal	1%
		Movement	33%
		Pressure	69%
		Pressure Release	63%
		Radio Frequency (RF)	7%
		Tilt	7%
		Vibration	7%
		Wi-Fi	1%
		X-Ray/Radiation	1%

Table 51

Hazard Selections for Scenario 14: NRF24L01 RCIED Circuit

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Radio Frequency (RF)	99%	Anti-Penetration	2%
		Anti-Tamper	17%
		Boobytrap	11%
		Capacitance	11%
		Collapsing Circuit	40%
		Electrostatic Discharge	23%
		Electromagnetic Radiation	31%
		Flame	2%
		Magnetic	4%
		Metal	1%
		Movement	6%
		Proximity	3%
		Tilt	1%
		Time	41%
		Vibration	7%
		Wi-Fi	22%
		X-Ray/Radiation	4%

Table 52

Hazard Selections for Scenario 15: Active-Infrared Sensor Violation Counter

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Movement	40%	Anti-Penetration	13%
Proximity	42%	Anti-Tamper	25%
		Boobytrap	25%
		Camera/Video	2%
		Capacitance	13%
		Collapsing Circuit	8%
		Light/Dark Sensor	44%
		Electrostatic Discharge	22%
		Electromagnetic Radiation	22%
		Flame	6%
		Metal	1%
		Radiant Heat	6%
		Radio Frequency (RF)	13%
		Smoke/Dust/Particulates	7%
		Tilt	1%
		Time	35%
		Vibration	2%
		Wi-Fi	3%
		X-Ray/Radiation	15%

Table 53

Hazard Selections for Scenario 16: Wire Disconnect Circuit

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Boobytrap	42%	Anti-Penetration	17%
Collapsing Circuit	20%	Anti-Tamper	50%
		Capacitance	15%
		Light/Dark Sensor	37%
		Electrostatic Discharge	20%
		Electromagnetic Radiation	17%
		Flame	2%
		Magnetic	3%
		Metal	4%
		Movement	22%
		Pressure	4%
		Pressure Release	2%
		Proximity	5%
		Radiant Heat	2%
		Radio Frequency (RF)	10%
		Tilt	6%
		Time	30%
		Vibration	10%
		X-Ray/Radiation	4%

Table 54

Hazard Selections for Scenario 17: Nano 33 BLE Sense Microwave Sensor Circuit

Correct Hazard Selected	Percent Selecting	Incorrect Hazard Selected	Percent Selecting
Proximity	17%	Acoustic/Sound Level	3%
		Anti-Penetration	17%
		Anti-Tamper	31%
		Boobytrap	26%
		Camera/Video	1%
		Capacitance	2%
		Collapsing Circuit	39%
		Light/Dark Sensor	87%
		Electrostatic Discharge	19%
		Electromagnetic Radiation	17%
		Flame	3%
		Gas/VOC	3%
		Magnetic	4%
		Metal	2%
		Movement	26%
		Piezo Electric	1%
		Pressure	2%
		Pressure Release	2%
		Radiant Heat	2%
		Radio Frequency (RF)	21%
		Smoke/Dust/Particulates	5%
		Tilt	6%
		Time	45%
		Vibration	8%
		Wi-Fi	11%
		X-Ray/Radiation	7%

Figure 28

Cumulative Correct Hazard Selections by Hazard Types

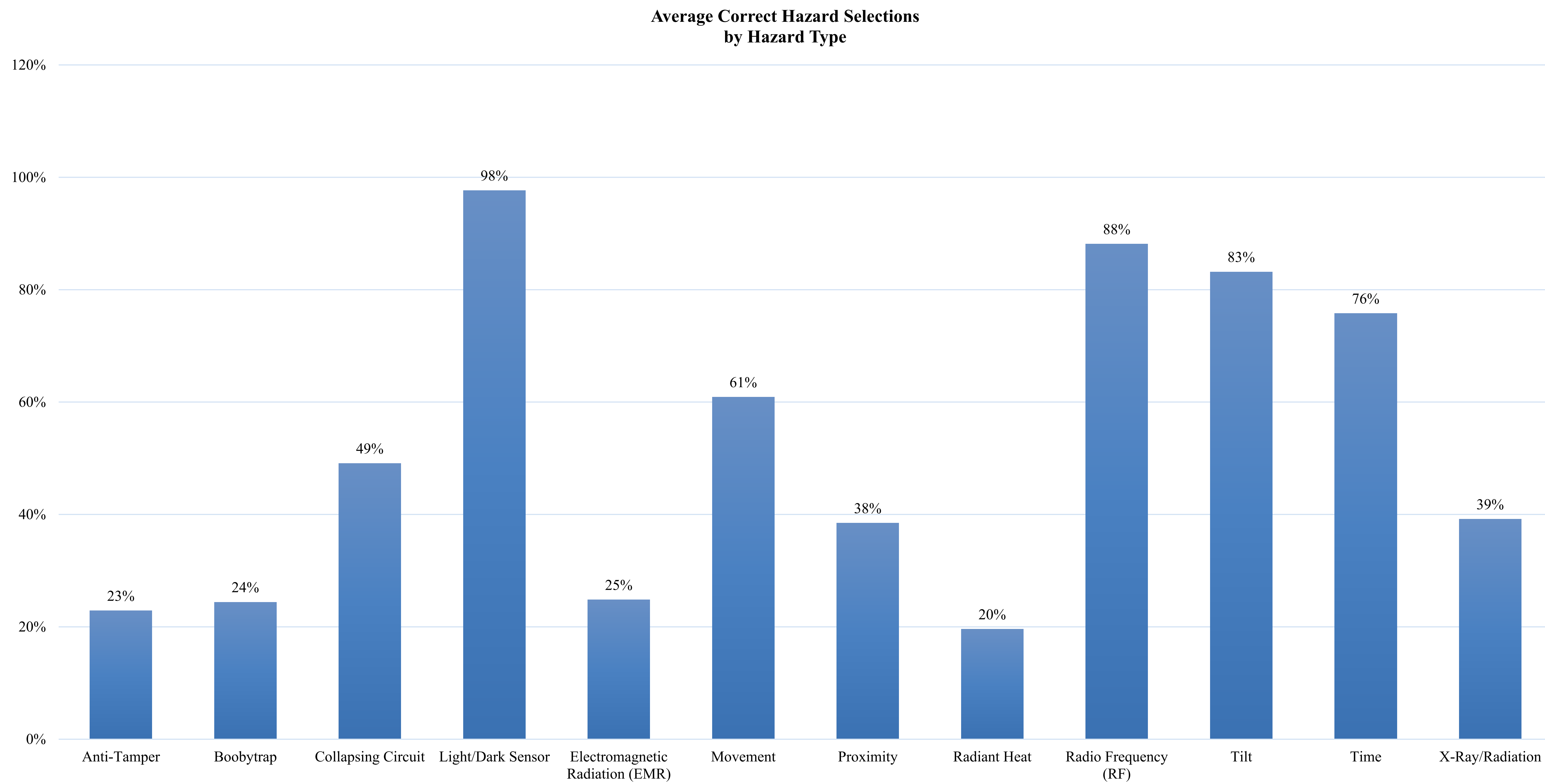
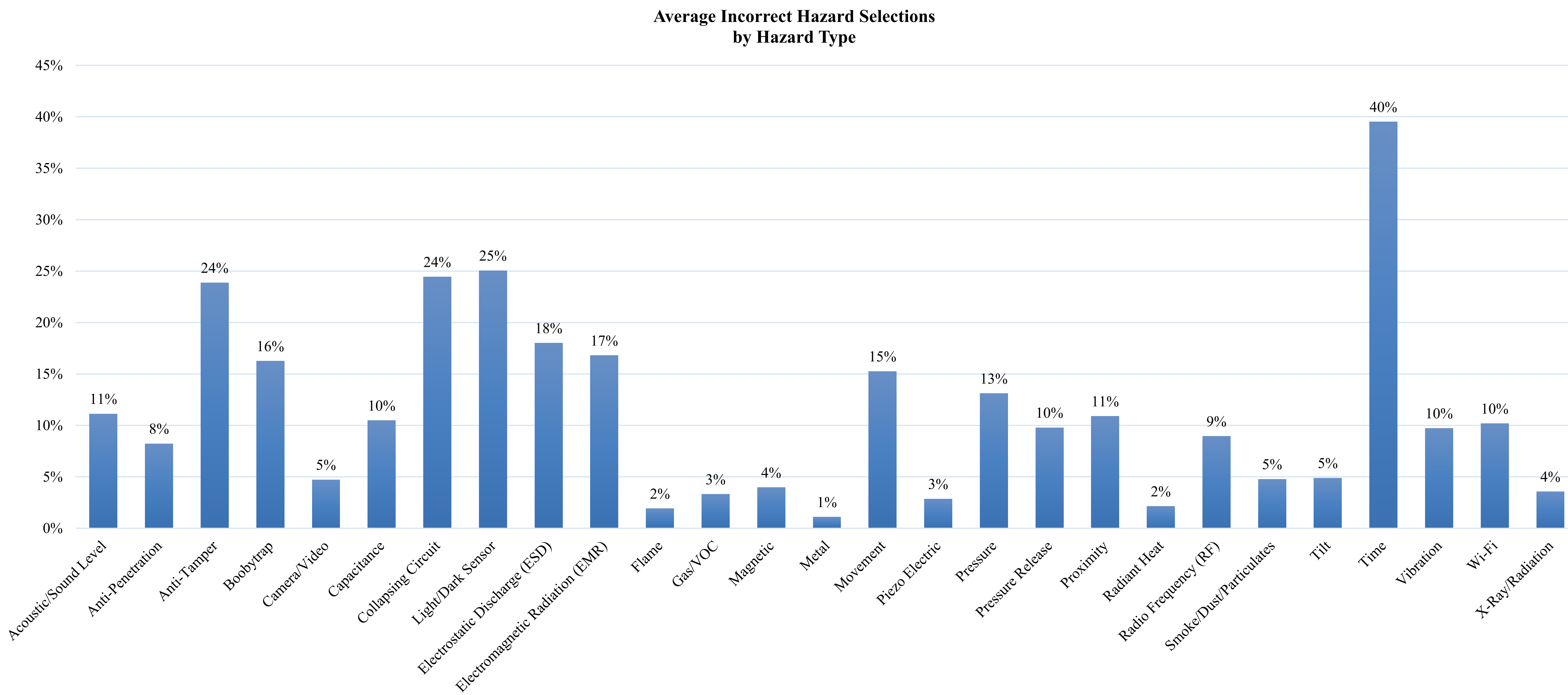


Figure 29

Cumulative Incorrect Hazard Selections by Hazard Types



Average Success Rates by Scenario for Circuit Type-by-Function

For *Circuit Type-by-Function*, the *mean score* for all scenarios was 51%, and the *range* for this variable was 71%. The *minimum score* was 18%, and the *maximum score* was 89% (see Figure 30). Tables 55-72 identify percentages of correct and incorrect hazard selections for each scenario. Figures 31 and 32 provide cumulative averages for correct and incorrect circuit type(s)-by-function selections, respectively.

Figure 30

Average Success Rates by Scenario For Circuit Type-By-Function

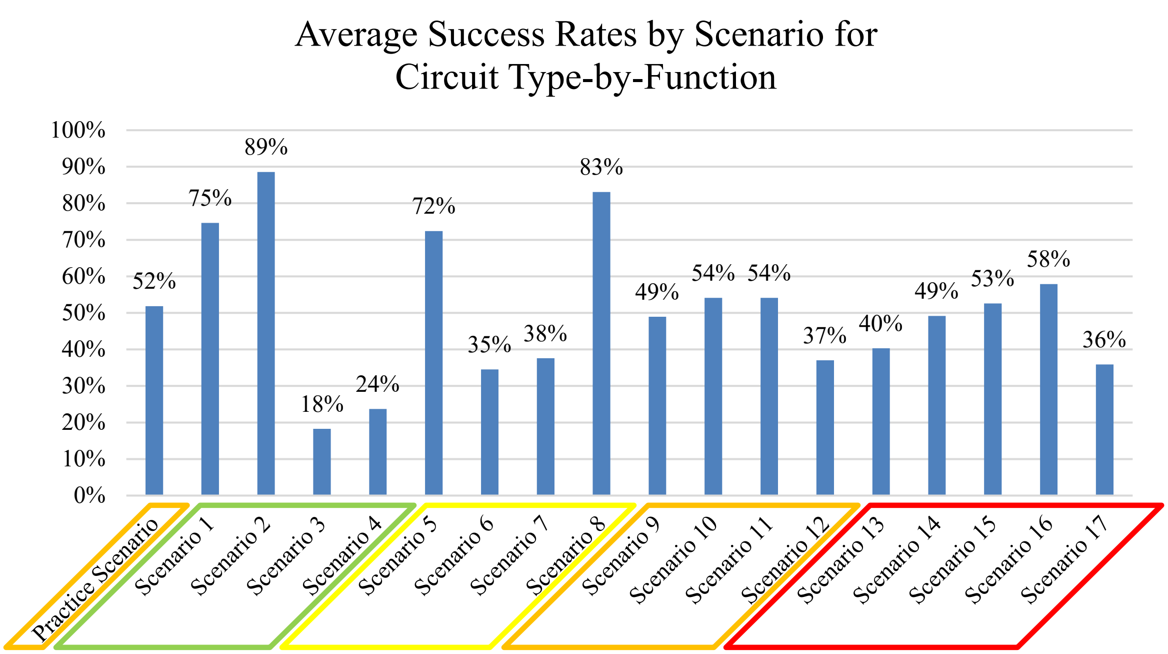


Table 55

Type-By-Function Selections *for* Practice Scenario: Microcontroller Enabled Mercury Tilt Switch

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Victim Operated	94%	Command	2%
		Time	47%

Table 56

Type-By-Function Selections for Scenario 1: Adjustable Light Sensor

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Victim Operated	100%	Command	6%
		Time	24%

Table 57

Type-By-Function Selections for Scenario 2: SCR Kitchen Timer

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Time	100%	Command	1%
		Victim Operated	10%

Table 58

Type-By-Function Selections for Scenario 3: Two Battery Collapsing Circuit

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Victim Operated	74%	Command	8%
		Time	78%

Table 59

Type-By-Function Selections for Scenario 4: Battery Removal Circuit

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Time	80%	Command	8%
Victim Operated	40%		

Table 60

Type-By-Function Selections for Scenario 5: 555 Timer Circuit

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Time	94%	Command	6%
		Victim Operated	23%

Table 61

Type-By-Function Selections for Scenario 6: Cell Phone Optocoupler Circuit

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Command	96%	Victim Operated	33%
Time	64%		

Table 62

Type-By-Function Selections for Scenario 7: Capacitor-Based Collapsing Circuit

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Time	85%	Command	3%
Victim Operated	52%		

Table 63

Type-By-Function Selections for Scenario 8: Radio Squelch SCR Circuit

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Command	99%	Time	3%
		Victim Operated	16%

Table 64

Type-By-Function Selections for Scenario 9: Microcontroller-Based PIR Circuit

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Victim Operated	99%	Command	8%
		Time	50%

Table 65

Type-By-Function Selections for Scenario 10: Microcontroller-Based Ultrasonic Circuit

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Victim Operated	99%	Command	6%
		Time	44%

Table 66

Type-By-Function Selections for Scenario 11: RF Receiver With SCR

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Command	87%	Time	32%
		Victim Operated	24%

Table 67

Type-By-Function Selections for Scenario 12: ATmega328P DTMF Circuit

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Command	99%	Time	58%
		Victim Operated	35%

Table 68

Type-By-Function Selections for Scenario 13: PIC16 Microcontroller Timer Circuit

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Victim Operated	92%	Command	17%
		Time	49%

Table 69

Type-By-Function Selections for Scenario 14: NRF24L01 RCIED Circuit

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Command	100%	Time	46%
		Victim Operated	25%

Table 70

Type-By-Function Selections for Scenario 15: Active-Infrared Sensor Violation Counter

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Victim Operated	86%	Command	13%
		Time	41%

Table 71

Type-By-Function Selections for Scenario 16: Wire Disconnect Circuit

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Victim Operated	85%	Command	10%
		Time	35%

Table 72

Type-By-Function Selections for Scenario 17: Nano 33 BLE Sense Microwave Sensor Circuit

Correct TbF Selected	Percent Selecting	Incorrect TbF Selected	Percent Selecting
Victim Operated	98%	Command	24%
		Time	56%

Figure 31

Average Correct Type-By-Function Selections

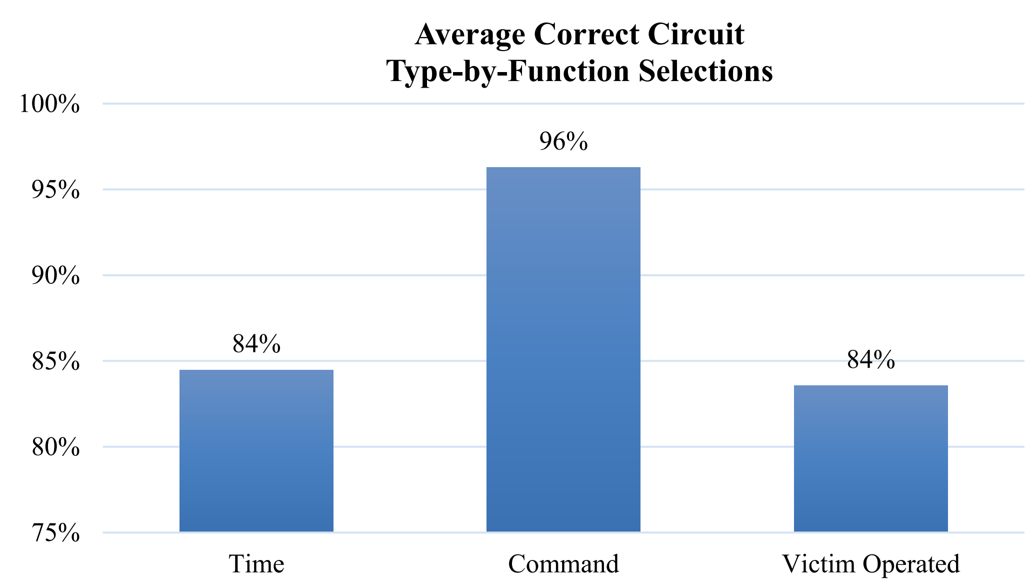
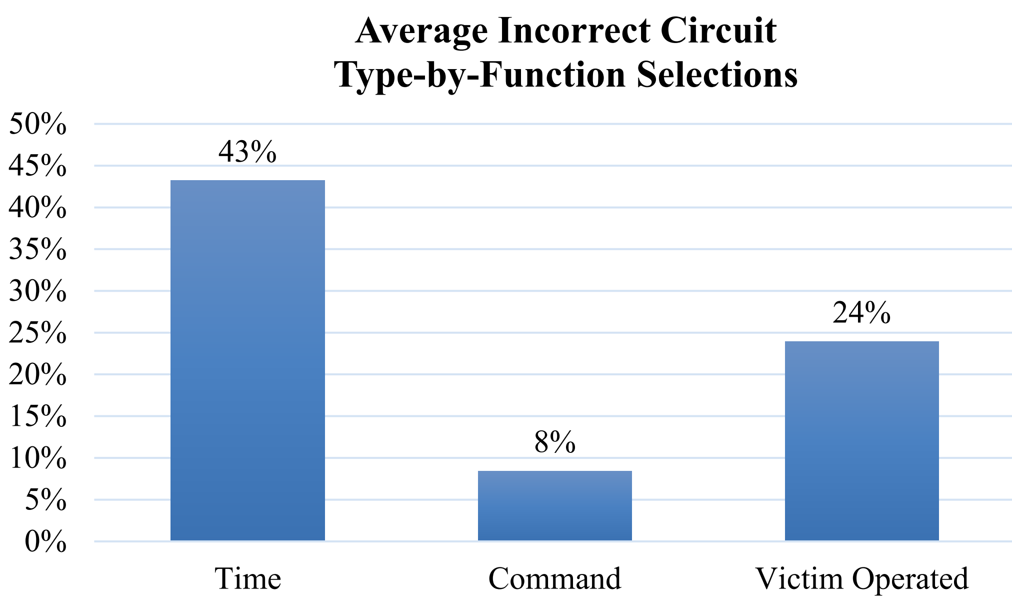


Figure 32

Average Incorrect Type-By-Function Selections



Average Success Rates by Independent Variables

As a reminder, independent variables for this study consist of the following:

Country of service

Years of bomb disposal experience

Bomb disposal school attended for initial training

Organizational affiliation

Length of initial training

Self-assessed IED electronics knowledge level

Specialized IED electronics and formal electronics training

IED electronics trainer experience

Highest education level achieved

Please note however, that due to the limited number of participants from other countries, and schools where participants did initial bomb disposal training other than the U.S., omission or binning was necessary for some groups in the *Country of Service* and *Bomb Disposal School Attended for Initial Training* variables. Additionally, as identified earlier in this chapter, many other variables have been divided into bins for purpose of analysis, but the binning for those variables follow throughout this document, except in cases where an individual variable might offer insights that would otherwise be missed if not shown in isolation, whereas the *Country of Service* and *Bomb Disposal School Attended for Initial Training* variables are only binned in this section.

Figures 33-35 identify cumulative success rates by independent variables. *Country of Service*, and *Bomb Disposal School Attended for Initial Training*, have been intentionally omitted from these figures.

Figure 33

Average Success Rates for Component Identification by Variable

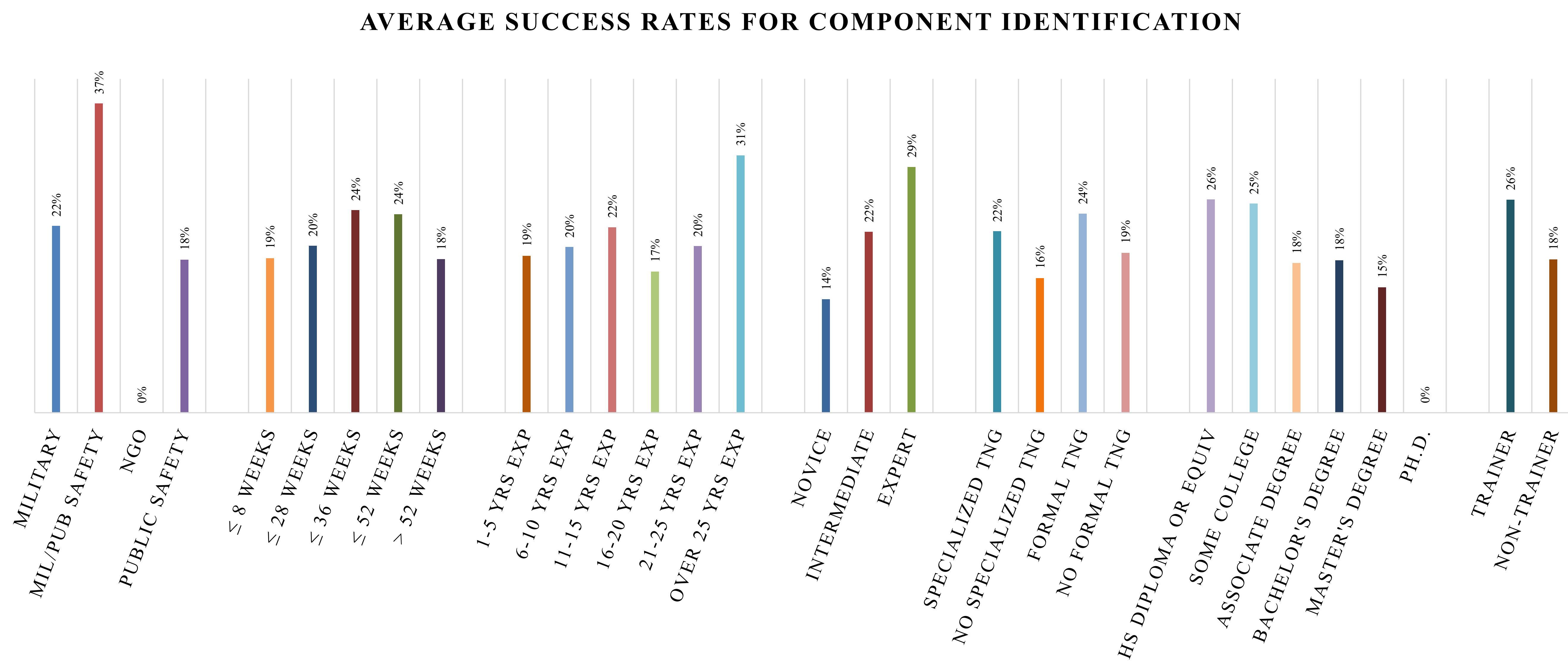


Figure 34

Average Success Rates for Associated Hazards by Variable

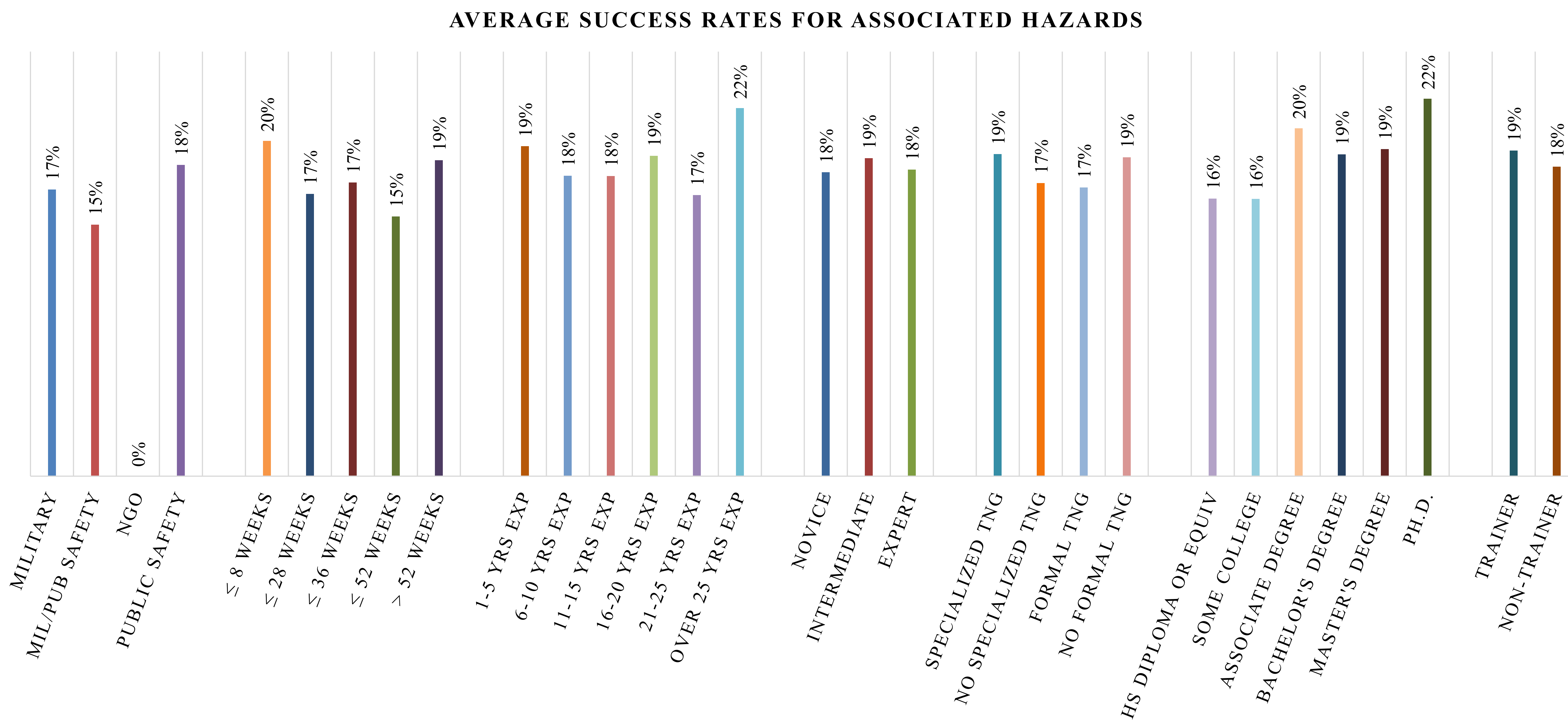
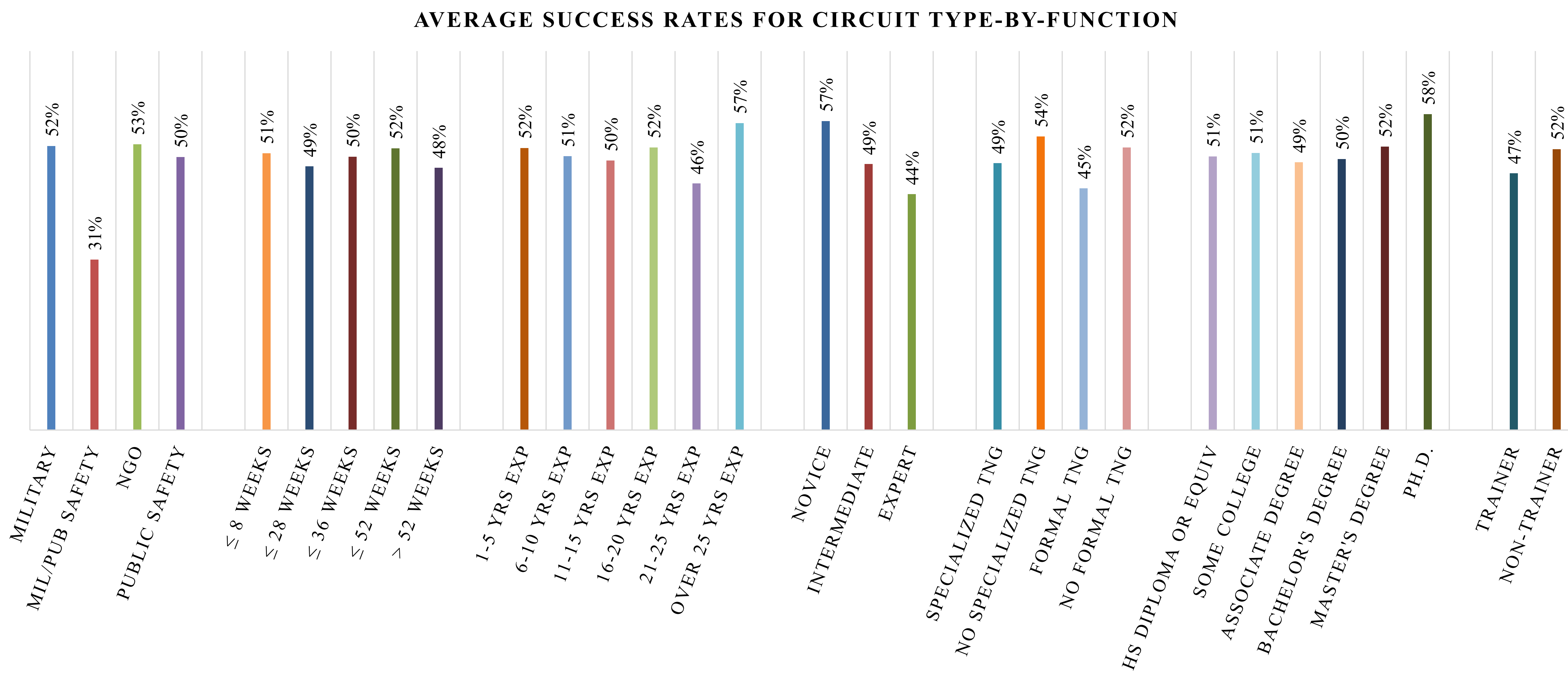


Figure 35

Average Success Rates for Circuit Type-By-Function by Variable



Country of Service

Table 73 and Figure 36 identify average success rate by country of service for study participants. Please note that countries listed as *All Others*, include countries where only one or two bomb technicians from that country are represented. Additionally, for the majority of these countries, English is not the primary language spoken.

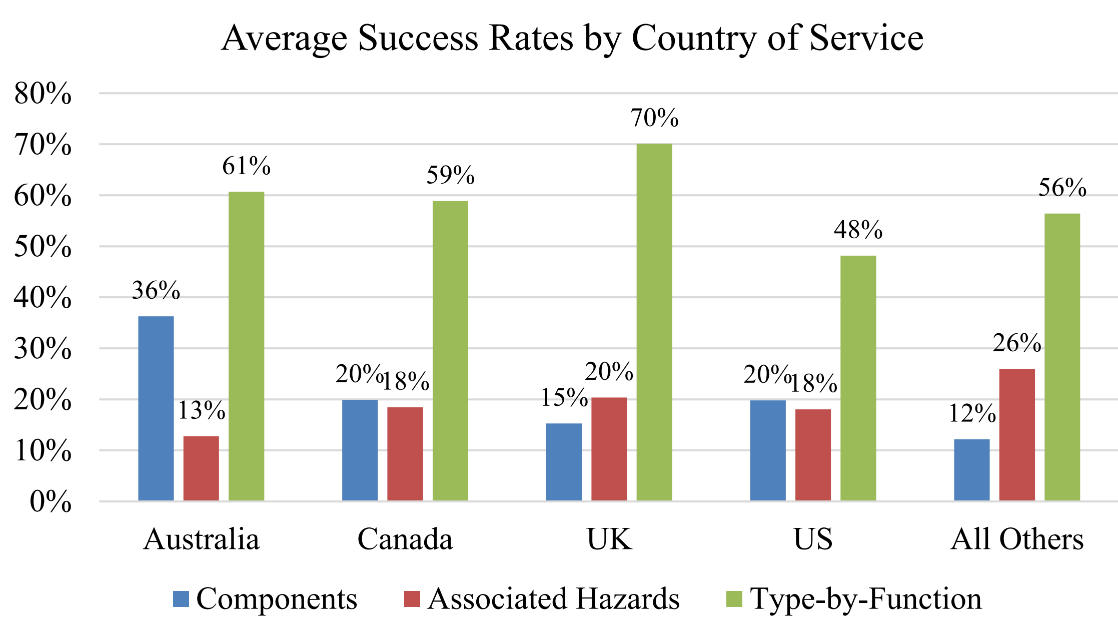
Table 73

Average Success Rates by Country of Service

	Components	Associated Hazards	Circuit Type-by-Function
Australia	36%	13%	51%
Canada	20%	18%	59%
UK	15%	20%	70%
US	20%	18%	48%
All Other	12%	26%	56%

Figure 36

Average Success Rates for Dependent Variables by Country of Service



A one-way ANOVA was conducted to compare the effects of a participants country on component identification, assessment of associated hazards, and determination of circuit type(s)-by-function.

The mean correct *component identification* responses for study participants from Australia was 36%; for study participants from Canada, 20%; from the UK, 15%; from the US, 20%; and cumulatively from all other countries, 12%. Initially, the ANOVA for this variable suggested that the null hypothesis was disproven, and statistically significant differences exist between participants from different countries for component identification scores, $F(4, 85) = 3.15$, $p = .018$. However, a post hoc analysis using the Kruskal-Wallis test indicated that the null was true ($p = .080$), suggesting that country of service has no effect on a bomb technician's ability to correctly identify components in a potential IED firing circuit.

For *assessment of associated hazards*, the mean correct responses for study participants from Australia was 13%; for study participants from Canada, 18%; from the UK, 20%; from the US, 18%; and cumulatively from all other countries, 26%. The null hypothesis was proven true, and no statistically significant differences were found between participants from different countries for assessment of associated hazards scores, $F(4, 85) = 0.66$, $p = .\ 0.620$. Therefore, the data suggests that country of service has little or no effect on a bomb technician's ability to correctly assess hazards associated with potential IED firing circuits.

For *determination of circuit type(s)-by-function*, the mean of correct responses for study participants from Australia was 61%; for study participants from Canada, 59%; from the UK, 70%; from the US, 48%; and cumulatively from all other countries, 56%.

The null hypothesis was proven true, and no statistically significant differences were found between participants from different countries for circuit type(s)-by-function scores, $F(4, 85) = 1.63$, $p = 0.175$. Therefore, the data suggests that country of service has little or no effect on a bomb technician's ability to correctly determine circuit type(s)-by-function for potential IED firing circuits.

Bomb Disposal School Attended for Initial Training

Table 74 and Figure 37 identify average success rate by country for study participants. Please note that only schools that had sufficient representation were included in this analysis. Unfortunately, not all schools were able to be included due to participant levels from those schools, and this researcher was unable to find an analysis tool that would allow for their inclusion without dramatically skewing analysis results.

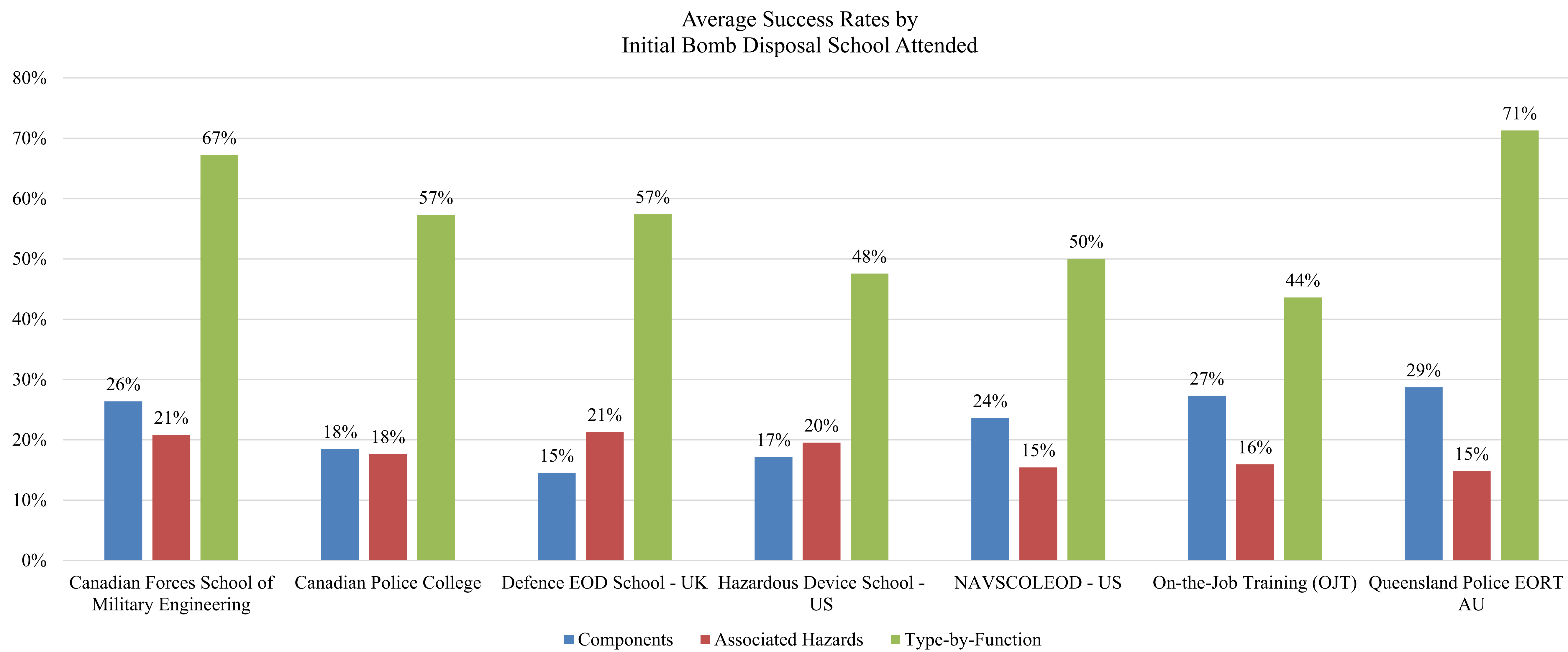
Table 74

Average Success Rates by Bomb Disposal School Attended for Initial Training

	Components	Associated Hazards	Circuit Type-by-Function
Canadian Forces School of Military Engineering	26%	21%	67%
Canadian Police College	18%	18%	57%
Defence EOD School – United Kingdom	15%	21%	57%
Hazardous Device School - United States	17%	20%	48%
NAVSCOLEOD – United States	24%	15%	50%
On-the-Job Training (OJT)	27%	16%	44%
Queensland Police EORT - Australia	29%	15%	71%

Figure 37

Average Success Rates for Dependent Variables by Initial Bomb Disposal School Attended



A one-way ANOVA was conducted to compare the effects of the bomb disposal school that a participant originally attended had on component identification, assessment of associated hazards, and determination of circuit type(s)-by-function.

The mean correct *component identification* responses for study participants from Canadian Forces School of Military Engineering was 26%; from the Canadian Police College was 18%; from the U.K. Defence EOD School was 15%; from the U.S. Hazardous Device School was 17%; from the U.S. NAVSCOLEOD was 24%; from On-the-Job Training (OJT) was 27%; and from the Queensland Police EORT in Australian was 29%. The null hypothesis was proven true, and no statistically significant differences were found for circuit type(s)-by-function scores, $F(6, 119) = 1.05$, $p = 0.399$, between participants who attended different bomb disposal schools for their initial training. Therefore, the data suggests that bomb disposal school attended for initial training has little or no effect on a bomb technician's ability to correctly determine circuit type(s)-by-function for potential IED firing circuits.

For *assessment of associated hazards*, the mean correct responses for study participants from Canadian Forces School of Military Engineering was 21%; from the Canadian Police College was 18%; from the U.K. Defence EOD School was 21%; from the U.S. Hazardous Device School was 20%; from the U.S. NAVSCOLEOD was 15%; from On-the-Job Training (OJT) was 16%; and from the Queensland Police EORT in Australian was 15%. The null hypothesis was proven true, and no statistically significant differences were found for circuit type(s)-by-function scores, $F(6, 119) = 0.21$, $p = 0.974$, between participants who attended different bomb disposal schools for their initial training. Therefore, the data suggests that bomb disposal school attended for initial training has little or no effect on a bomb technician's ability to correctly assess hazards associated with potential IED firing circuits.

For *determination of circuit type(s)-by-function*, the mean correct responses for study participants from Canadian Forces School of Military Engineering was 67%; from the Canadian Police College was 57%; from the U.K. Defence EOD School was 67%; from the U.S. Hazardous Device School was 48%; from the U.S. NAVSCOLEOD was 50%; from On-the-Job Training (OJT) was 44%; and from the Queensland Police EORT in Australian was 71%. The ANOVA did suggest however, that for this variable the null hypothesis was disproven, and statistically significant differences exist between participants who attended different bomb disposal schools for their initial training, $F(6, 119) = 2.43$, $p = .030$. A post hoc analysis using the Kruskal-Wallis test supports this contention, confirming that the null hypothesis was disproven (p = .022).

A pairwise Mann-Whitney test was then used to look at specific groups of participants, based on initial bomb disposal schools attended, where statistically significant differences might exist. This test found that statistically significant differences exist between participants who attended Canadian Forces School of Military Engineering compared to the Hazardous Device School ($p = .002$); participants who attended Canadian Forces School of Military Engineering compared to NAVSCOLEOD ($p = .019$); Hazardous Device School compared to the Queensland Police EORT ($p = .021$); NAVSCOLEOD compared to the Queensland Police EORT (p = .021); and On-the-Job Training compared to the Queensland Police EORT (p = .019).

This data suggests that while statistically significant differences exist between these specific groups, for the remaining groups, where a bomb technician undertook initial training had little or no effect on their ability to correctly determine circuit type-by-function for a potential IED firing circuit. Readers are cautioned to remember however, that for the groups identified as having statistically significant differences, the tests used for analysis do not indicate direction, positive or negative, of those differences, and only suggest that statistically significant differences exist.

Years of Bomb Disposal Experience

Table 75 and Figure 38 identify average success rate for study participants by years of bomb disposal experience.

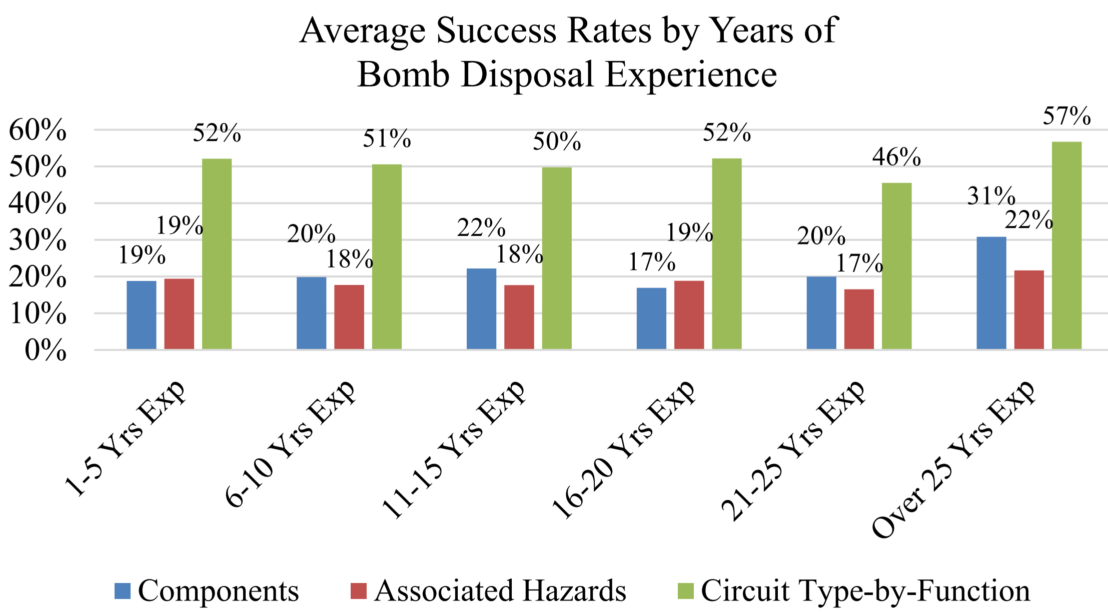
Table 75

Average Success Rates by Years of Bomb Disposal Experience

	Components	Associated Hazards	Circuit Type-by-Function
1-5 Years	19%	19%	52%
6-10 Years	20%	18%	51%
11-15 Years	22%	18%	50%
16-20 Years	17%	19%	52%
21-25 Years	20%	17%	46%
Over 25 Years	31%	22%	57%

Figure 38

Average Success Rates for Variables by Years of Bomb Disposal Experience



A one-way ANOVA was conducted to compare the effects of years of experience on component identification, assessment of associated hazards, and determination of circuit type(s)-by-function.

The mean correct *component identification* responses for study participants with 1-5 years of experience was 19%; for study participants with 6-10 years of experience, 20%; for 11-15 years of experience, 22%; for 16-20 years of experience, 17%; for 21-25 years of experience, 20%; and over 25 years of experience, 31%. The null hypothesis was proven true, and no statistically significant differences were found between years of experience for component identification scores, $F(5, 102) = 1.09$, $p = .370$. Therefore, the data suggests that differences in years of bomb disposal experience has little or no effect on a bomb technician's ability to identify components in a potential IED firing circuit.

For *assessment of associated hazards*, the mean correct responses for study participants with 1-5 years of experience was 19%; for study participants with 6-10 years of experience was 18%; for 11-15 years of experience was 18%; for 16-20 years of experience was 19%; for 21-25 years of experience was 17%; and over 25 years of experience was 22%. The null hypothesis was proven true, and no statistically significant differences were found between years of experience for associated hazard scores, $F(5, 102) = 0.10$, $p = .\ 0.992$. Therefore, the data suggests that differences in years of bomb disposal experience has little or no effect on a bomb technician's ability to correctly assess hazards associated with potential IED firing circuits.

For *determination of circuit type(s)-by-function*, the mean of correct responses for study participants with 1-5 years of experience was 52%; for study participants with 6-10 years of experience was 51%; for 11-15 years of experience was 50%; for 16-20 years of experience was 52%; for 21-25 years of experience was 46%; and over 25 years of experience was 57%. The null hypothesis was proven true, and no statistically significant differences were found between years of experience for circuit type(s)-by-function scores, $F(5, 102) = 0.46$, $p = 0.804$. Therefore, the data suggests that differences in years of bomb disposal experience has little or no effect on a bomb technician's ability to correctly determine circuit type(s)-by-function for potential IED firing circuits.

Organizational Affiliation

Table 76 and Figure 39 identify average success rate for study participants by organizational affiliation. This label is meant to identify the organization which grants or granted authorization of the participant's render safe authority.

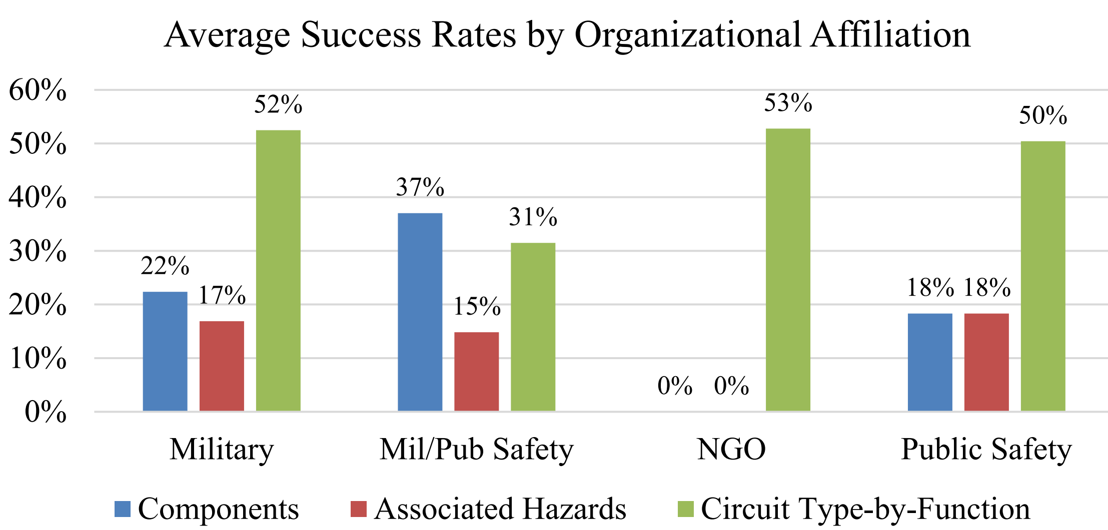
Table 76

Average Success Rates by Organizational Affiliation

	Components	Associated Hazards	Circuit Type-by-Function
Military	22%	17%	52%
Military/Public Safety	37%	15%	31%
NGO	0%	0%	53%
Public Safety	18%	18%	50%

Figure 39

Average Success Rates for Variables By Organizational Affiliation



A one-way ANOVA was conducted to compare the effects of organizational affiliation on component identification, assessment of associated hazards, and determination of circuit type(s)-by-function.

The mean correct *component identification* responses for study participants from the military sector was 22%; for study participants from the public safety sector, 37%; for participants who are, or were bomb technicians for both the military and public safety sectors, 22%; and finally, participants from the Non-Governmental Organization (NGO) sector had 0% mean correct responses. However, since the number of participants from the both the military/public safety sector and NGO sector was so small ($n \leq 3$), they were not calculated into the ANOVA for component identification. The null hypothesis was proven true, and no statistically significant differences were found between participants from the military and public safety sectors for component identification scores, $F(1, 34) = 0.51$, $p = .482$. Therefore, the data suggests that neither being a military bomb technician, or a public safety bomb technician, has any effect on a bomb technician's ability to identify components in a potential IED firing circuit.

For *assessment of associated hazards*, the mean correct responses for study participants from the military sector was 17%; for study participants from the public safety sector, 18%; for participants who are, or were bomb technicians for both the military and public safety sectors, 15%; and finally, participants from the Non-Governmental Organization (NGO) sector had 0% mean correct responses. However, since the number of participants from the both the military/public safety sector and NGO sector was so small ($n \leq 3$), they were not calculated into the ANOVA for associated hazards. The null hypothesis was proven true, and no statistically significant differences were found between participants from the military and public safety sectors for assessment of associated hazards scores, $F(1, 34) = 0.12$, $p = .\ 0.733$. Therefore, the data suggests that neither being a military, or a public safety bomb technician, has any effect on a bomb technician's ability to correctly assess hazards associated with potential IED firing circuits.

For *determination of circuit type(s)-by-function*, the mean of correct responses for study participants from the military sector was 52%; for study participants from the public safety sector, 50%; for participants who are, or were bomb technicians for both the military and public safety sectors, 31%; and finally, participants from the Non-Governmental Organization (NGO) sector had 53% mean correct responses. However, since the number of participants from the both the military/public safety sector and NGO sector was so small ($n \leq 3$), they were not calculated into the ANOVA for circuit type(s)-by-function. The null hypothesis was proven true, and no statistically significant differences were found between military and public safety bomb technician circuit type(s)-by-function scores, $F(1, 34) = 0.10$, $p = 0.755$. Therefore, the data suggests that neither being a military, or a public safety bomb technician, has any effect on a bomb technician's ability to correctly determine circuit type(s)-by-function for potential IED firing circuits.

Length of Initial Training

Table 77 and Figure 40 identify average success rate for study participants by length of initial bomb disposal training. These figures do not include OJT or apprenticeships.

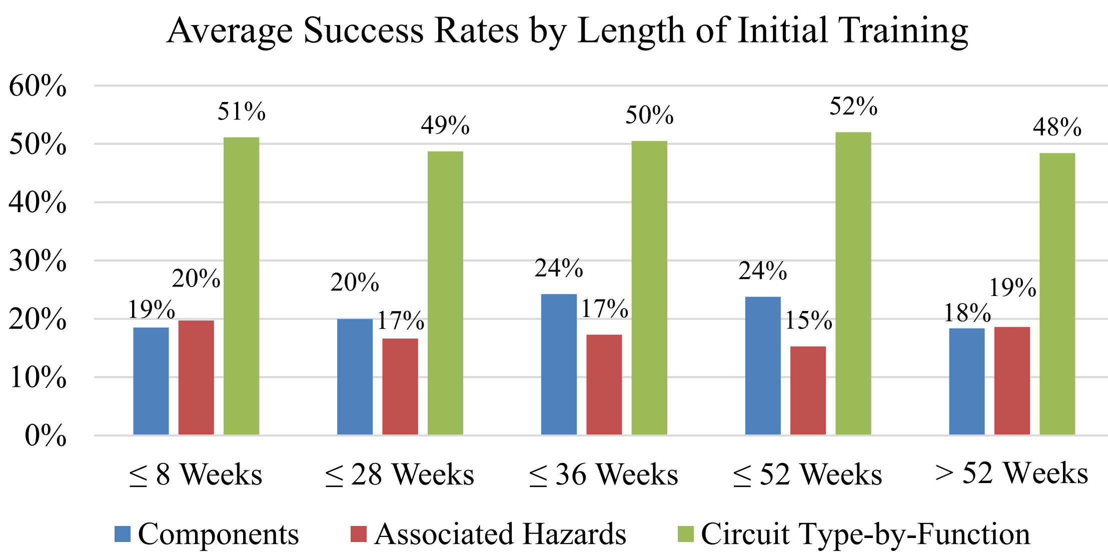
Table 77

Average Success Rates by Length of Initial Training

	Components	Associated Hazards	Circuit Type-by-Function
≤ 8 Weeks	19%	20%	51%
≤ 28 Weeks	20%	17%	49%
≤ 36 Weeks	24%	17%	50%
≤ 52 Weeks	24%	15%	52%
> 52 Weeks	18%	19%	48%

Figure 40

Average Success Rates for Variables by Length of Initial Training



A one-way ANOVA was conducted to compare the effects of length of initial bomb disposal training on component identification, assessment of associated hazards, and determination of circuit type(s)-by-function.

The mean correct *component identification* responses for study participants whose initial training was less than or equal to 8 weeks was 19%; for study participants whose initial training was less than or equal to 28 weeks, 20%; for less than or equal to 36 weeks, 24%; for less than or equal to 52 weeks, 24%; and for study participants whose initial training was for more than 52 weeks, 18%. The null hypothesis was proven true, and no statistically significant differences were found between participants for length of initial bomb disposal training as it relates to component identification scores, $F(4, 85) = 0.40$, $p = .806$. Therefore, the data suggests that differences in length of initial bomb disposal training has little or no effect on a bomb technician's ability to identify components in a potential IED firing circuit.

For *assessment of associated hazards*, the mean correct responses for study participants whose initial training was less than or equal to 8 weeks was 20%; for study participants whose initial training was less than or equal to 28 weeks, 17%; for less than or equal to 36 weeks, 17%; for less than or equal to 52 weeks, 15%; and for study participants whose initial training was for more than 52 weeks, 19%. The null hypothesis was proven true, and no statistically significant differences were found between participants for length of initial bomb disposal training as it relates to assessment of associated hazards scores, $F(4, 85) = 0.10$, $p = .\ 0.981$. Therefore, the data suggests that differences in length of initial bomb disposal training has little or no effect on a bomb technician's ability to correctly assess hazards associated with potential IED firing circuits.

For *determination of circuit type(s)-by-function*, the mean of correct responses for study participants whose initial training was less than or equal to 8 weeks was 51%; for study participants whose initial training was less than or equal to 28 weeks, 49%; for less than or equal to 36 weeks, 50%; for less than or equal to 52 weeks, 52%; and for study participants whose initial training was for more than 52 weeks, 48%. The null hypothesis was proven true, and no statistically significant differences were found between participants for length of initial bomb disposal training as it relates to determination of circuity type(s)-by-function scores, $F(4, 85) = 0.10$, $p = 0.984$. Therefore, the data suggests that differences in length of initial bomb disposal training has little or no effect on a bomb technician's ability to correctly determine circuit type(s)-by-function for potential IED firing circuits.

Self-Assessed IED Electronics Knowledge Level

Table 78 and Figure 41 identify average success rate for study participants by self-assessed IED electronics knowledge level.

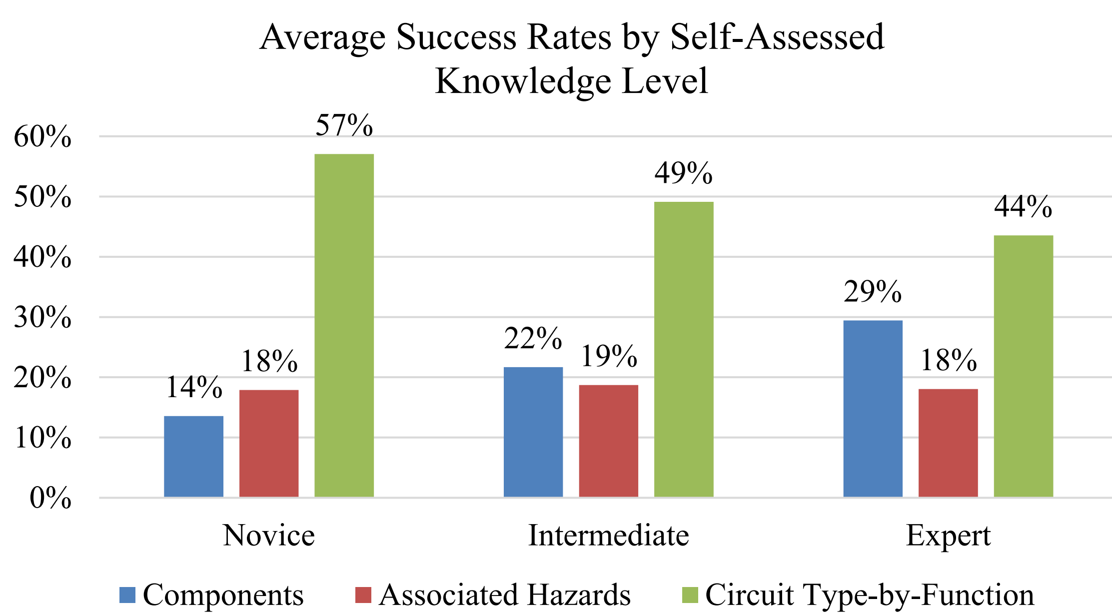
Table 78

Average Success Rates by Self-Assessed IED Electronics Knowledge Level

	Components	Associated Hazards	Circuit Type-by-Function
Novice	14%	18%	57%
Intermediate	22%	19%	49%
Expert	29%	18%	44%

Figure 41

Average Success Rates for Variables by Self-Assessed Knowledge Level



A one-way ANOVA was conducted to compare the effects of a participants self-assessed IED electronics knowledge level on component identification, assessment of associated hazards, and determination of circuit type(s)-by-function.

The mean correct *component identification* responses for study participants who rated themselves as having a *novice* knowledge level was 14%; for study participants who rated themselves as having an *intermediate* knowledge level, the mean was 22%; and for study participants who rated themselves as having an *expert* knowledge level, the mean was 29%. Initially, the ANOVA for this variable suggested that the null hypothesis was disproven, and statistically significant differences exist between participants with different self-assessed knowledge levels for component identification scores, $F(2, 51) = 3.42$, $p = .040$. However, a post hoc analysis using the Kruskal-Wallis test indicated that the null was true ($p = .069$), suggesting that self-assessed knowledge level has little or no effect on a bomb technician's ability to correctly identify components in a potential IED firing circuit.

For *assessment of associated hazards*, the mean correct responses for study participants who rated themselves as having a *novice* knowledge level was 18%; for study participants who rated themselves as having an *intermediate* knowledge level, the mean was 19%; and for study participants who rated themselves as having an *expert* knowledge level, the mean was 18%. The null hypothesis was proven true, and no statistically significant differences were found between participants for self-assessed knowledge level as it relates to assessment of associated hazards scores, $F(2, 51) = 0.01$, $p = .994$. Therefore, the data suggests that self-assessed IED electronics knowledge level has little or no effect on a bomb technician's ability to correctly assess hazards associated with potential IED firing circuits.

For *determination of circuit type(s)-by-function*, the mean of correct responses for study participants who rated themselves as having a *novice* knowledge level was 57%; for study participants who rated themselves as having an *intermediate* knowledge level, the mean was 22%; and for study participants who rated themselves as having an *expert* knowledge level, the mean was 29%. The null hypothesis was proven true, and no statistically significant differences were found between participants for self-assessed knowledge level as it relates to determination of circuity type(s)-by-function scores, $F(2, 51) = 1.78$, $p = .178$. Therefore, the data suggests that self-assessed IED electronics knowledge level has little or no effect on a bomb technician's ability to correctly determine circuit type(s)-by-function for potential IED firing circuits.

Specialized IED Electronics and Formal Electronics Training

Table 79 and Figure 42 identify average success rate for study participants by having participated in specialized IED electronics training, or lack thereof, and any formal electronics education or training that a study participant may have.

A one-way ANOVA was conducted to compare the effects of specialized IED electronics training that a study participant may have on component identification, assessment of associated hazards, and determination of circuit type(s)-by-function. Additionally, a one-way ANOVA was conducted to compare the effect that any formal electronics education or training that a study participant might have on component identification, assessment of associated hazards, and determination of circuit type(s)-by-function.

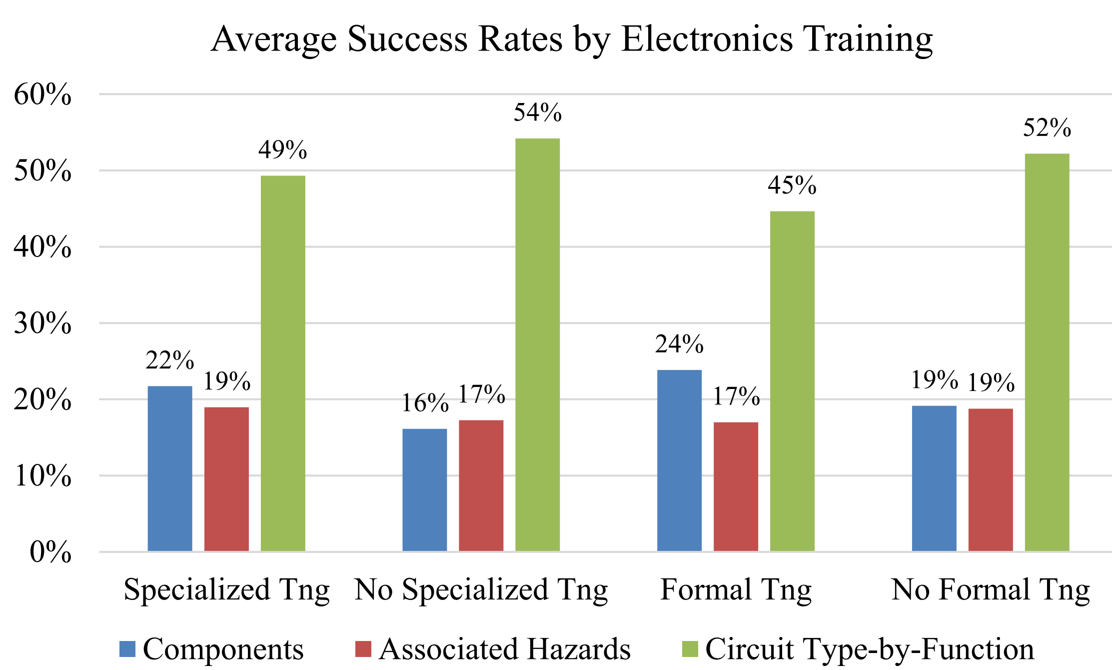
Table 79

Average Success Rates by Specialized IED Electronics and Formal Electronics Training

	Components	Associated Hazards	Circuit Type-by-Function
Specialized IED Electronics Training	22%	19%	49%
No Specialized IED Electronics Training	16%	17%	54%
Formal Electronics Training	24%	17%	45%
No Formal Electronics Training	19%	19%	52%

Figure 42

Average Success Rates for Variables by Specialized and Formal Training



The mean correct *component identification* responses for study participants *with specialized training* was 22%, and *without specialized training*, was 16%. The mean correct *component identification* responses for study participants *with formal electronics education or training* was 24%, and *without formal electronics education or training*, was 19%. The null hypothesis was proven true for both of these variables, and no statistically significant differences were found between participants with or without specialized IED electronics training, $F(1, 34) = 1.06$, $p = .311$, or with or without formal electronics education or training, $F(1, 34) = 0.60$, $p = .452$. Therefore, the data suggests that having specialized IED electronics training, or formal education or training in electronics, has little or no effect on a bomb technician's ability to identify components in a potential IED firing circuit.

For *assessment of associated hazards*, the mean correct responses for study participants *with specialized training* was 19%, and *without specialized training*, was 17%. The mean correct *assessment of associated hazards* responses for study participants *with formal electronics education or training* was 17%, and *without formal electronics education or training*, was 19%. The null hypothesis was proven true for both of these variables, and no statistically significant differences were found between participants with or without specialized IED electronics training, $F(1, 34) = 0.05$, $p = .825$, or with or without formal electronics education or training, $F(1, 34) = 0.05$, $p = .818$. Therefore, the data suggests that having specialized IED electronics training, or formal education or training in electronics, has little or no effect on a bomb technician's ability to correctly assess hazards associated with potential IED firing circuits.

For *determination of circuit type(s)-by-function*, the mean correct responses for study participants *with specialized training* was 49%, and *without specialized training*, was 54%. The mean correct *assessment of associated hazards* responses for study participants *with formal electronics education or training* was 45%, and *without formal electronics education or training*, was 52%. The null hypothesis was proven true for both of these variables, and no statistically significant differences were found between participants with or without specialized IED electronics training, $F(1, 34) = 0.56$, $p = .458$, or with or without formal electronics education or training, $F(1, 34) = 1.26$, $p = .269$. Therefore, the data suggests that having specialized IED electronics training, or formal education or training in electronics, has little or no effect on a bomb technician's ability to correctly determine circuit type(s)-by-function for potential IED firing circuits.

IED Electronics Trainer Experience

Table 80 and Figure 43 identify average success rate for study participants by having served as IED electronics trainers. A one-way ANOVA was conducted to compare the effects of a study participant being, or having been an IED electronics trainer on component identification, assessment of associated hazards, and determination of circuit type(s)-by-function.

The mean correct *component identification* responses for study participants *with IED electronics trainer experience* was 26%, and *without IED electronics trainer experience*, was 18%. The null hypothesis was proven true for this variable, and no statistically significant differences were found between participants with or without IED electronics trainer experience, $F(1, 34) = 1.30$, $p = .263$. Therefore, the data suggests that being, or having been an IED electronics trainer has little or no effect on a bomb technician's ability to identify components in a potential IED firing circuit.

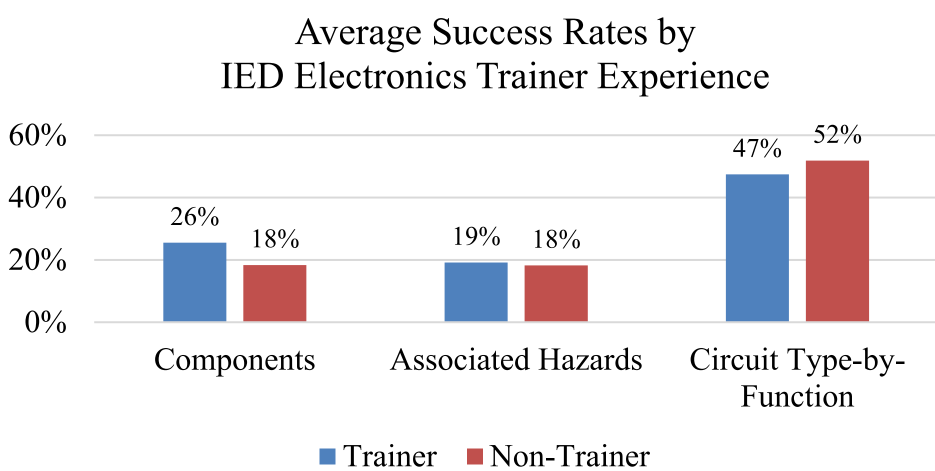
Table 80

Average Success Rates by IED Electronics Trainer Experience

	Components	Associated Hazards	Circuit Type-by-Function
Trainer	26%	19%	47%
Non-Trainer	18%	18%	52%

Figure 43

Average Success Rates for Variables by IED Electronics Trainer Experience



For *assessment of associated hazards*, the mean correct responses for study participants *with IED electronics trainer experience* was 19%, and *without IED electronics trainer experience*, was 18%. The null hypothesis was proven true for this variable, and no statistically significant differences were found between participants with or without IED electronics trainer experience, $F(1, 34) = 0.01$, $p = .903$. Therefore, the data suggests that being, or having been an IED electronics trainer has little or no effect on a bomb technician's ability to correctly assess hazards associated with potential IED firing circuits.

For *determination of circuit type(s)-by-function*, the mean correct responses for study participants *with IED electronics trainer experience* was 47%, and *without IED electronics trainer experience*, was 52%. The null hypothesis was proven true for this variable, and no statistically significant differences were found between participants with or without IED electronics trainer experience, $F(1, 34) = 0.44$, $p = .513$. Therefore, the data suggests that being, or having been an IED electronics trainer has little or no effect on a bomb technician's ability to correctly determine circuit type(s)-by-function for potential IED firing circuits.

Highest Education Level Achieved

Table 81 and Figure 44 identify average success rate for study participants by highest education level achieved. Please note that because the number of study participants with a *Ph.D. or Advanced Professional Degree* were so low (*n*=2), they were not included in the ANOVA results.

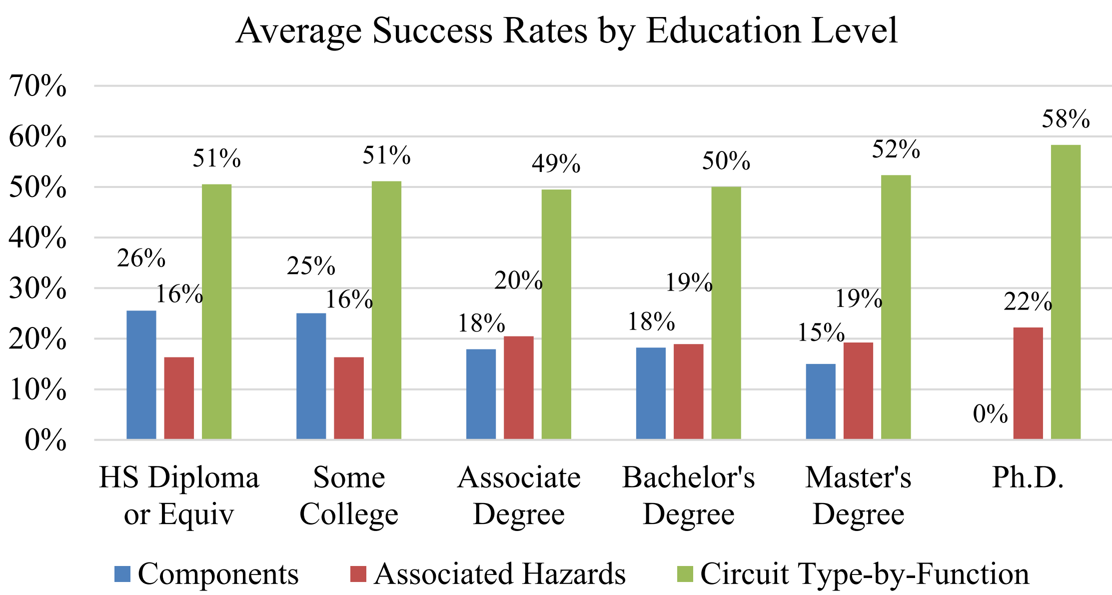
Table 81

Average Success Rates by Highest Education Level Achieved

	Components	Associated Hazards	Circuit Type-by-Function
High School Diploma or Equivalent	26%	16%	51%
Some College	25%	16%	51%
Associate Degree or Certificate	18%	20%	49%
Bachelor's Degree	18%	19%	50%
Master's Degree	15%	19%	52%
Ph.D. or Advance Professional Degree	0%	22%	58%

Figure 44

Average Success Rates for Variables by Highest Education Level Attained



A one-way ANOVA was conducted to compare the effects that a participant's highest level of education achieved has on component identification, assessment of associated hazards, and determination of circuit type(s)-by-function.

The mean correct *component identification* responses for study participants with a *High School Diploma or Equivalent* was 26%; with *Some College* was 25%; with an *Associate Degree or Certificate* was 18%; a *Bachelor's Degree*, 18%; a *Master's Degree*, 15%; and a *Ph.D. or Advance Professional Degree*, 0%. The null hypothesis was proven true for this variable, and no statistically significant differences were found between participants, regardless of highest education level achieved, $F(4, 85) = 1.11$, $p = .355$. Therefore, the data suggests that highest education level achieved has little or no effect on a bomb technician's ability to identify components in a potential IED firing circuit.

For *assessment of associated hazards*, the mean correct responses for study participants with a *High School Diploma or Equivalent* was 16%; with *Some College* was 16%; with an *Associate Degree or Certificate* was 20%; a *Bachelor's Degree*, 19%; a *Master's Degree*, 19%; and a *Ph.D. or Advance Professional Degree*, 22%. The null hypothesis was proven true for this variable, and no statistically significant differences were found between participants, regardless of highest education level achieved, $F(4, 85) = 0.11$, $p = .979$. Therefore, the data suggests that highest education level achieved has little or no effect on a bomb technician's ability to correctly assess hazards associated with potential IED firing circuits.

For *determination of circuit type(s)-by-function*, the mean correct responses for study participants with a *High School Diploma or Equivalent* was 51%; with *Some College* was 51%; with an *Associate Degree or Certificate* was 49%; a *Bachelor's Degree*, 50%; a *Master's Degree*, 52%; and a *Ph.D. or Advance Professional Degree*, 58%. The null hypothesis was proven true for this variable, and no statistically significant differences were found between participants, regardless of highest education level achieved, $F(4, 85) = 0.05$, $p = .996$. Therefore, the data suggests that highest education level achieved has little or no effect on a bomb technician's ability to correctly determine circuit type(s)-by-function for potential IED firing circuits.

To summarize the Average Success Rates by Independent Variables section, only participants who attended specific bomb disposal schools for their initial training showed statistically significant differences from other participants in their success rates, and only for circuit type(s)-by-function determination. The data suggests that none of the other variables assessed had any effect on a bomb technician's ability to successfully perform component identification, assessment of associated hazards, and determination of circuit type(s)-by-function.

Qualitative Findings

As a great many scholars on the subject (e.g., Dixon-Woods, Shaw, Agarwal, and Smith, 2004; Delmar, 2010; Levitt, Morrill, Collins, and Rizo, 2021; Taquette, and Borges da Matta Souza, 2022) will caution, qualitative findings can be more subjective than quantitative findings, and depend largely on the thoroughness and impartiality of the researcher analyzing the data. Additionally, various types of error can creep into qualitative research, both on the part of the researcher, as well as on the part of study participants. This is not to say that qualitative findings are not, or cannot be as insightful as quantitative findings, rather that the reader should use caution in generalizing too broadly when interpreting the results of qualitative research. With that admonition in mind, the qualitative findings for this study will be segmented by scenario, and data covered by four types of representation to include: 1) text visualization of component and hazard selections; 2) participant self-assessed confidence levels; 3) identification of diagnostic reasoning approaches used; and 4) driving factors for associated hazards and circuit types by function. A brief overview and description of each representation will be covered before delving into individual scenario findings.

Visualization of Component and Hazard Selections

The first representation covered is text visualization. Many readers may be familiar with the use of word clouds from social media sites. However, word clouds, which are also known as tag clouds, can also be used in qualitative research to aid in visualization of textual data, because while analyzing and presenting quantitative data in meaningful ways is well-established, conveying the significance of, and relationships between word and labels can often be more elusive (Sellars, Sherrod, and Chappel-Aiken, 2018). In short, word clouds, or more specifically the software programs that create them, allow textual data to be summarized and analyzed and then presented in visual form in such a way that meaningfulness is interpreted by differences in text size and color (Sen, 2008). According to DePaolo and Wilkinson (2014), the size and color variations of words, concepts, or terms analyzed by word cloud software packages are designed to, provide easily understandable visual representations and graphic portrayals of patterns, which in turn allows viewers to easily identify relationships and assign meaning.

In this study, the use of word clouds is simply intended to provide readers with a visual representation of what electronic components were most selected by study participants for any given scenario, as well as which hazards they selected most often for that same scenario. The word cloud generator used by this researcher is called WordItOut, and the online version can be found at https://worditout.com/word-cloud/create. Word clouds were generated for all scenarios included in this study, and for each scenario, a word cloud for components and associated hazards by study participants, as well as expert panelists. The word clouds by study participants and expert panelists help to compare and contrast the two groups. Please note that the correctness or incorrectness of responses is not depicted in these figures, only the frequency that the words were selected, which is shown relationally by the size of the text and color hue (i.e., larger text connotes a higher selection rate).

Additionally, because of the way that WordItOut treats text, words that would normally be hyphenated or multi-word terms have been compressed into single word label. For example, in Figure 45, the word *Mercury Switch* was compressed to the single label *MercurySwitch*. Hopefully the reader can also see by the variation in size and color hue in this same figure, that *MercurySwitch* was selected more often than other components since the text for that label is the largest and lightest hue. Conversely, the *Capacitor* was selected less often than the *555IntegratedCircuit*, as is connoted by *Capacitor* being in smaller text, and having a lighter hue than the *555IntegratedCircuit*, even though in reality, there was actually no *555IntegratedCircuit* used in the Practice Scenario circuit, and was only a mis-identification of the component.

To understand the value of these types of visualizations, this author would suggest looking first at the word clouds for Scenario 1, the Adjustable Light Circuit (Figures 49-52), which was rated *Very Easy* by the Expert Panel, and then Scenario 4, the Battery Removal Circuit (Figures 61-64), which was also rated as *Very Easy* by the Expert Panel. In these two scenarios, the difference between component selection by panelists and study participants is self-evident, and Figures 63 and 64 could not provide any starker contrast between approaches for hazard assessment.

Scenario 10 is also enlightening, since it is one of the more difficult circuits, and its components unfamiliar to many study participants. This circuit, a microcontroller-based ultrasonic sensor, was familiar to expert panelists, so component selection and hazard assessment resulted in relatively little divergence in responses amongst panelists (see Figures. 85-88). However, for study participants, some of whom were familiar with this type of circuit and some not, the diversity of components selected, as well as hazards, varied significantly.

Practice Scenario - Microcontroller Enabled Mercury Tilt Switch

Figure 45

Word Cloud for Practice Scenario Components Selected by Participants

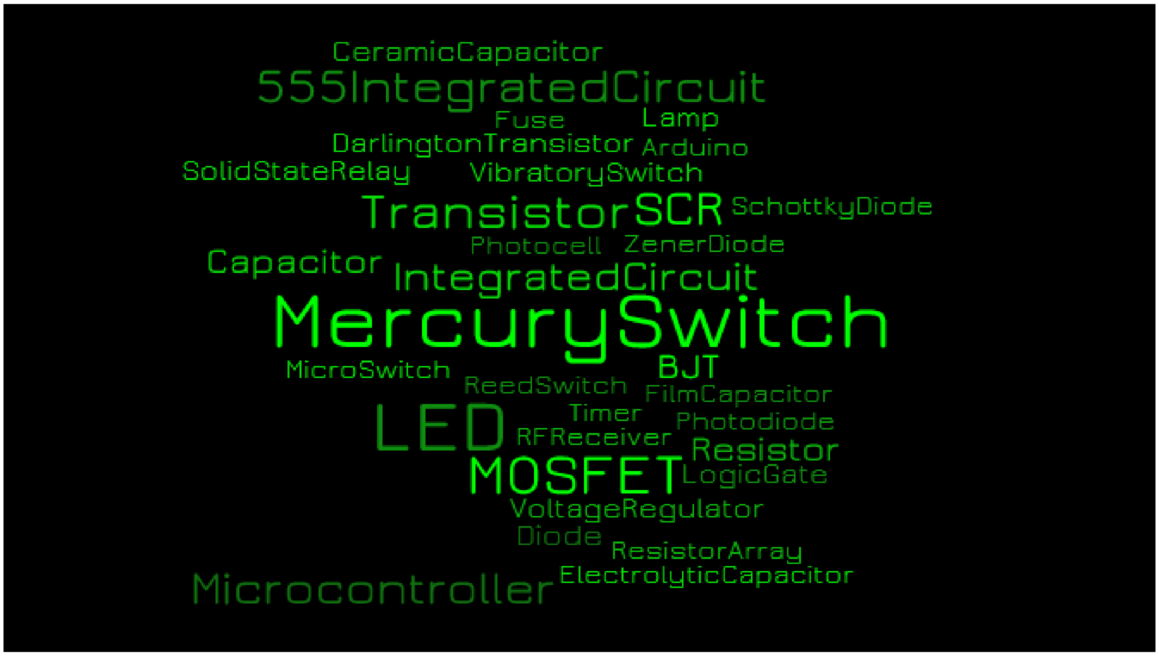


Figure 46

Word Cloud for Practice Scenario Components Selected by Expert Panelists

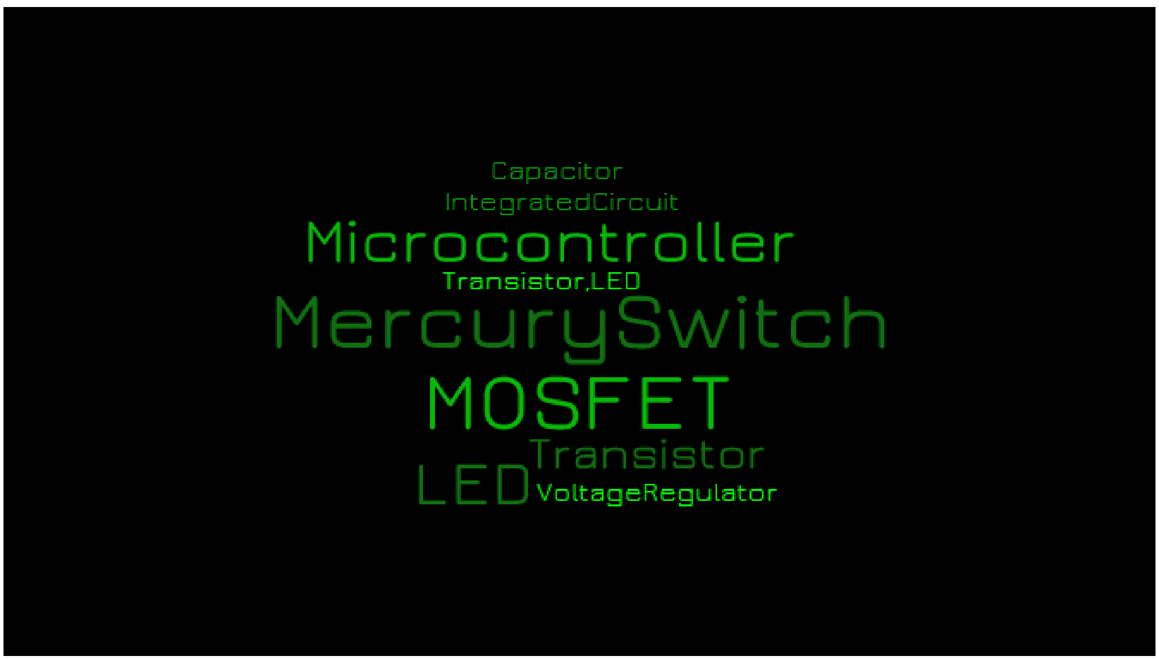


Figure 47

Word Cloud for Practice Scenario Hazards Selected by Participants

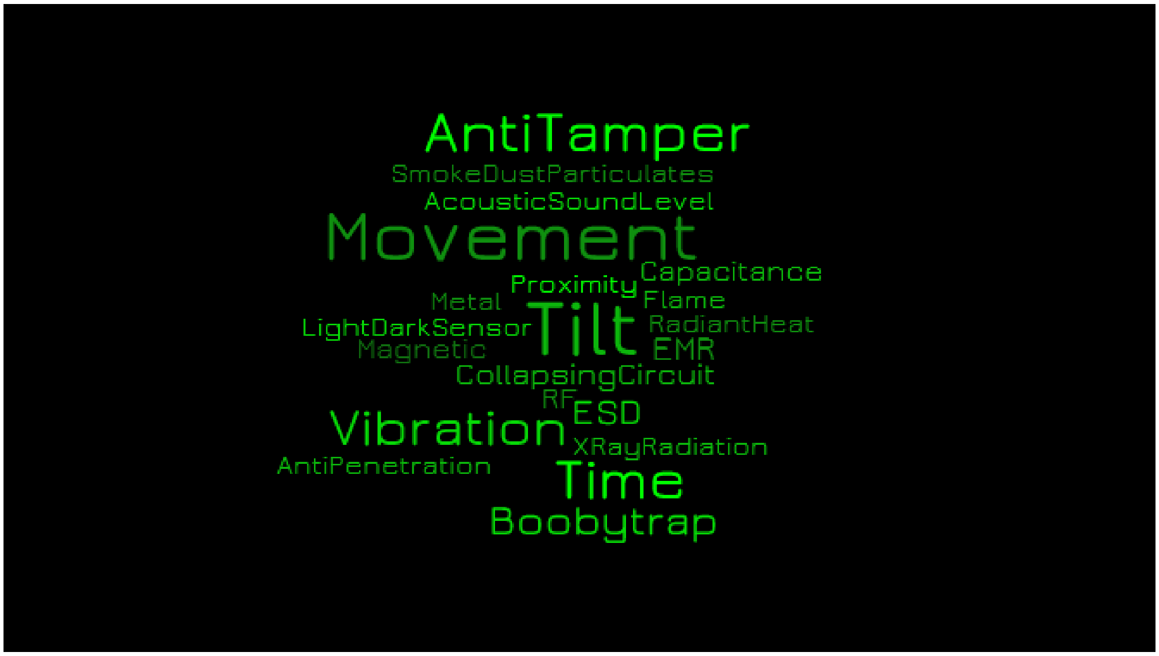


Figure 48

Word Cloud for Practice Scenario Hazards Selected by Expert Panelists

Scenario 1 - Adjustable Light Sensor

Figure 49

Word Cloud for Scenario 1 Components Selected by Participants

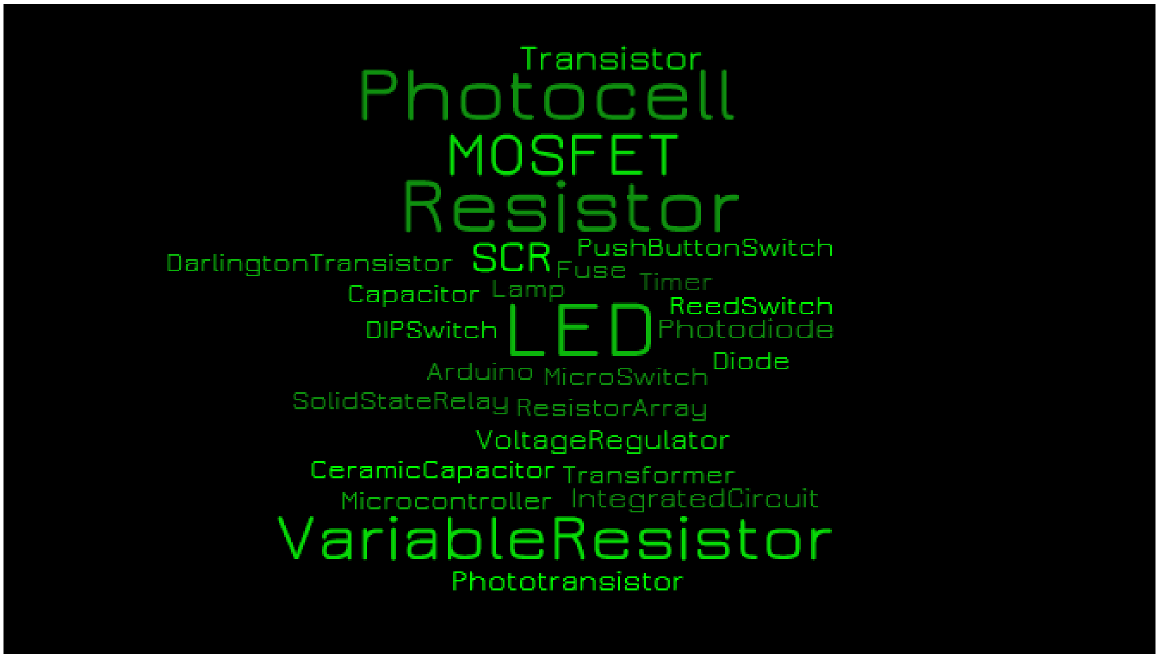


Figure 50

Word Cloud for Scenario 1 Components Selected by Expert Panelists

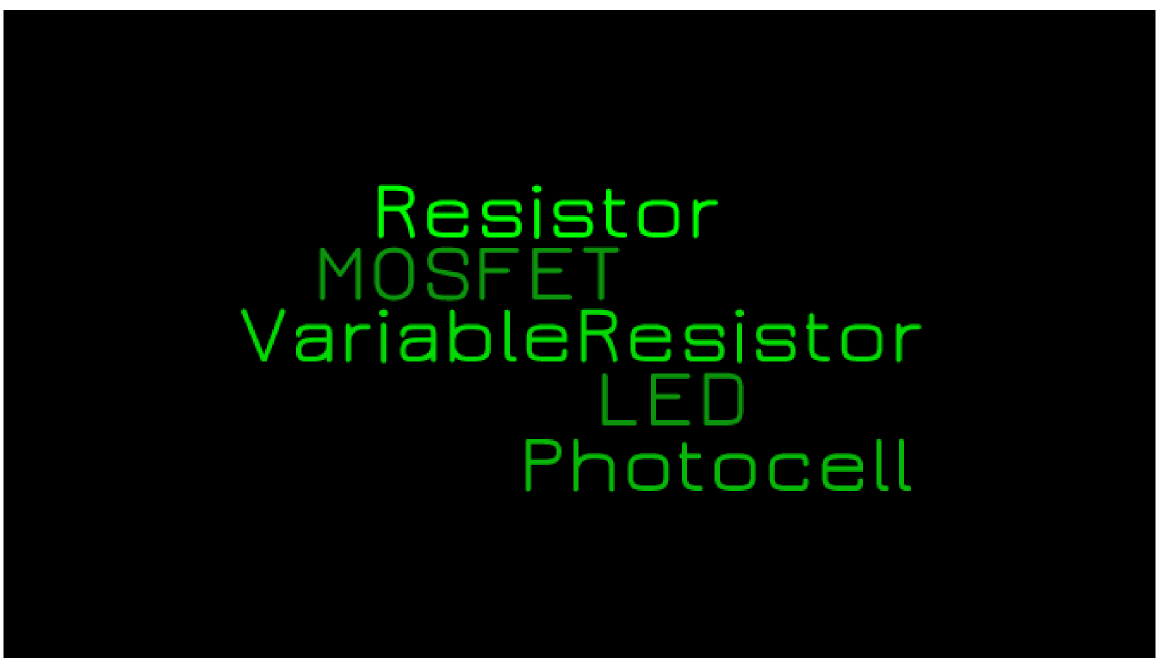


Figure 51

Word Cloud for Scenario 1 Hazards Selected by Participants

Figure 52

Word Cloud for Scenario 1 Hazards Selected by Expert Panelists

Scenario 2 - SCR Kitchen Timer

Figure 53

Word Cloud for Scenario 2 Components Selected by Participants

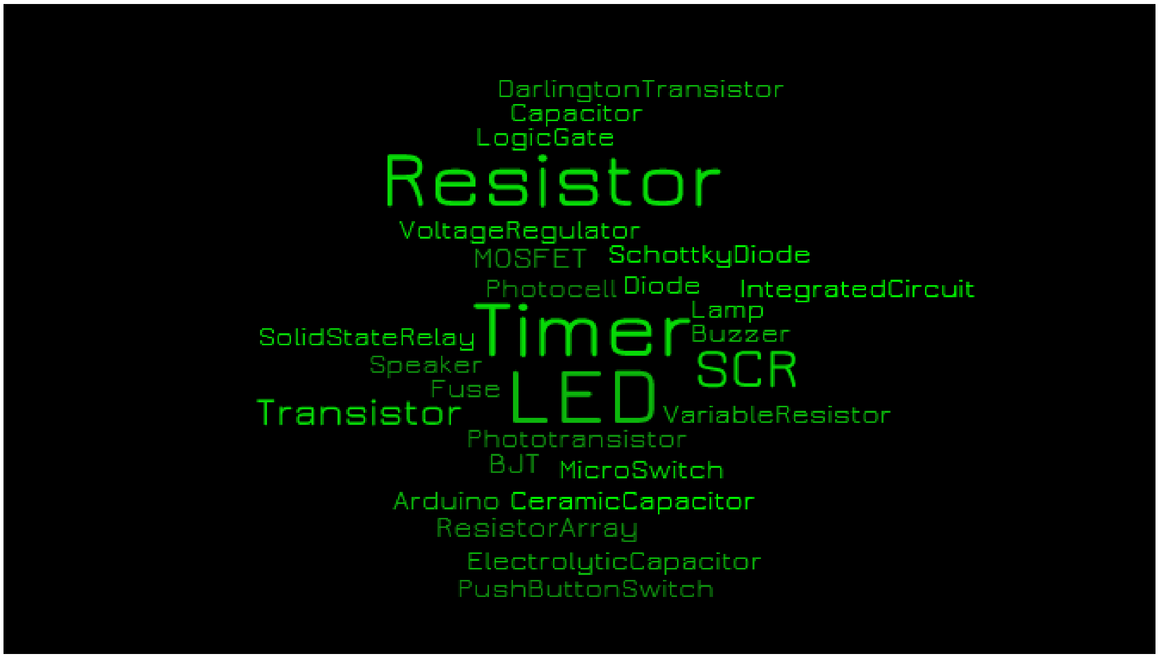


Figure 54

Word Cloud for Scenario 2 Components Selected by Expert Panelists

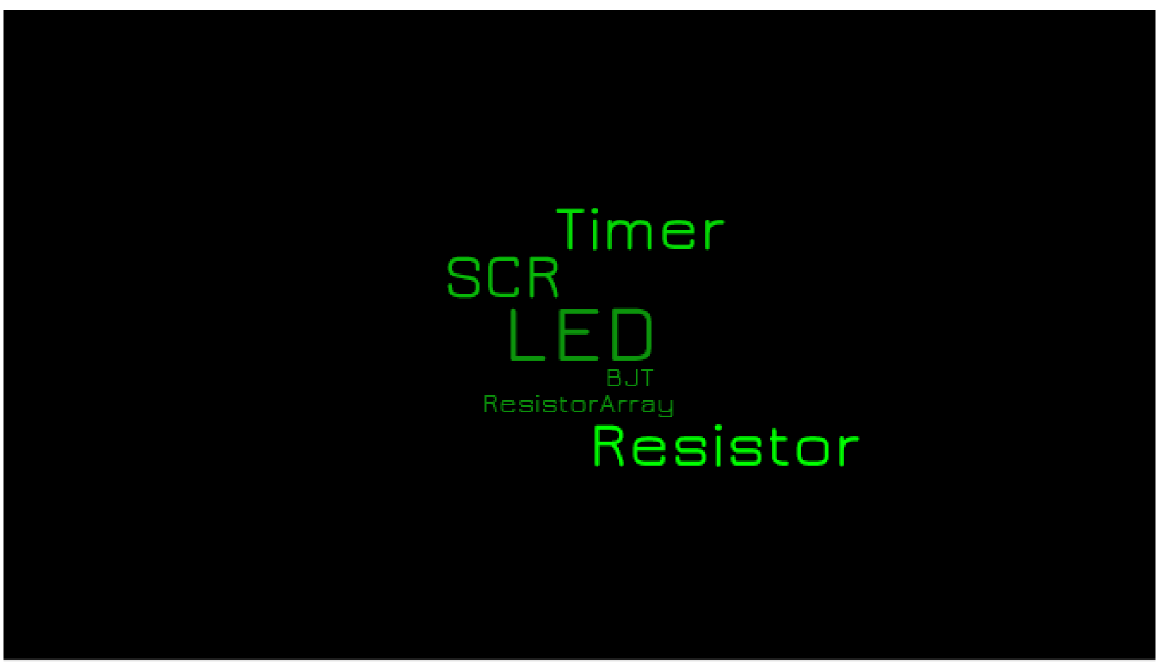


Figure 55

Word Cloud for Scenario 2 Hazards Selected by Participants

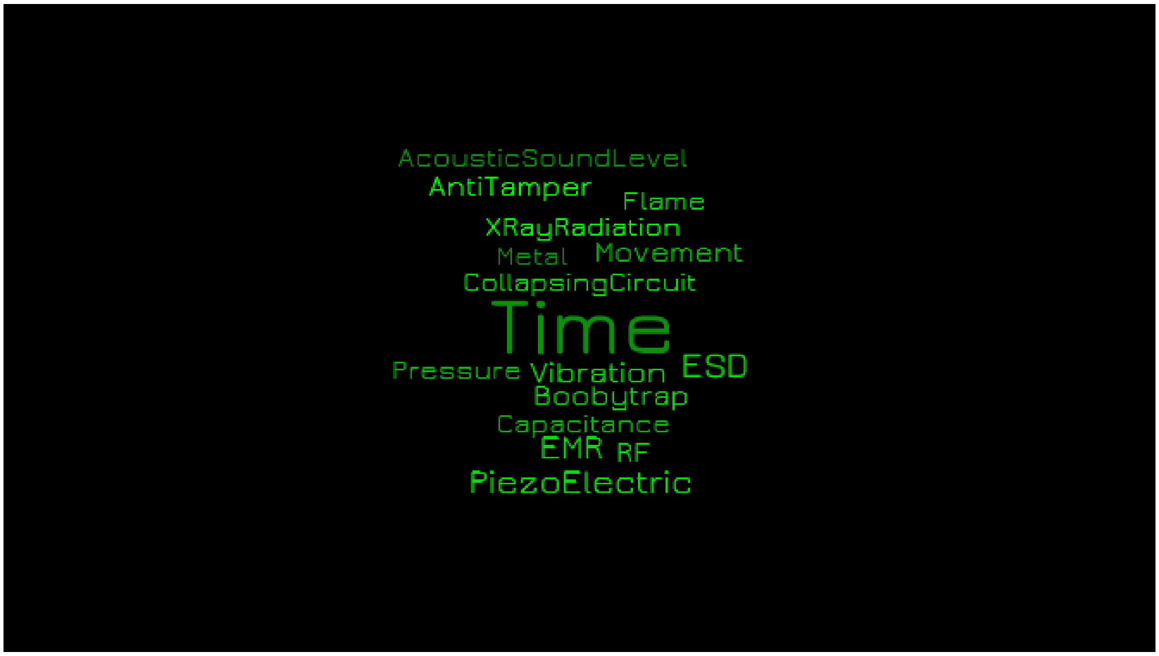


Figure 56

Word Cloud for Scenario 2 Hazards Selected by Expert Panelists

Scenario 3 - Two Battery Collapsing Circuit

Figure 57

Word Cloud for Scenario 3 Components Selected by Participants

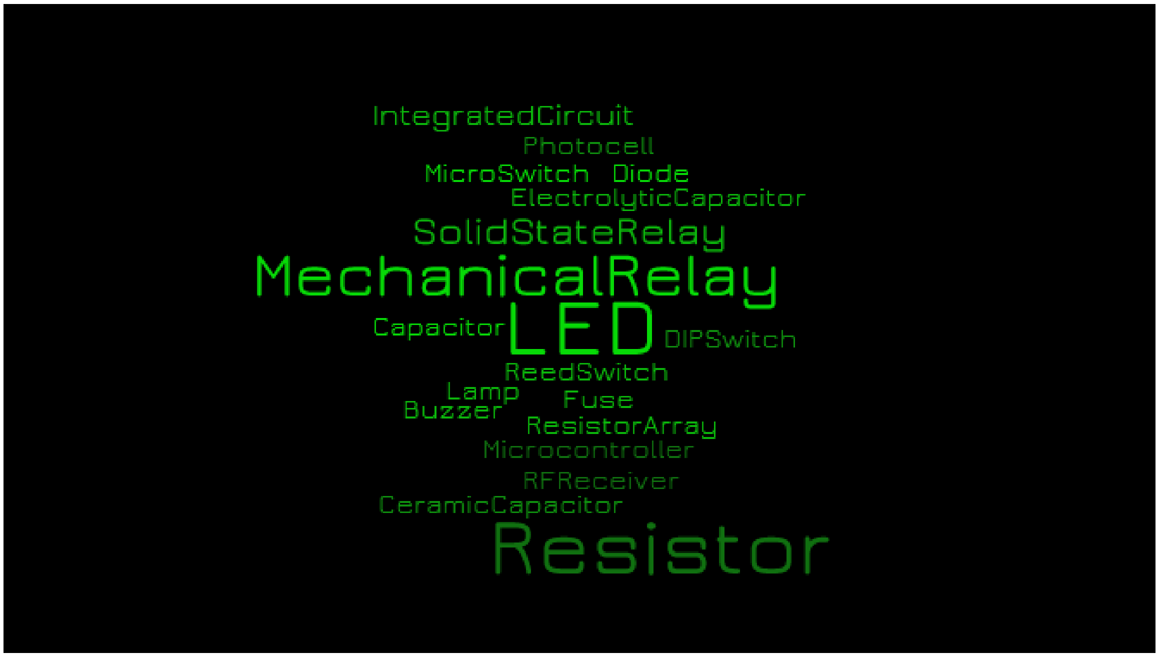


Figure 58

Word Cloud for Scenario 3 Components Selected by Expert Panelists

Figure 59

Word Cloud for Scenario 3 Hazards Selected by Participants

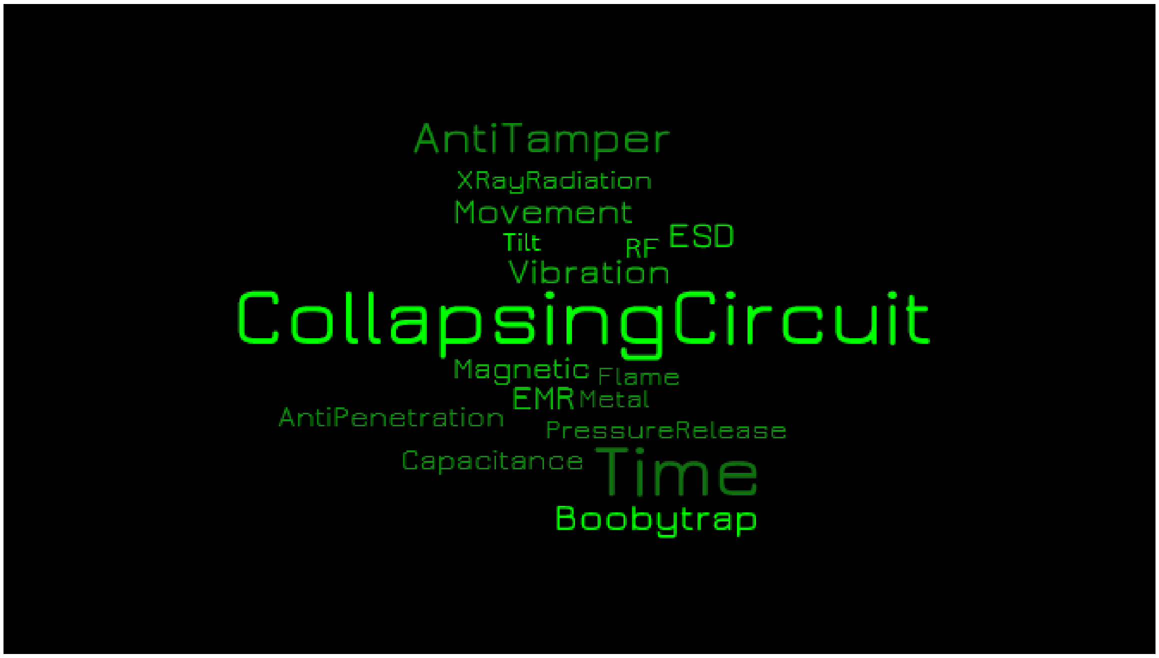


Figure 60

Word Cloud for Scenario 3 Hazards Selected by Expert Panelists

Scenario 4 - Battery Removal Circuit

Figure 61

Word Cloud for Scenario 4 Components Selected by Participants

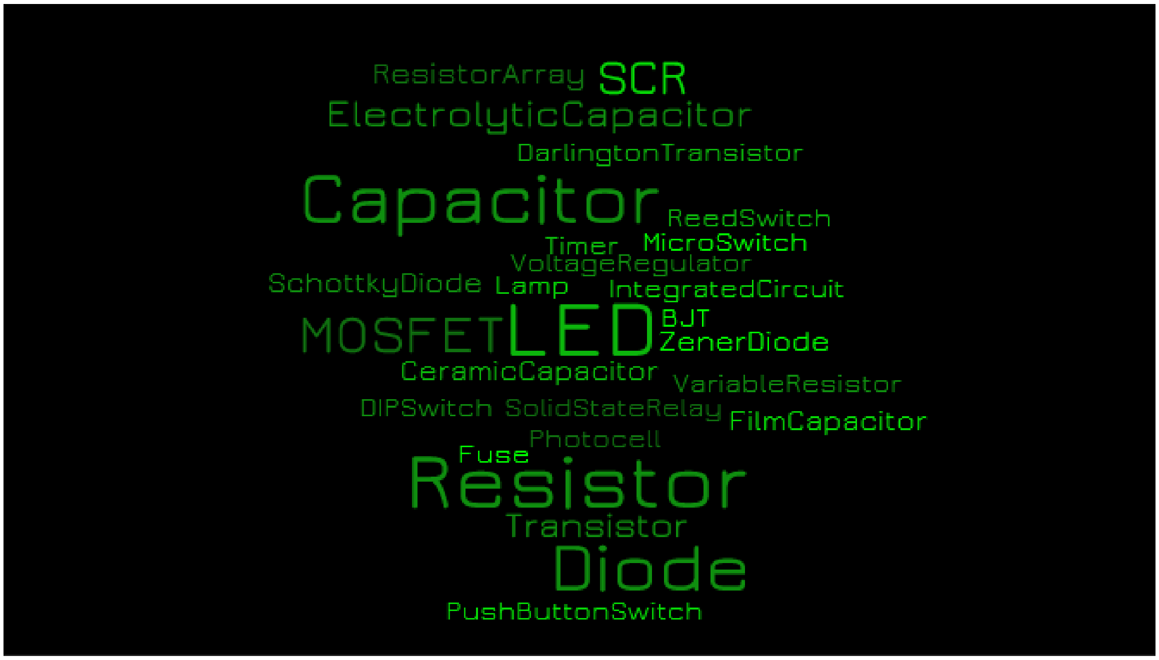


Figure 62

Word Cloud for Scenario 4 Components Selected by Expert Panelists

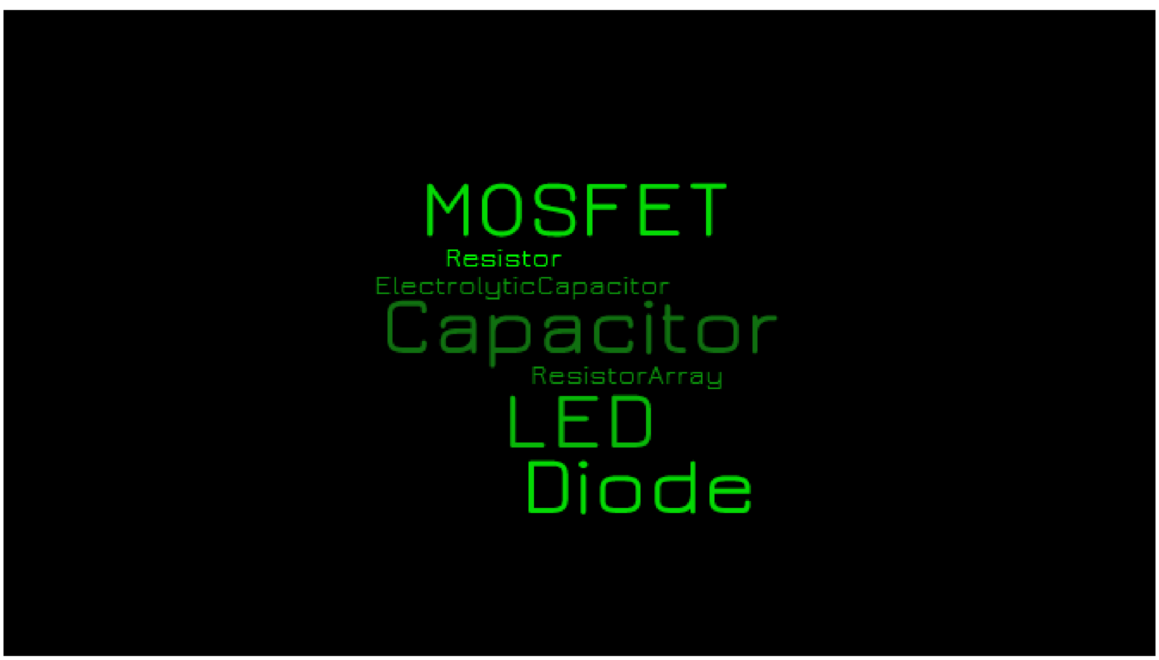


Figure 63

Word Cloud for Scenario 4 Hazards Selected by Participants

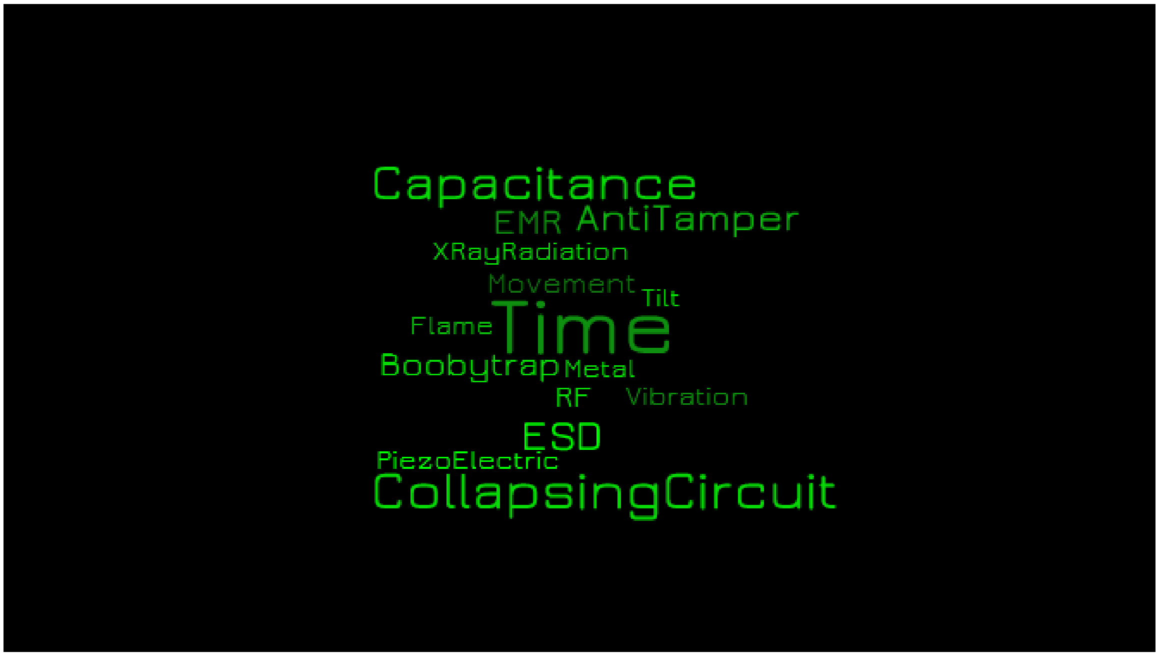


Figure 64

Word Cloud for Scenario 4 Hazards Selected by Expert Panelists

Scenario 5 - 555 Timer Circuit

Figure 65

Word Cloud for Scenario 5 Components Selected by Participants

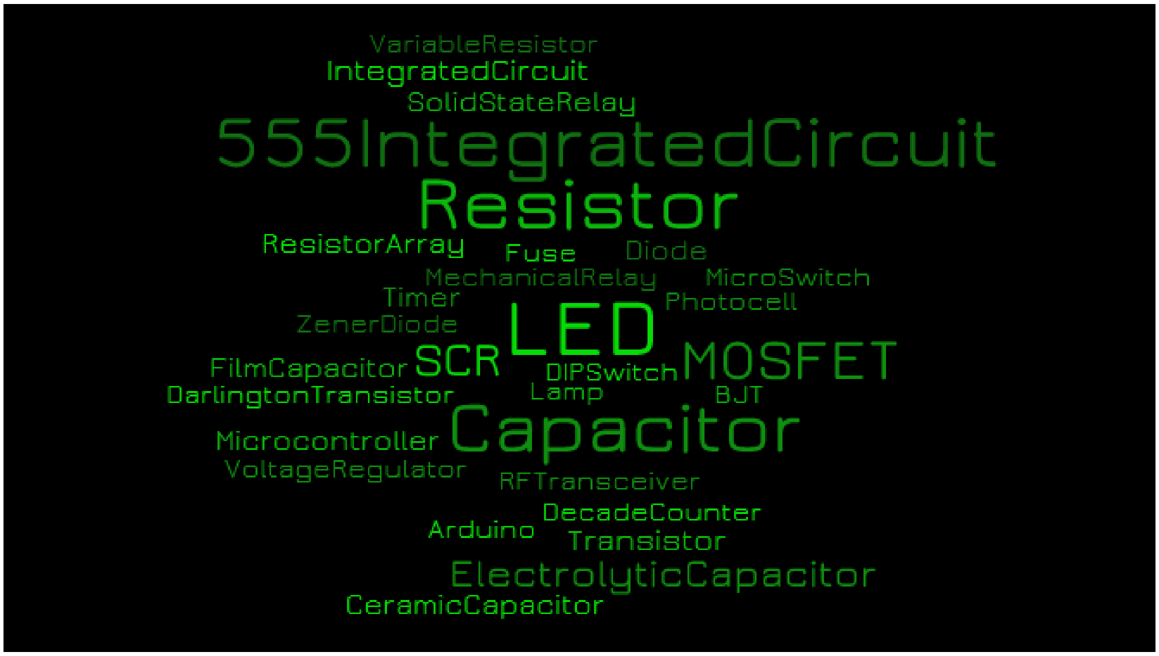


Figure 66

Word Cloud for Scenario 5 Components Selected by Expert Panelists

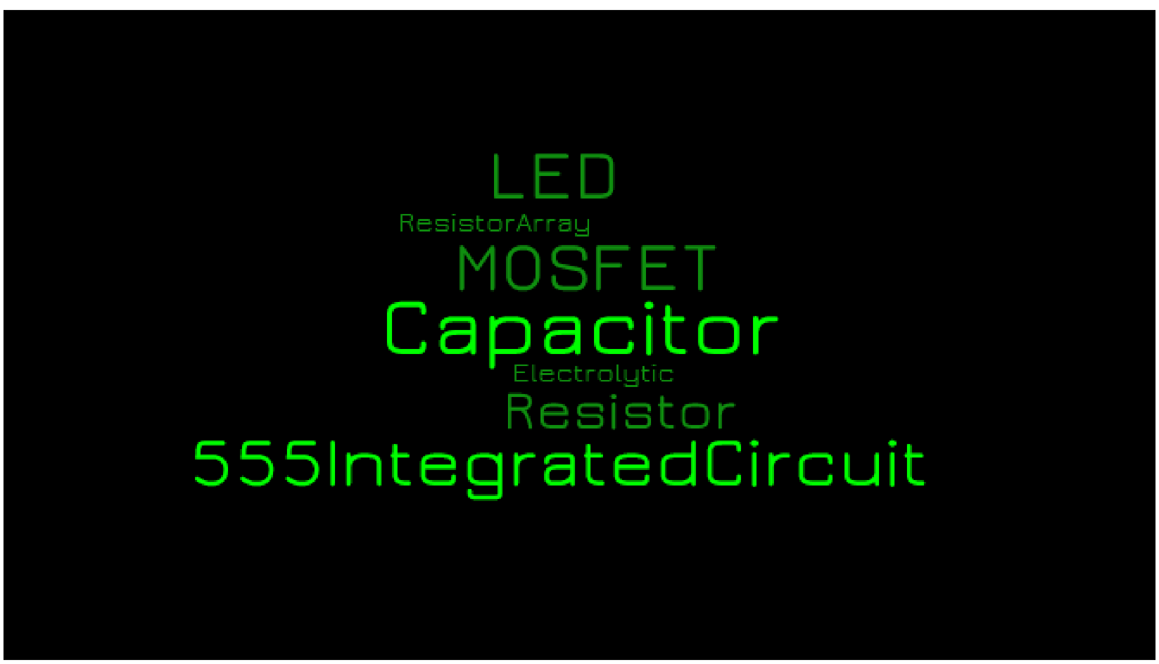


Figure 67

Word Cloud for Scenario 5 Hazards Selected by Participants

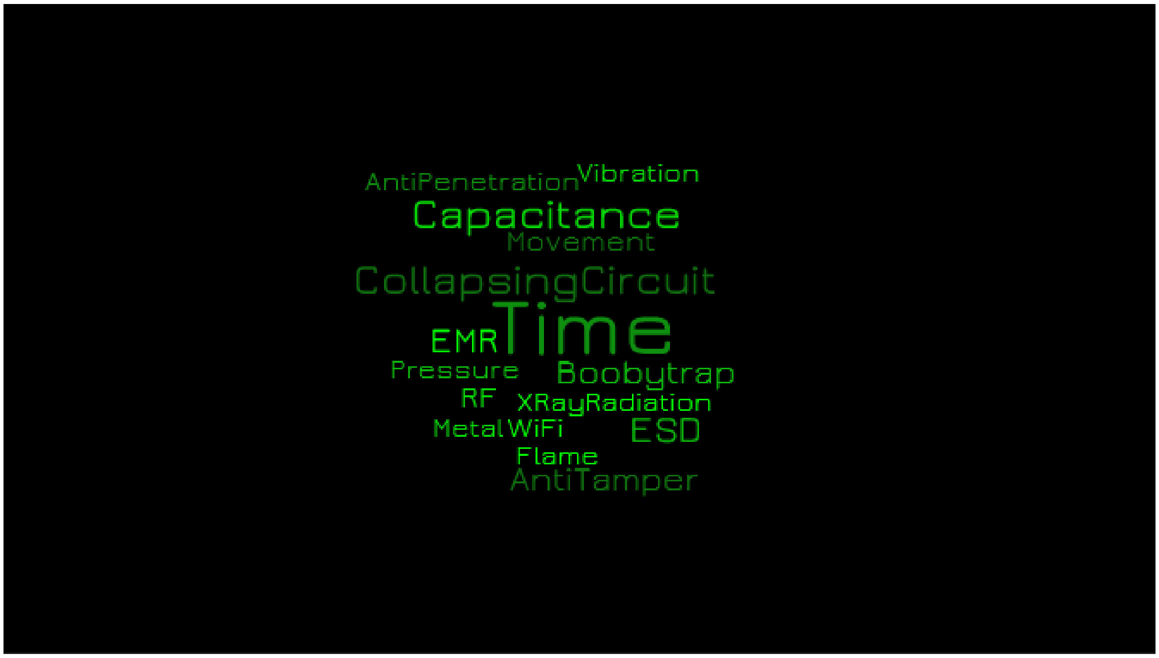


Figure 68

Word Cloud for Scenario 5 Hazards Selected by Expert Panelists

Scenario 6 - Cell Phone Optocoupler Circuit

Figure 69

Word Cloud for Scenario 6 Components Selected by Participants

Figure 70

Word Cloud for Scenario 6 Components Selected by Expert Panelists

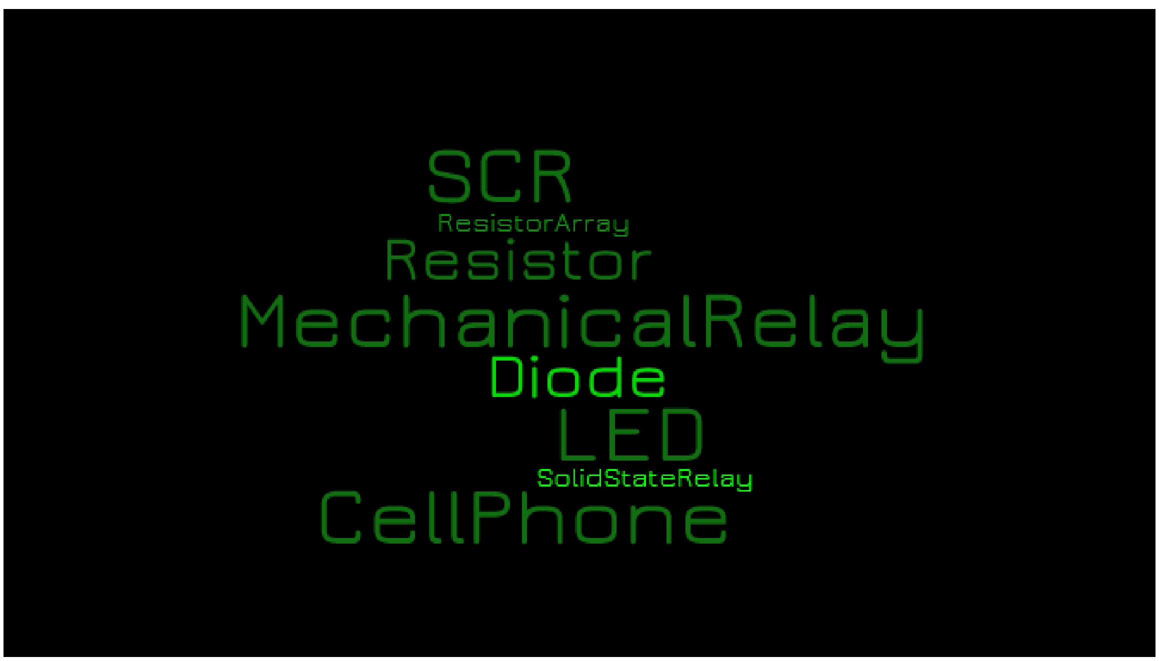


Figure 71

Word Cloud for Scenario 6 Hazards Selected by Participants

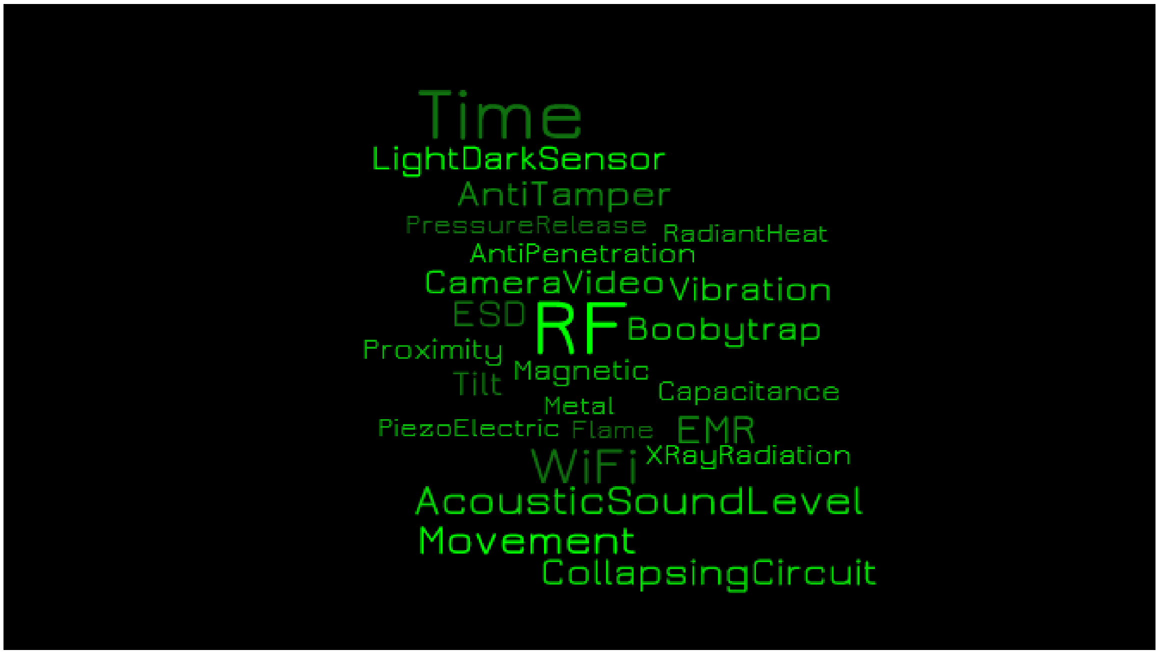
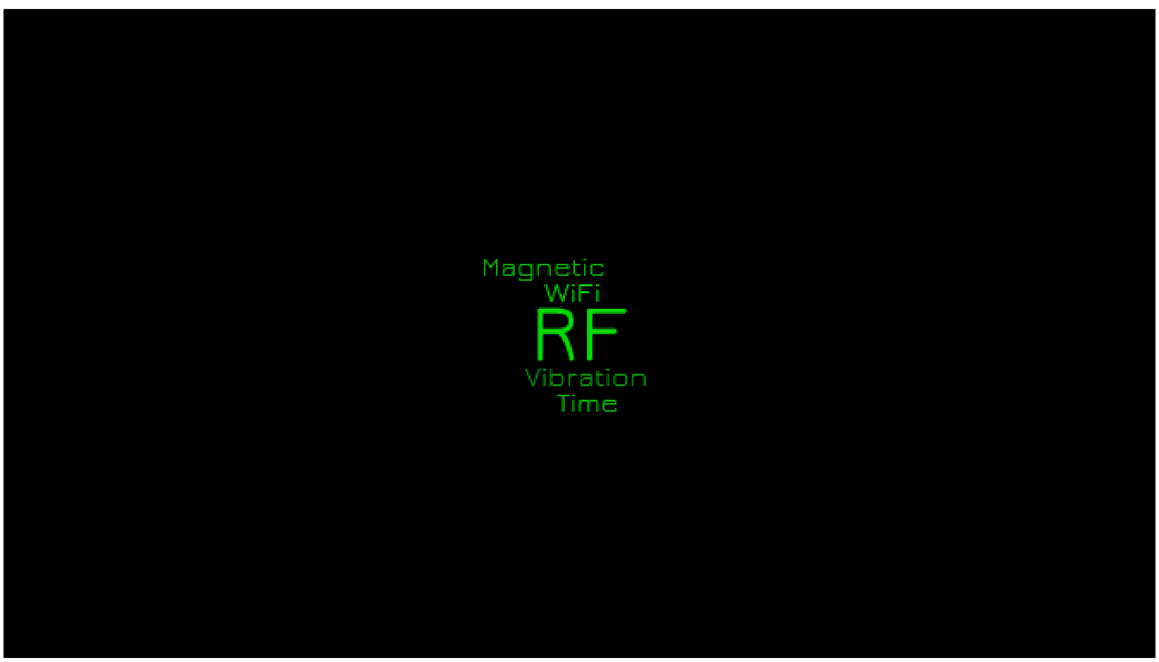


Figure 72

Word Cloud for Scenario 6 Hazards Selected by Expert Panelists



Scenario 7 - Capacitor-Based Collapsing Circuit

Figure 73

Word Cloud for Scenario 7 Components Selected by Participants

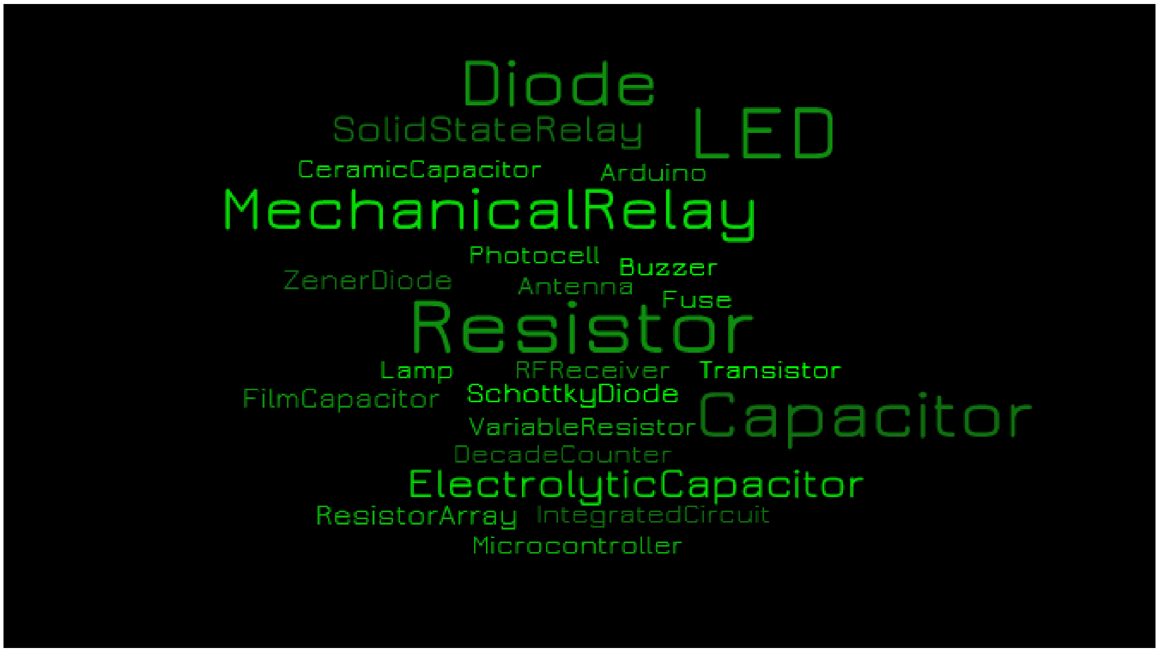


Figure 74

Word Cloud for Scenario 7 Components Selected by Expert Panelists

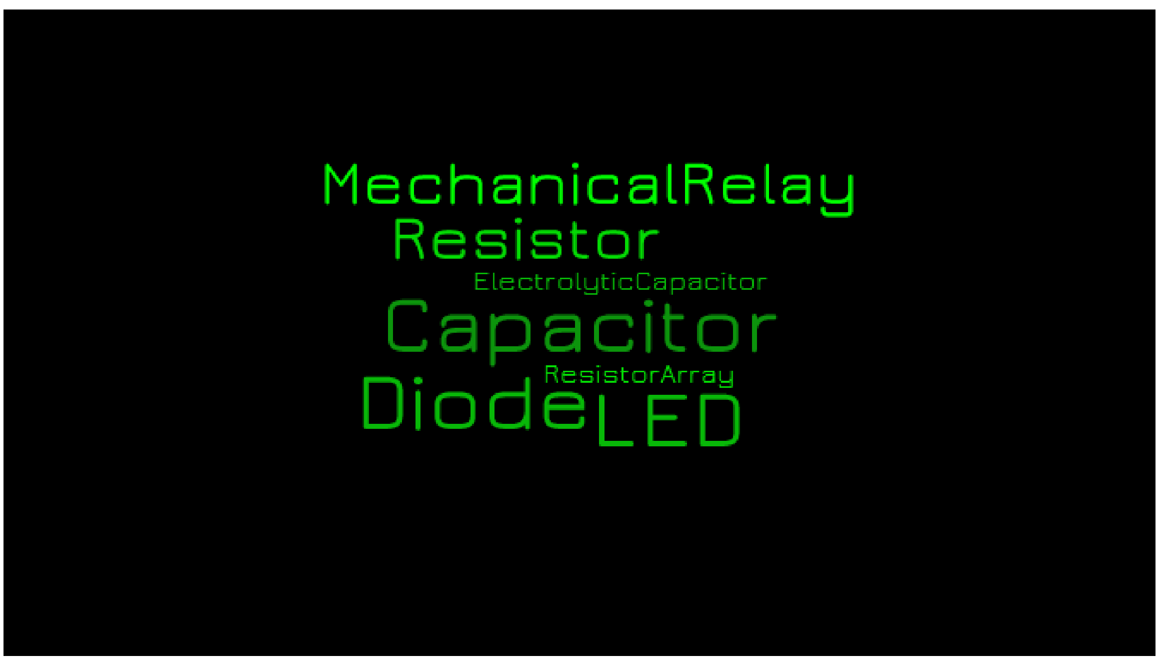


Figure 75

Word Cloud for Scenario 7 Hazards Selected by Participants

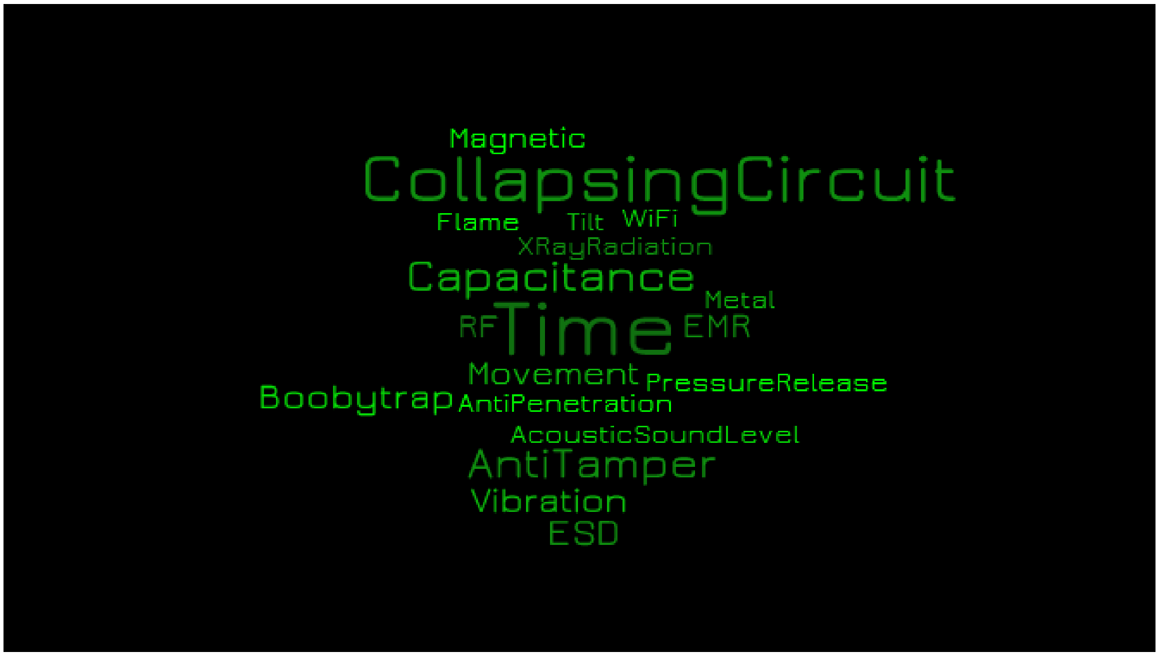
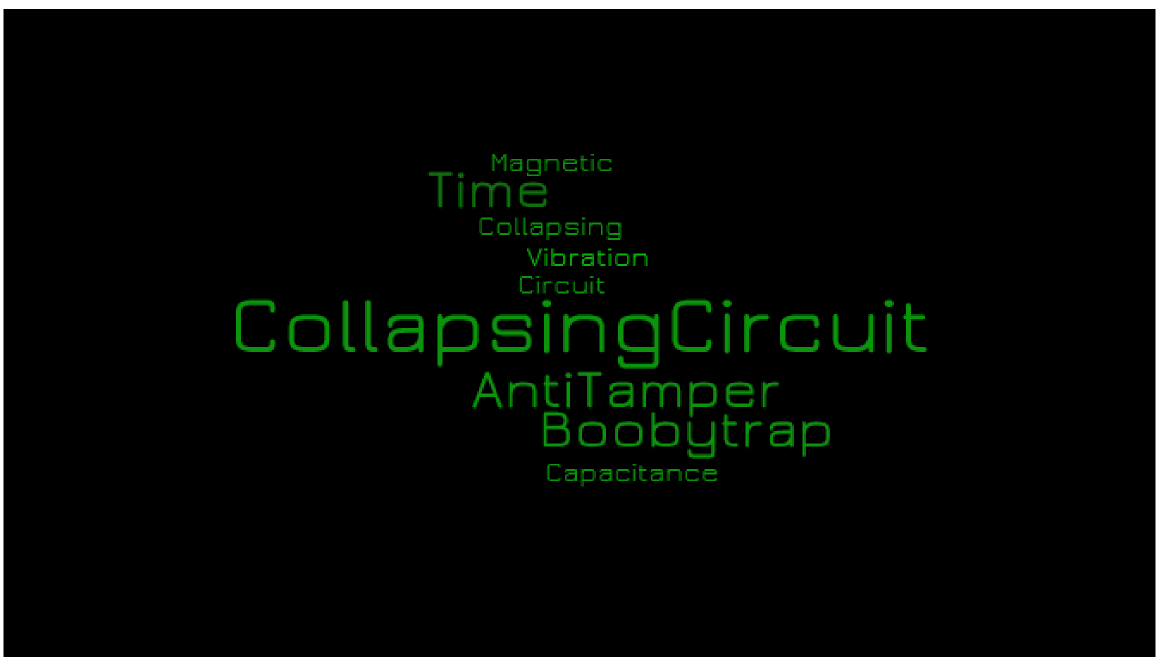


Figure 76

Word Cloud for Scenario 7 Hazards Selected by Expert Panelists



Scenario 8 - Radio Squelch SCR Circuit

Figure 77

Word Cloud for Scenario 8 Components Selected by Participants

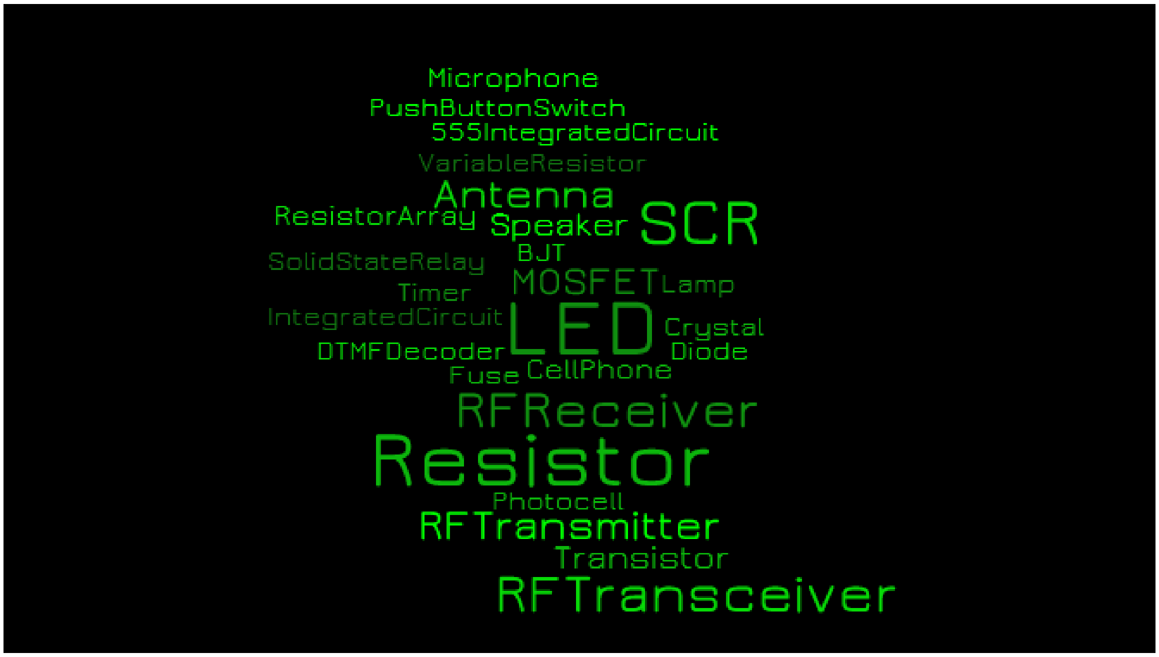


Figure 78

Word Cloud for Scenario 8 Components Selected by Expert Panelists

Figure 79

Word Cloud for Scenario 8 Hazards Selected by Participants

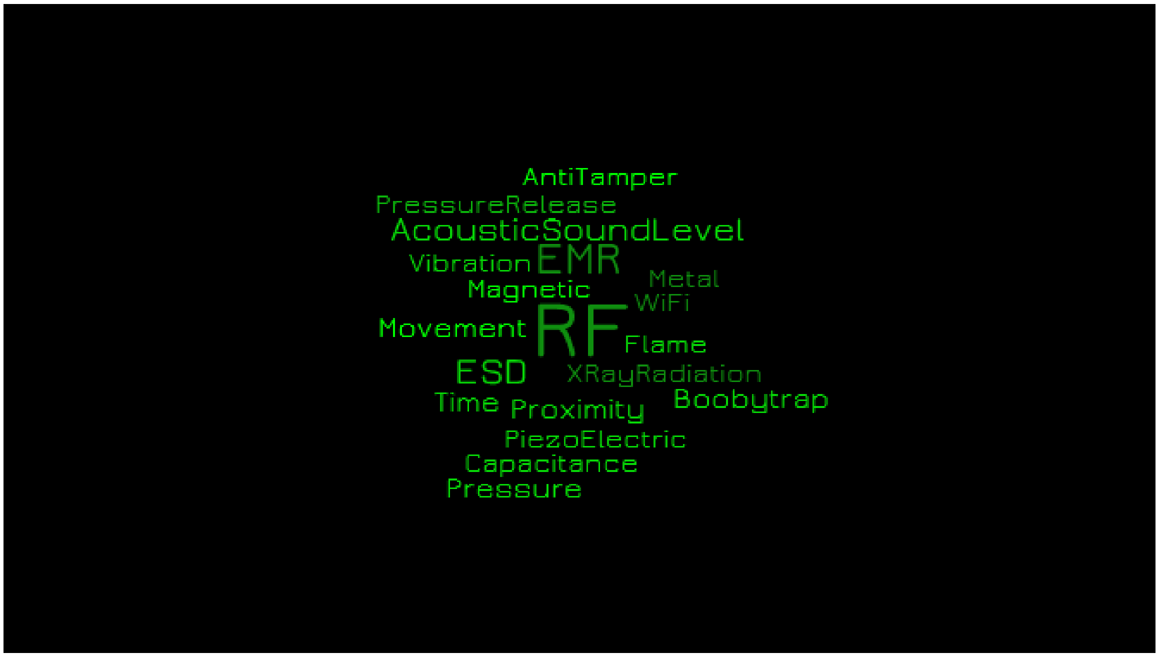


Figure 80

Word Cloud for Scenario 8 Hazards Selected by Expert Panelists

Scenario 9 - Microcontroller-Based PIR Circuit

Figure 81

Word Cloud for Scenario 9 Components Selected by Participants

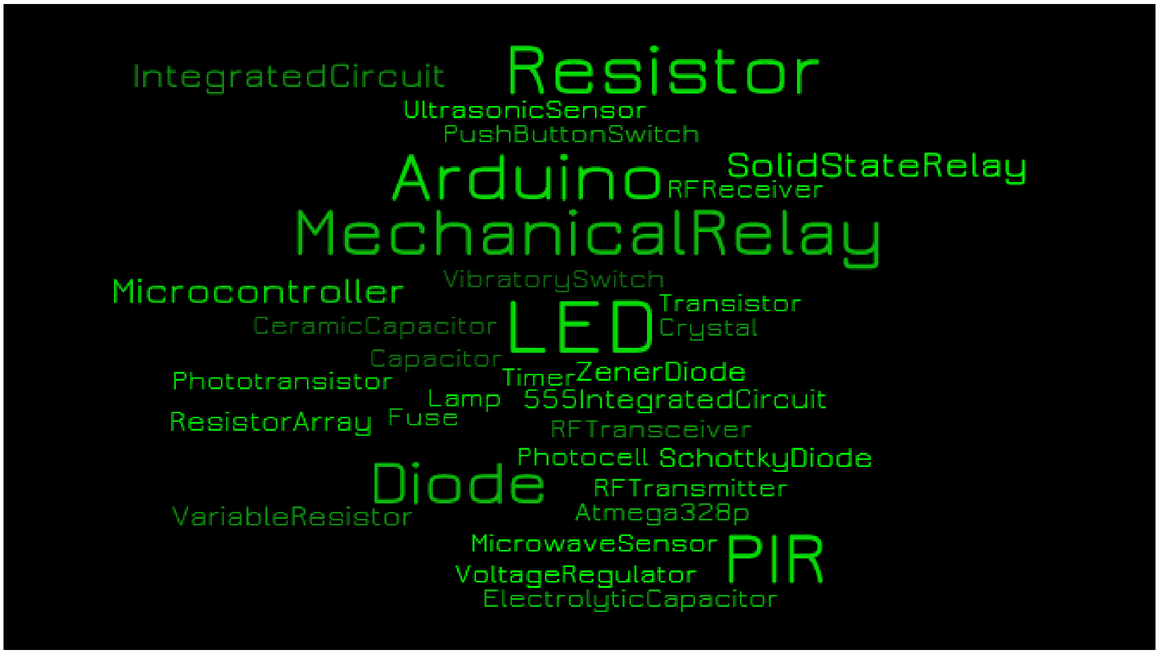


Figure 82

Word Cloud for Scenario 9 Components Selected by Expert Panelists

Figure 83

Word Cloud for Scenario 9 Hazards Selected by Participants

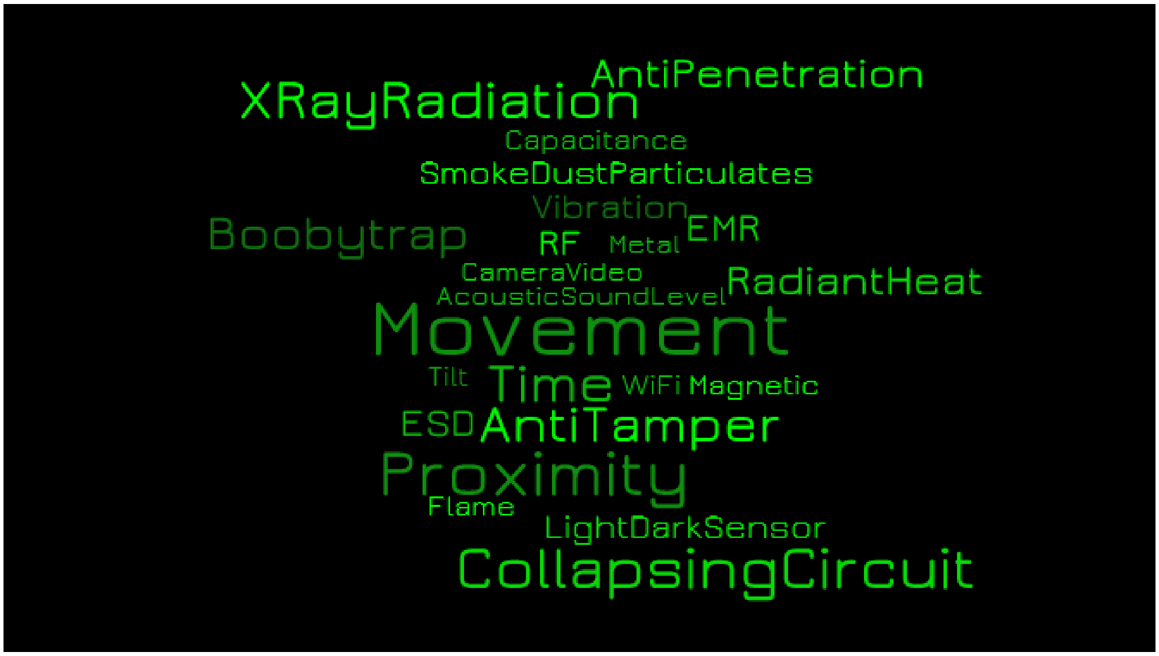
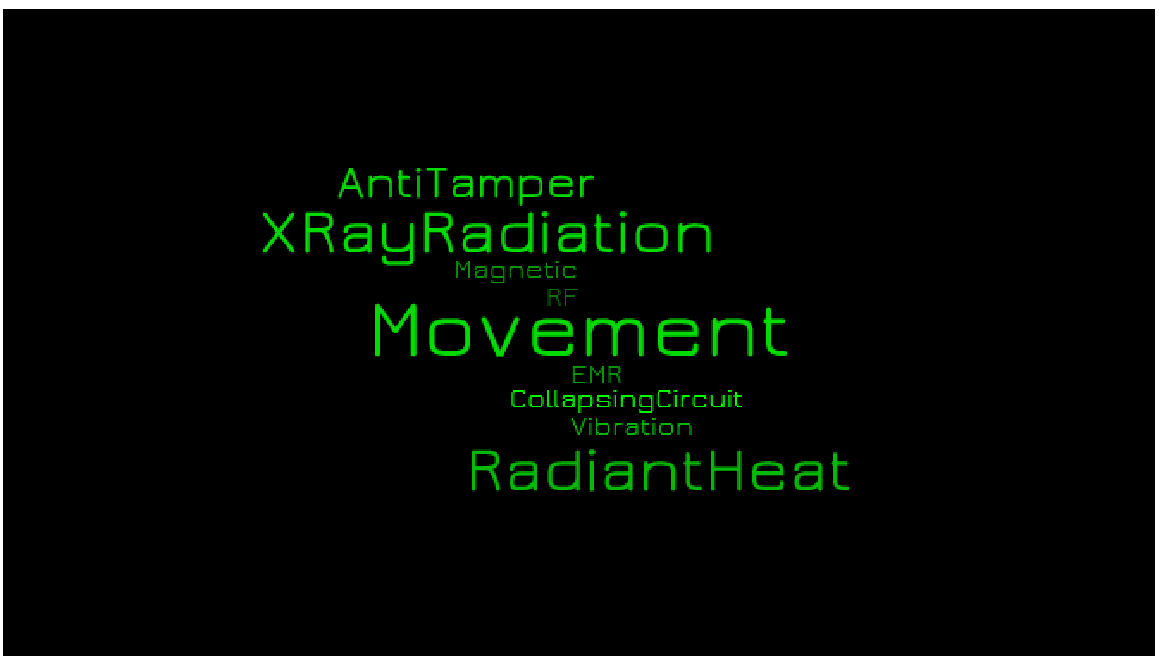


Figure 84

Word Cloud for Scenario 9 Hazards Selected by Expert Panelists



Scenario 10 - Microcontroller-Based Ultrasonic Circuit

Figure 85

Word Cloud for Scenario 10 Components Selected by Participants

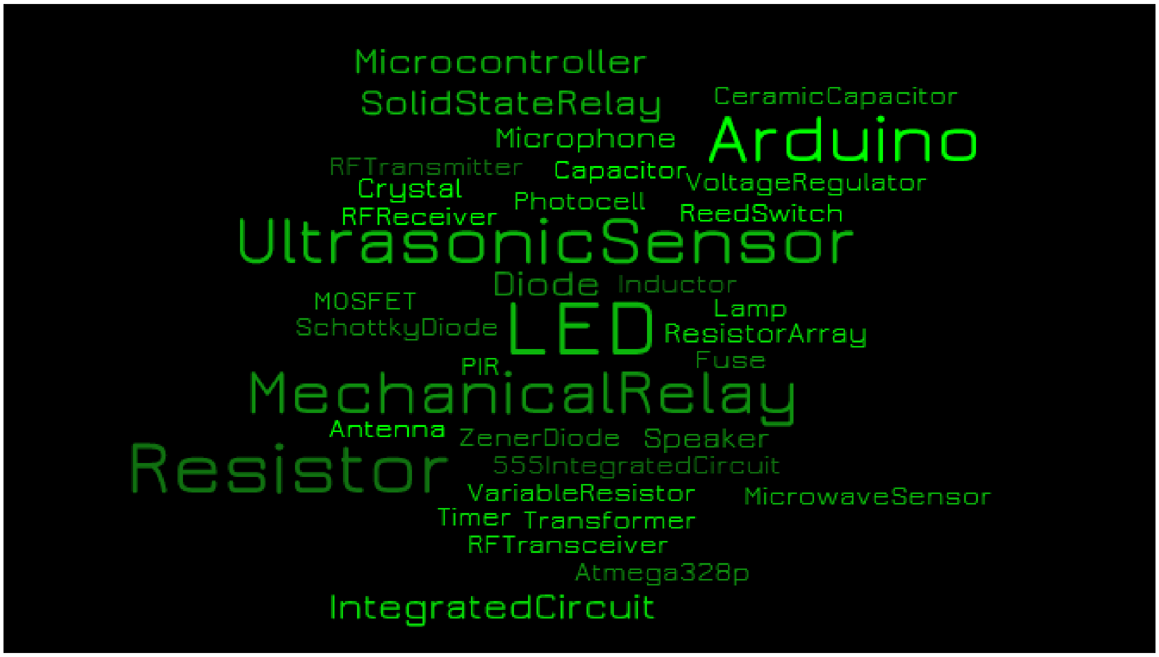


Figure 86

Word Cloud for Scenario 10 Components Selected by Expert Panelists

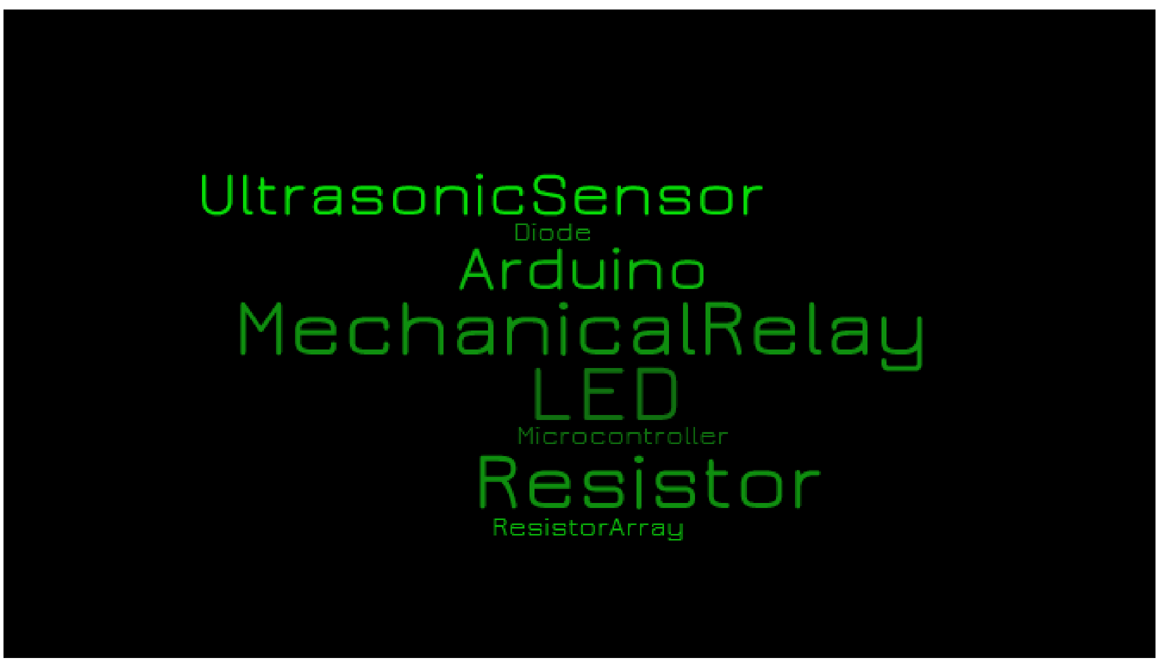


Figure 87

Word Cloud for Scenario 10 Hazards Selected by Participants

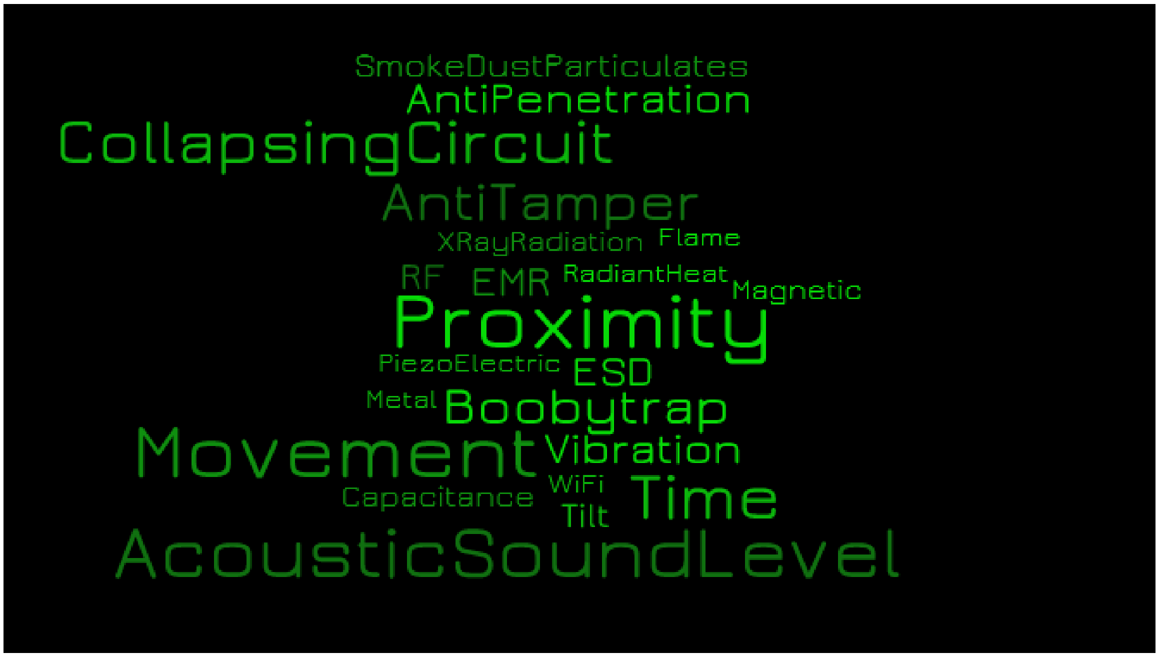


Figure 88

Word Cloud for Scenario 10 Hazards Selected by Expert Panelists

Scenario 11 - RF Receiver with SCR

Figure 89

Word Cloud for Scenario 11 Components Selected by Participants

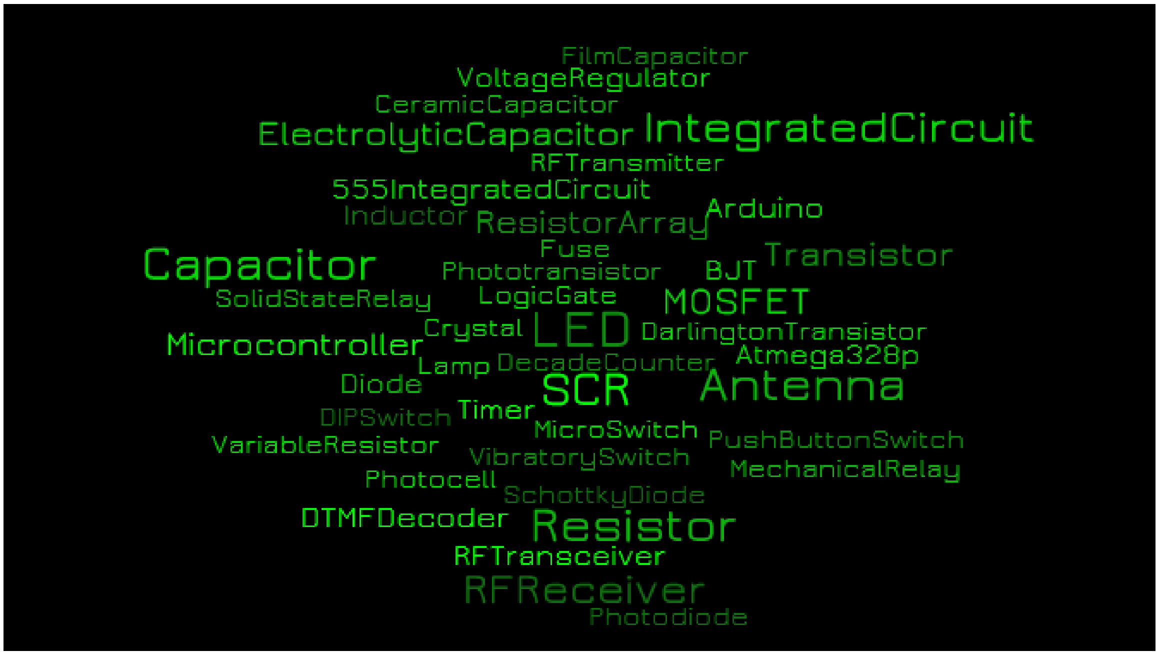


Figure 90

Word Cloud for Scenario 11 Components Selected by Expert Panelists

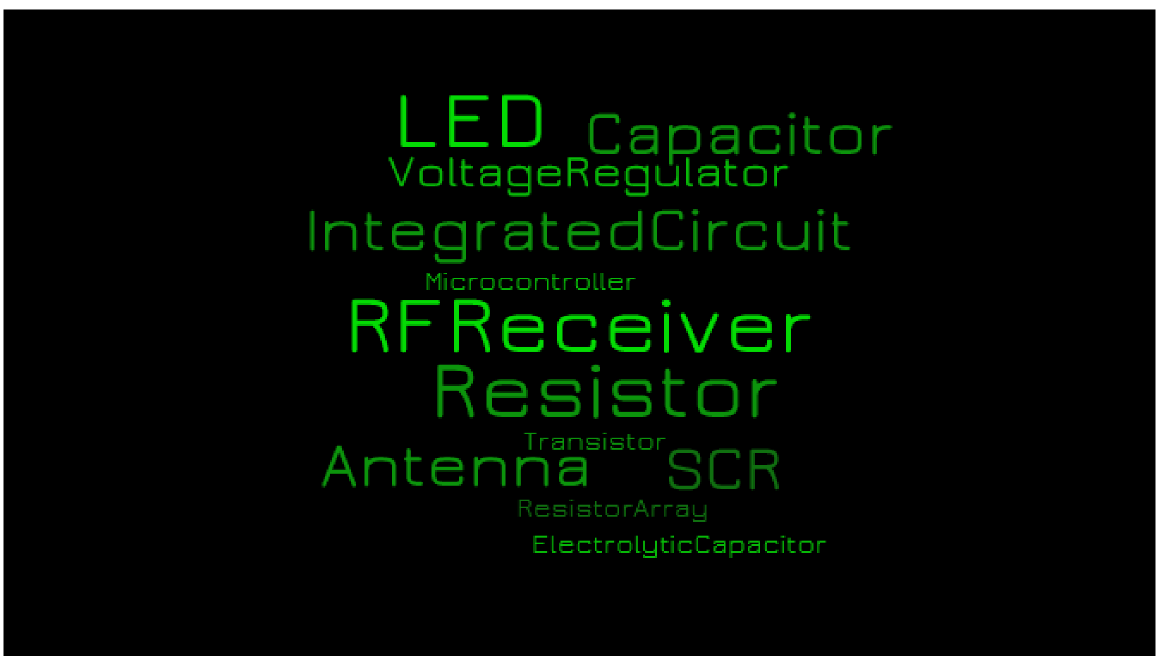


Figure 91

Word Cloud for Scenario 11 Hazards Selected by Participants

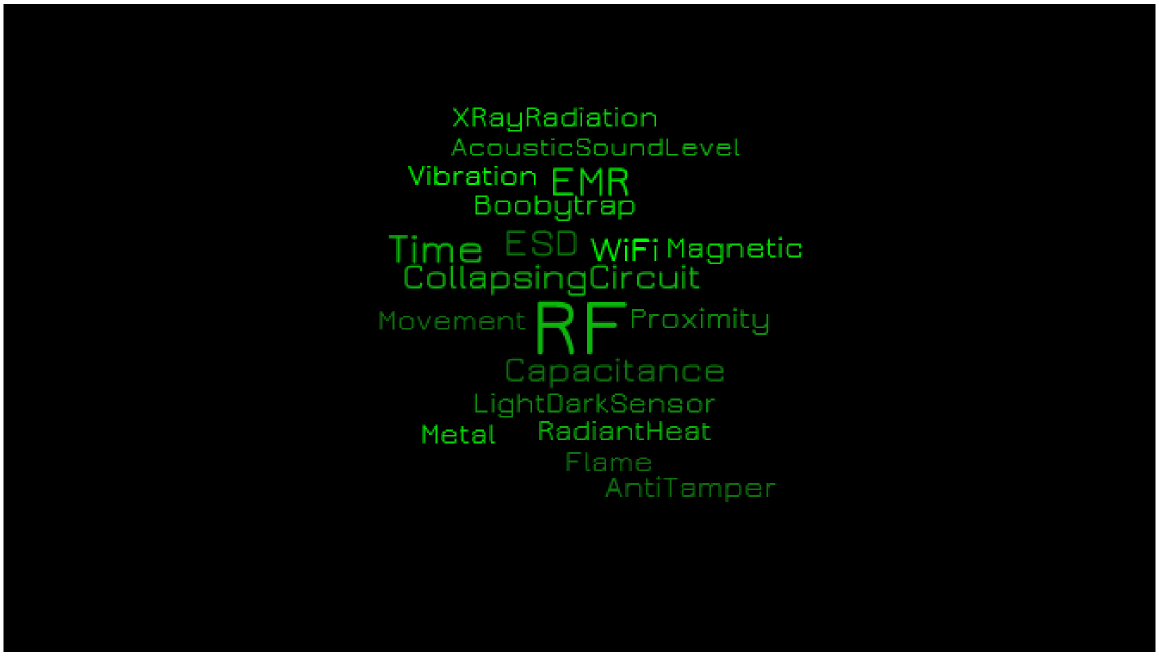


Figure 92

Word Cloud for Scenario 11 Hazards Selected by Expert Panelists

Scenario 12 - ATmega328P DTMF Circuit

Figure 93

Word Cloud for Scenario 12 Components Selected by Participants

Figure 94

Word Cloud for Scenario 12 Components Selected by Expert Panelists

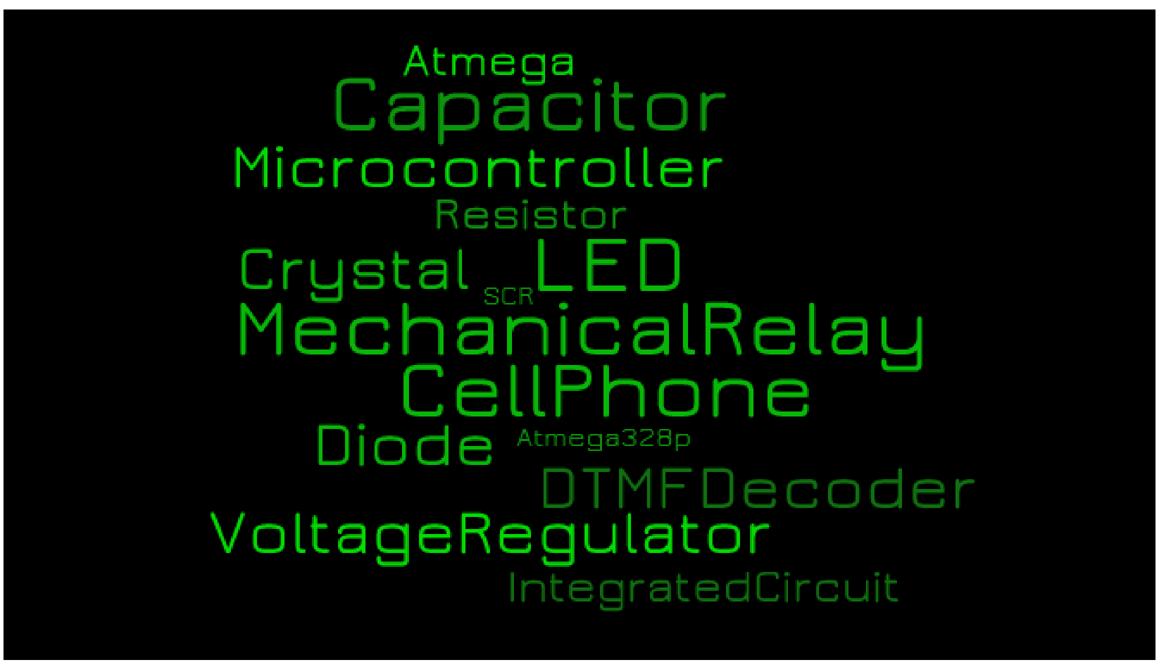


Figure 95

Word Cloud for Scenario 12 Hazards Selected by Participants

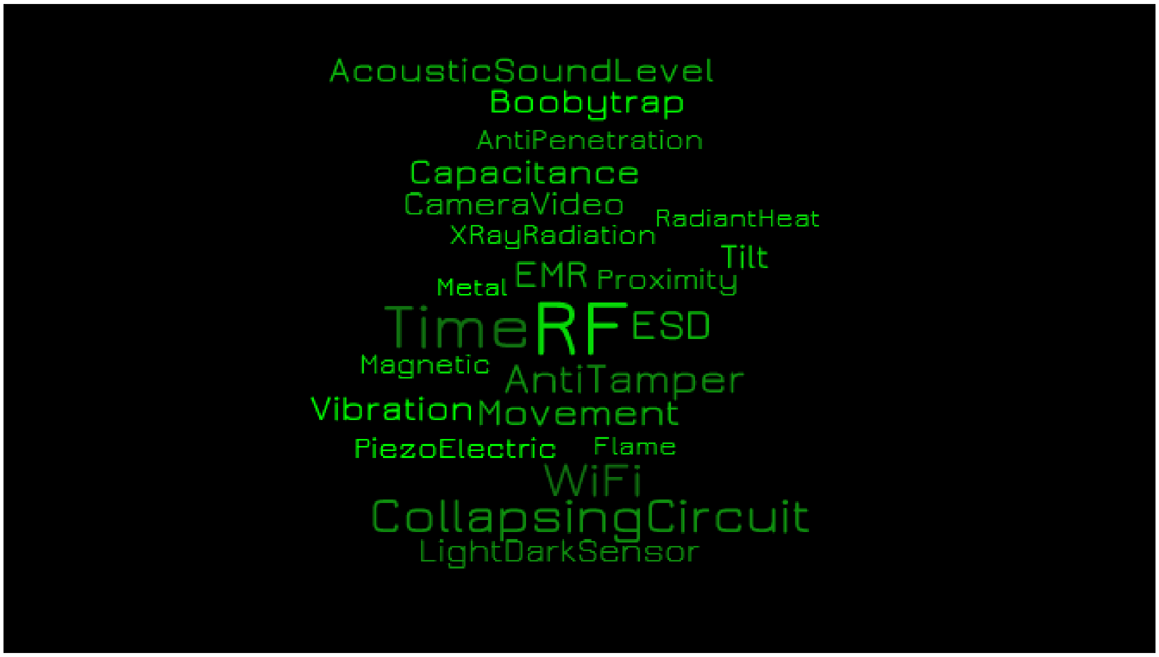
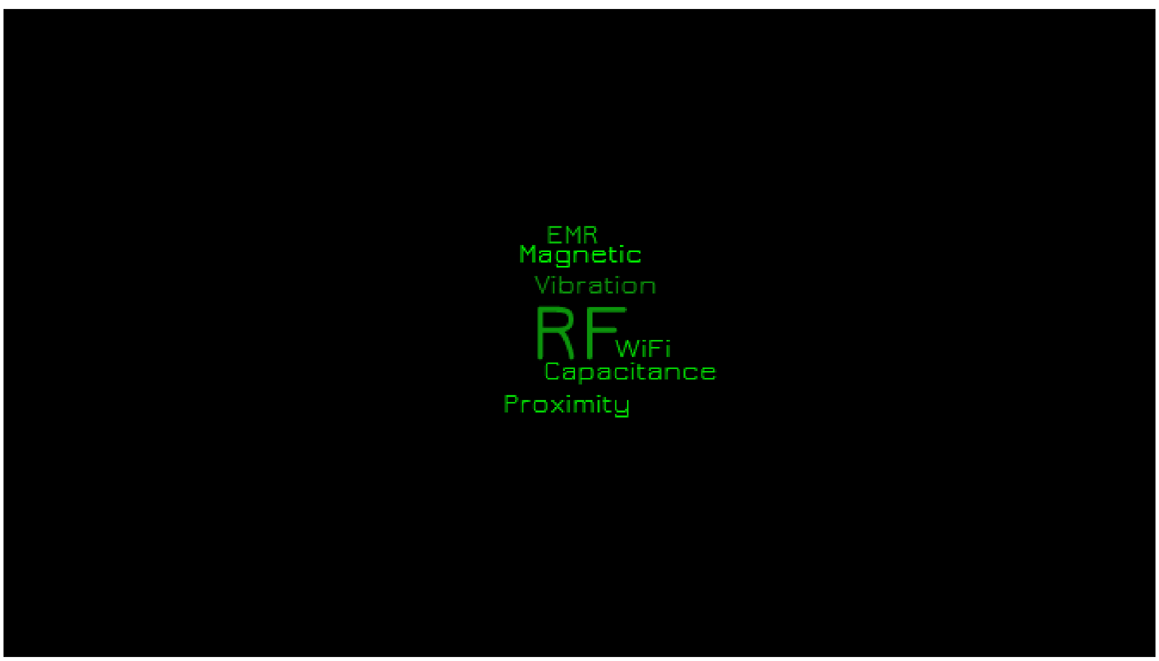


Figure 96

Word Cloud for Scenario 12 Hazards Selected by Expert Panelists



Scenario 13 - PIC16 Microcontroller Timer Circuit

Figure 97

Word Cloud for Scenario 13 Components Selected by Participants

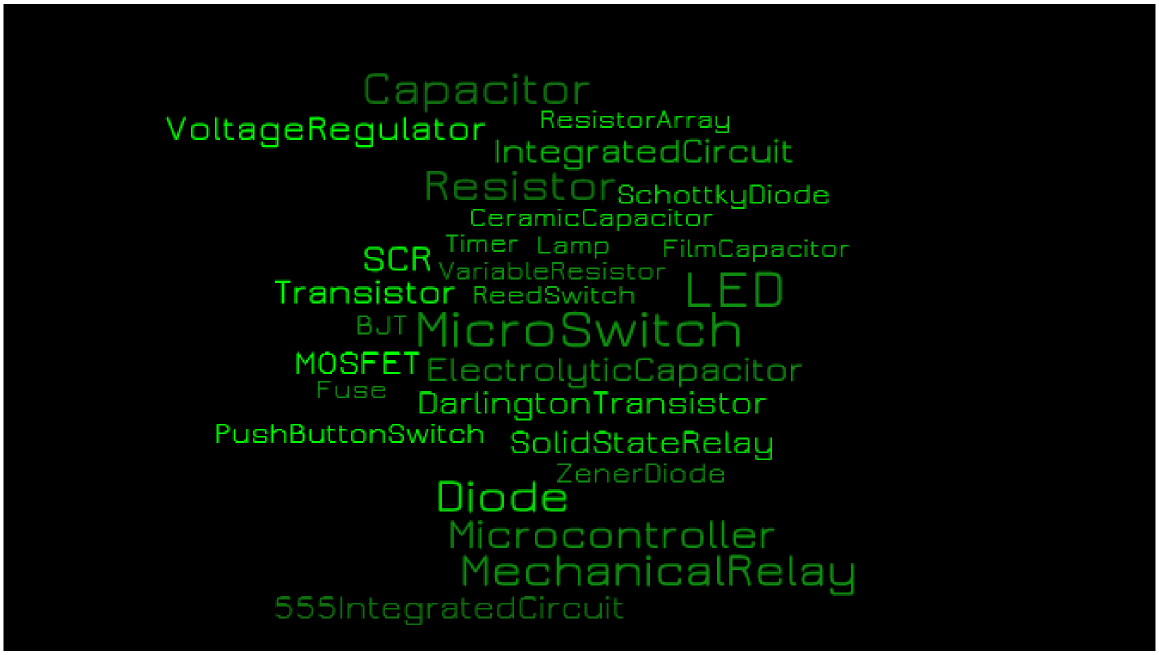


Figure 98

Word Cloud for Scenario 13 Components Selected by Expert Panelists

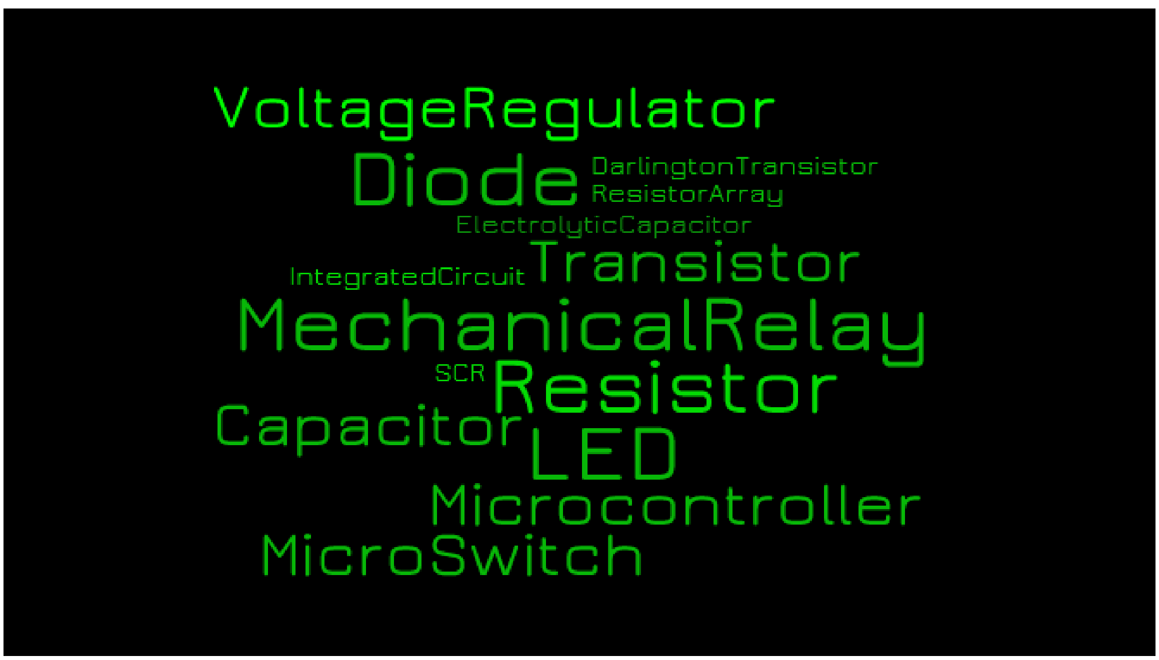


Figure 99

Word Cloud for Scenario 13 Hazards Selected by Participants

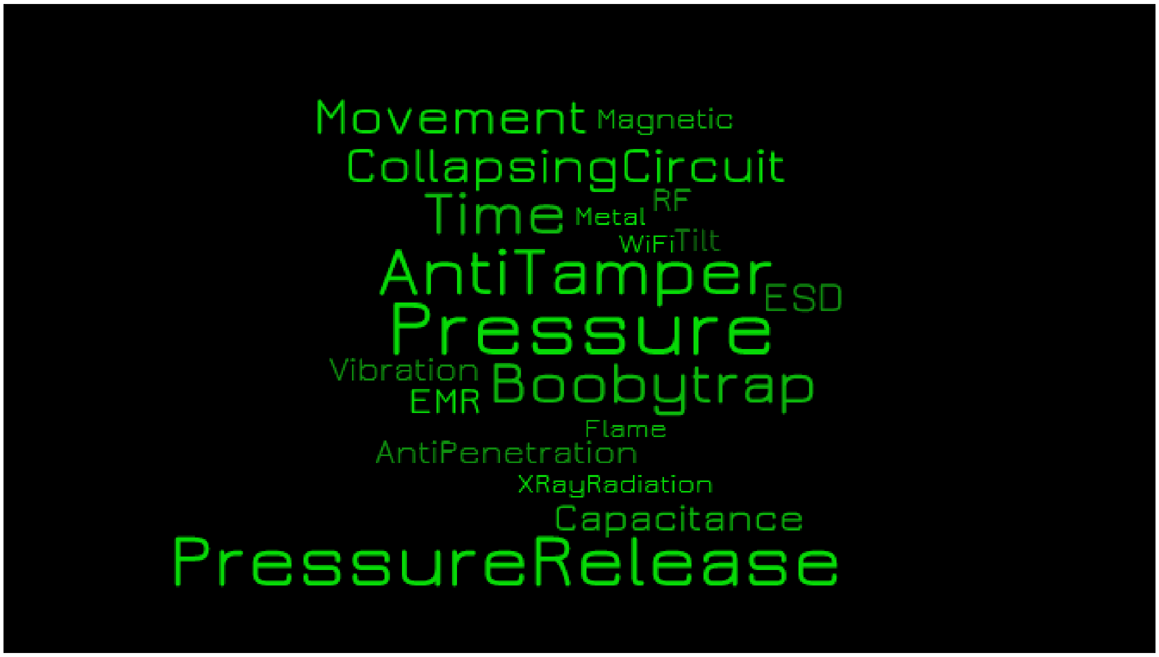


Figure 100

Word Cloud for Scenario 13 Hazards Selected by Expert Panelists

Scenario 14 - NRF24L01 RCIED Circuit

Figure 101

Word Cloud for Scenario 14 Components Selected by Participants

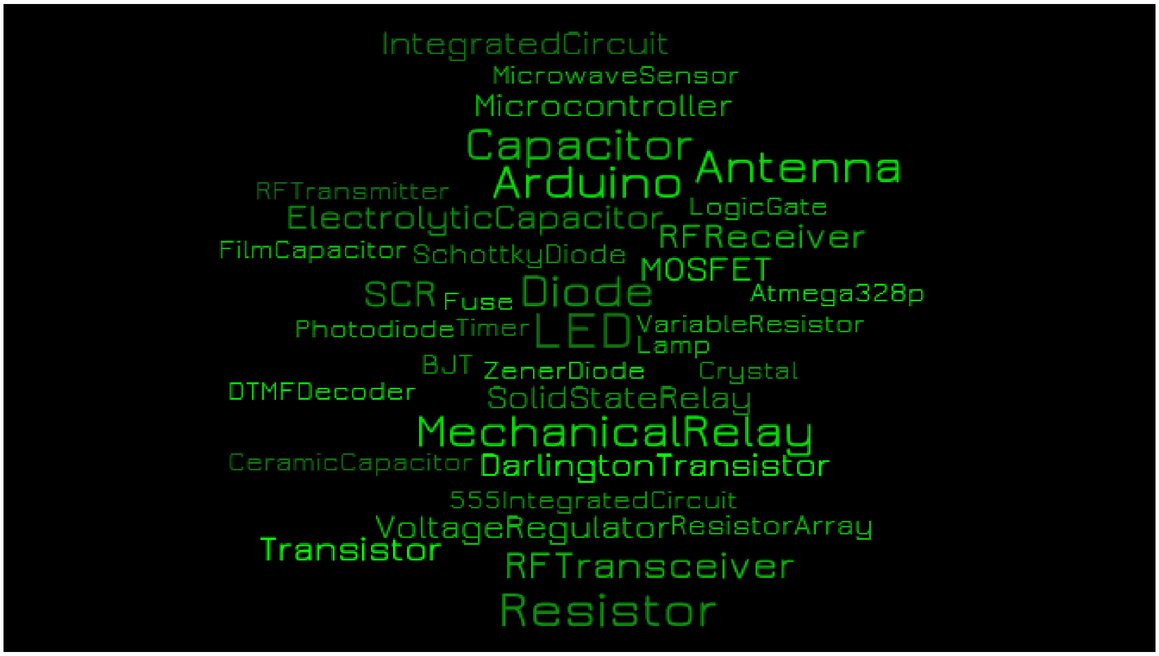


Figure 102

Word Cloud for Scenario 14 Components Selected by Expert Panelists

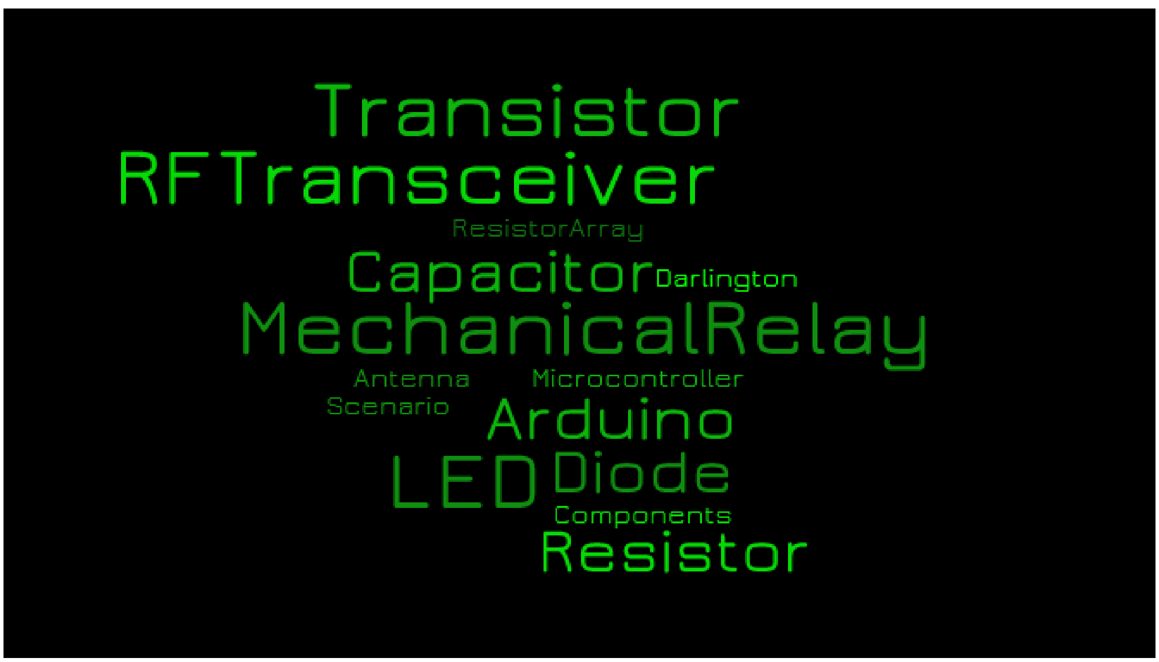


Figure 103

Word Cloud for Scenario 14 Hazards Selected by Participants

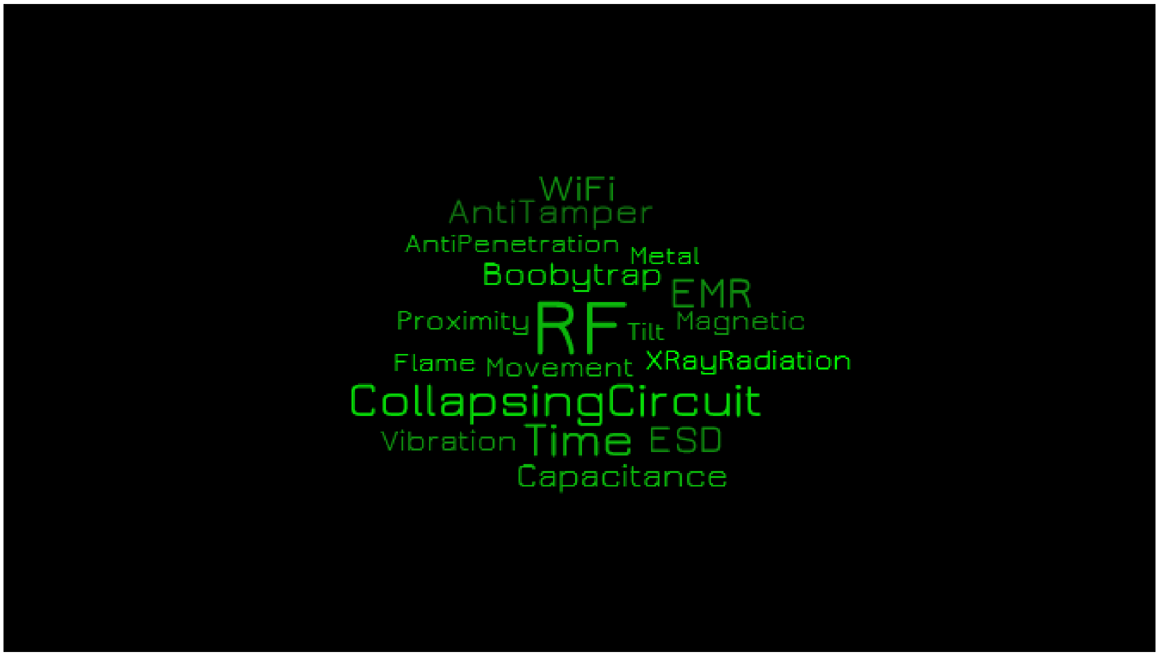
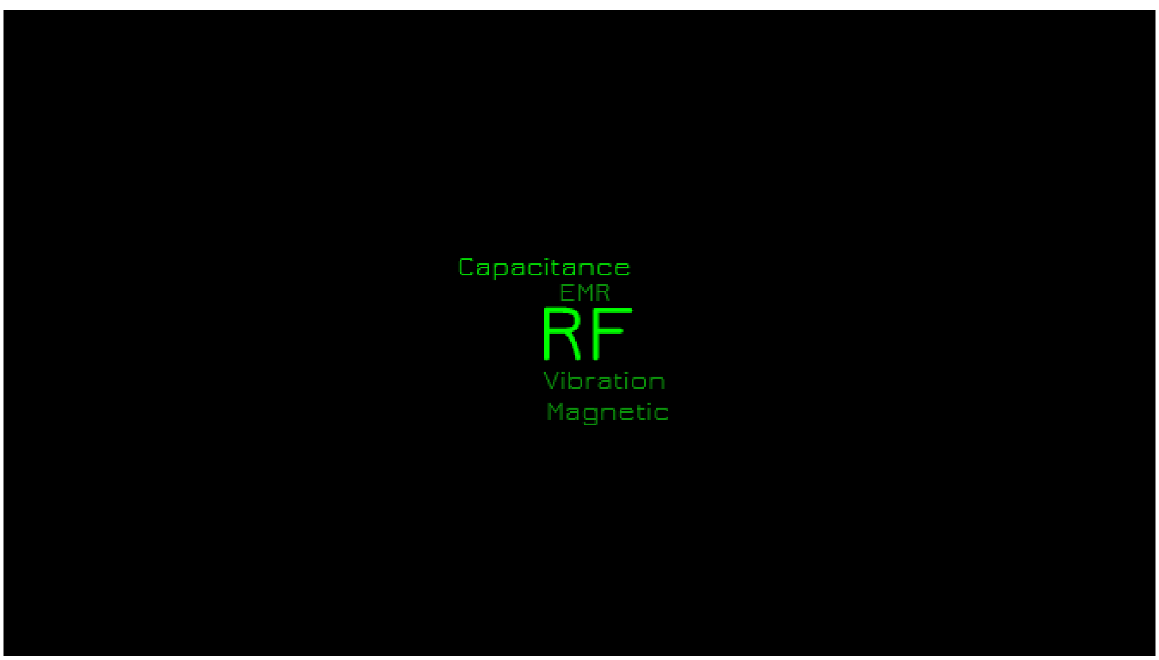


Figure 104

Word Cloud for Scenario 14 Hazards Selected by Expert Panelists



Scenario 15 - Active-Infrared Sensor Violation Counter

Figure 105

Word Cloud for Scenario 15 Components Selected by Participants

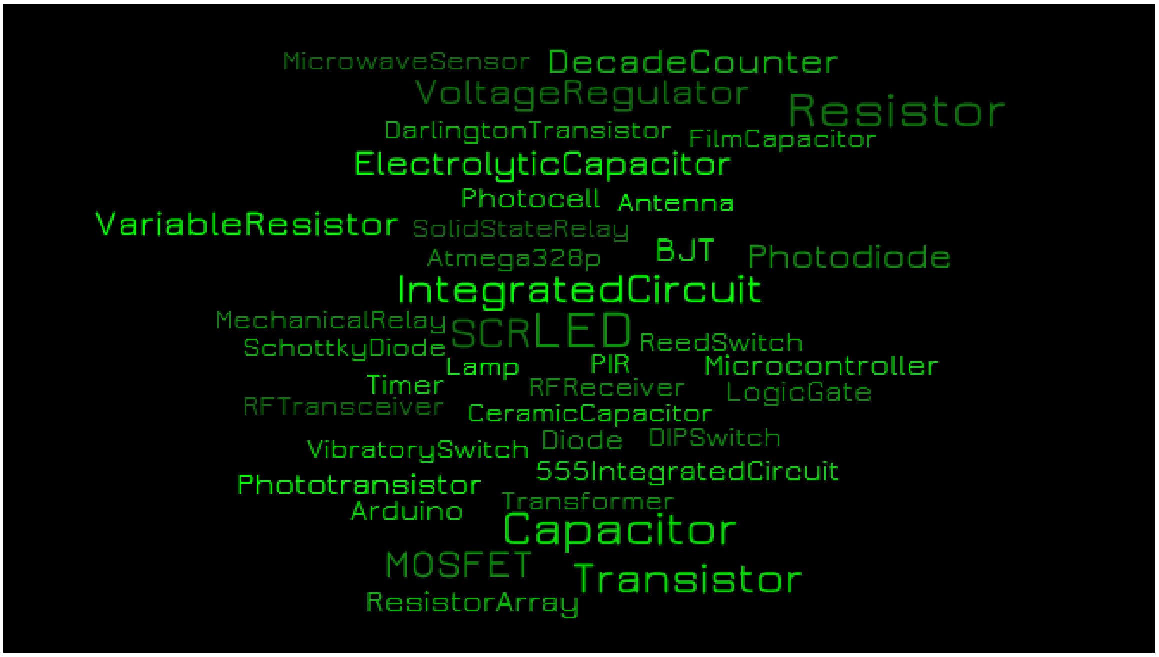


Figure 106

Word Cloud for Scenario 15 Components Selected by Expert Panelists

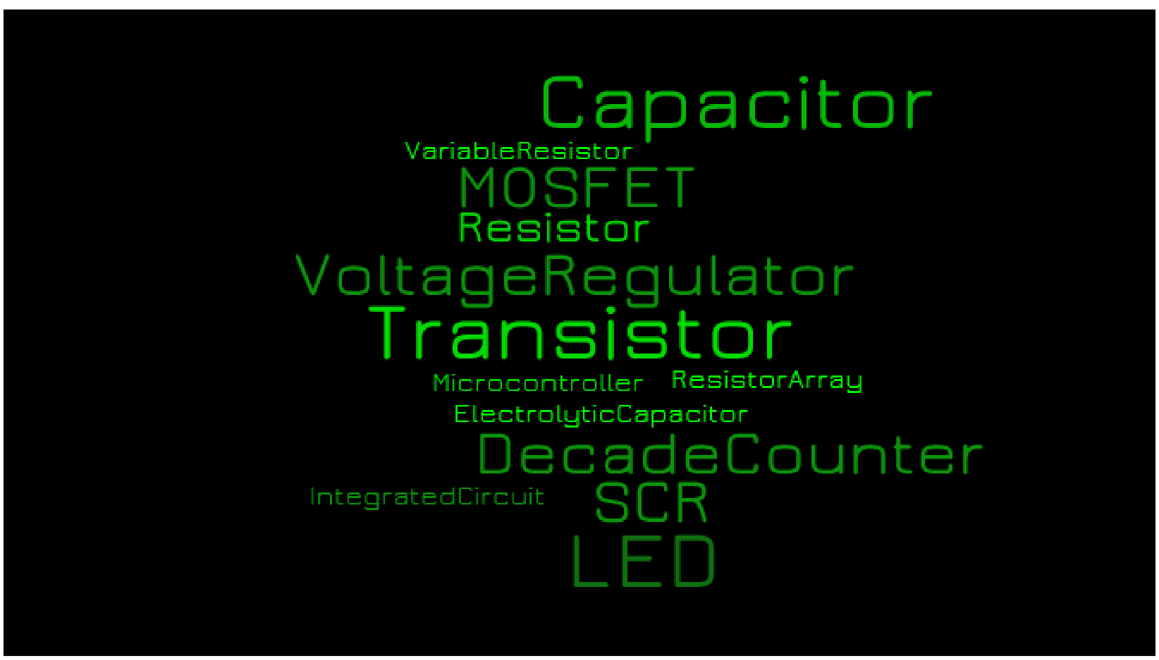


Figure 107

Word Cloud for Scenario 15 Hazards Selected by Participants

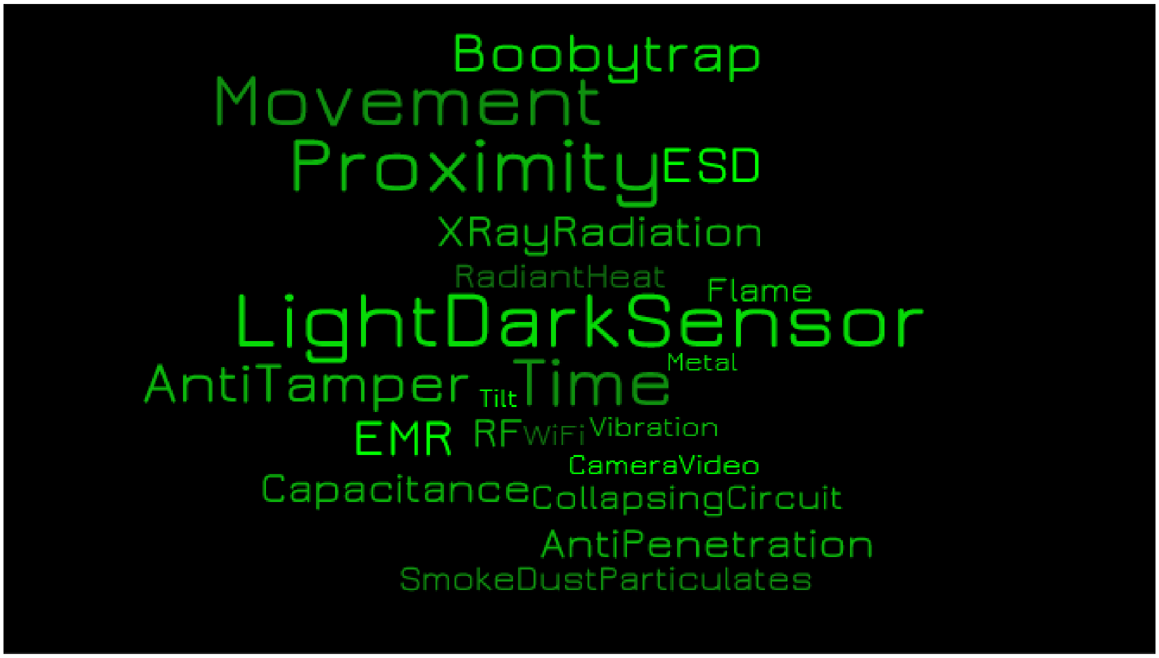


Figure 108

Word Cloud for Scenario 15 Hazards Selected by Expert Panelists

Scenario 16 - Wire Disconnect Circuit

Figure 109

Word Cloud for Scenario 16 Components Selected by Participants

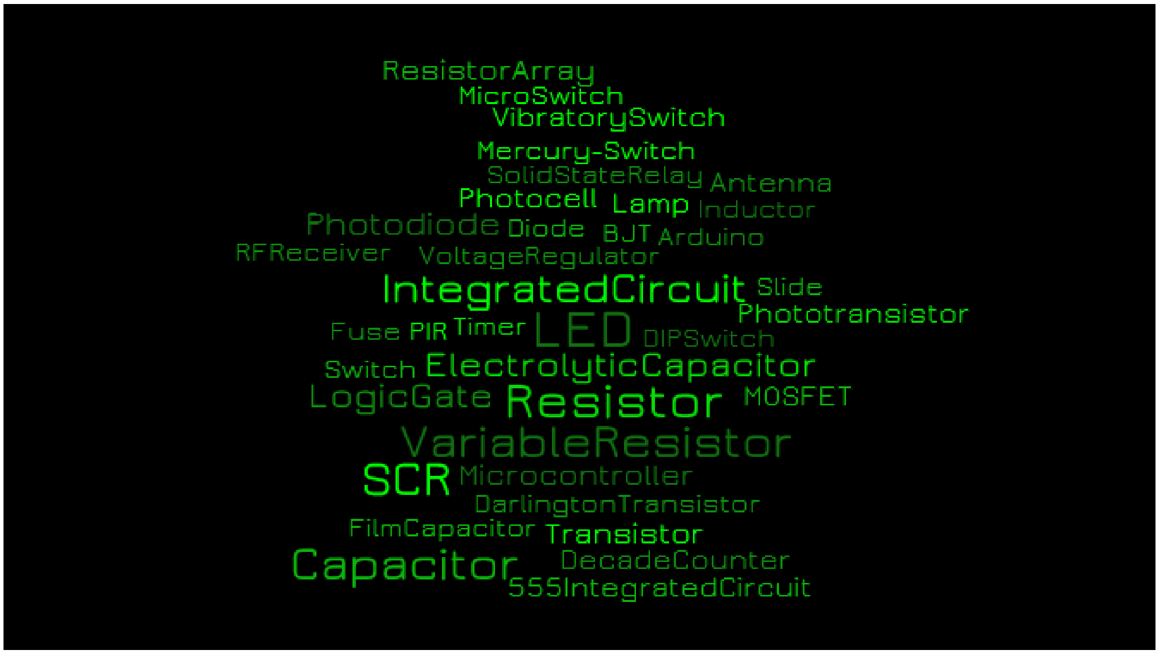


Figure 110

Word Cloud for Scenario 16 Components Selected by Expert Panelists

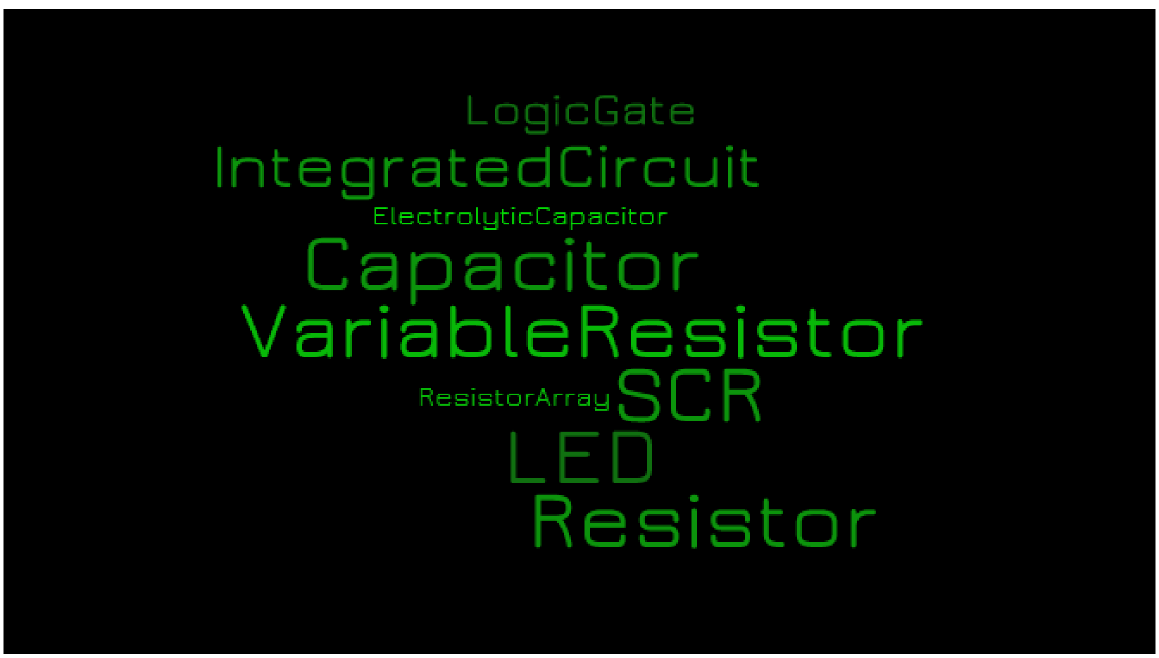


Figure 111

Word Cloud for Scenario 16 Hazards Selected by Participants

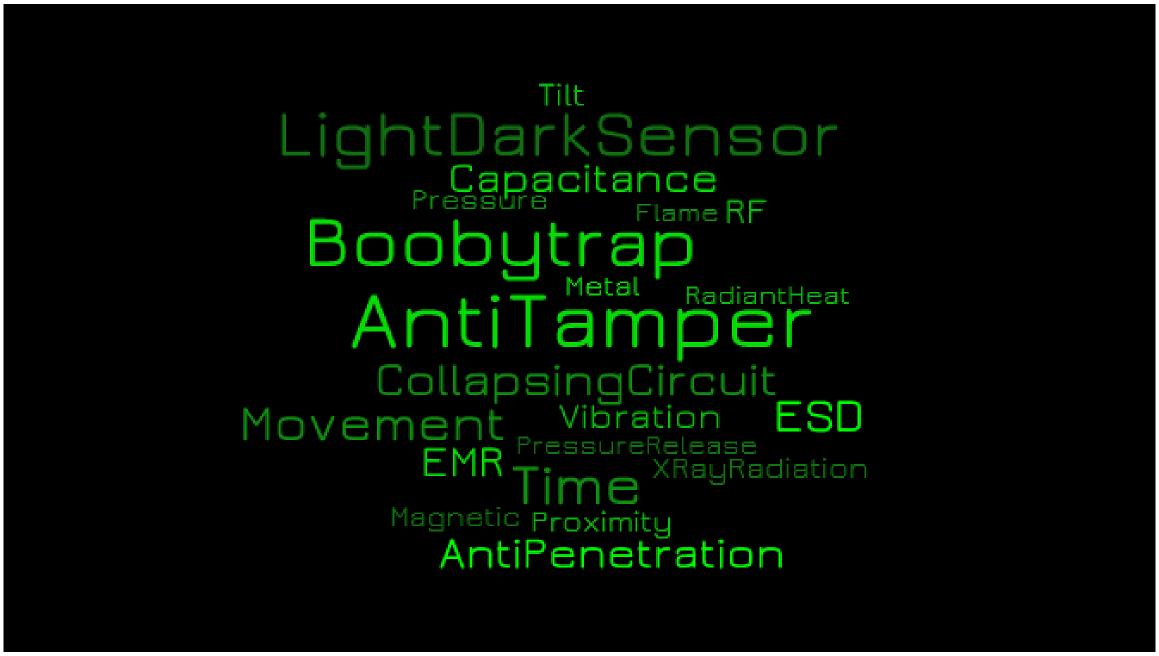


Figure 112

Word Cloud for Scenario 16 Hazards Selected by Expert Panelists

Scenario 17 - Nano 33 BLE Sense Microwave Sensor Circuit

Figure 113

Word Cloud for Scenario 17 Components Selected by Participants

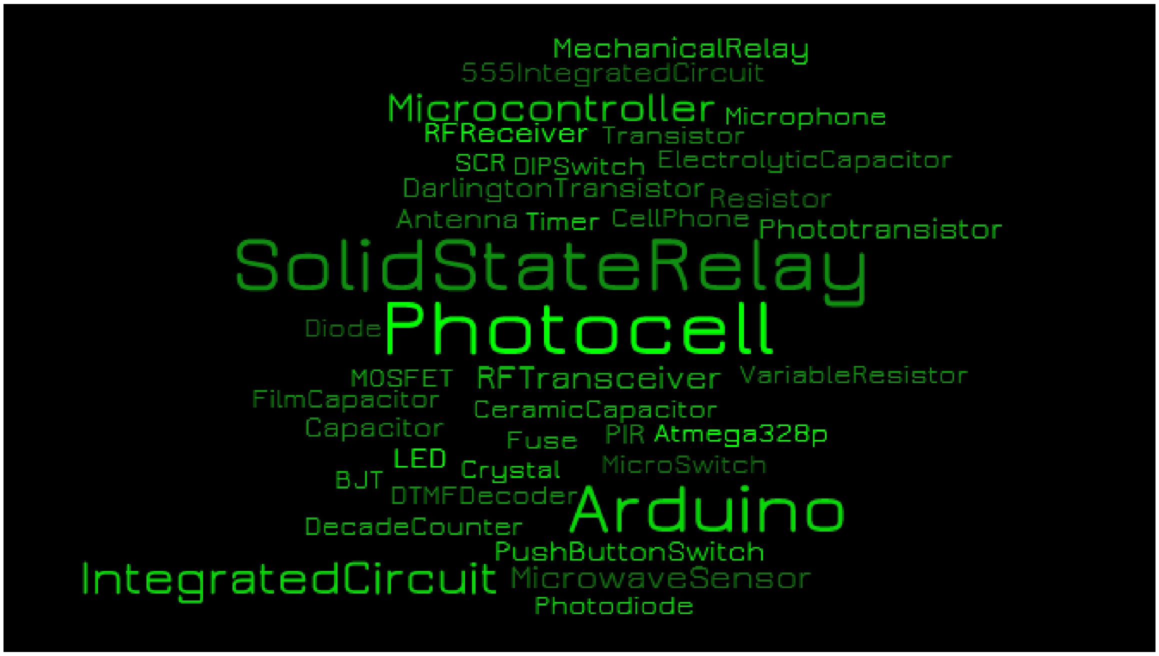


Figure 114

Word Cloud for Scenario 17 Components Selected by Expert Panelists

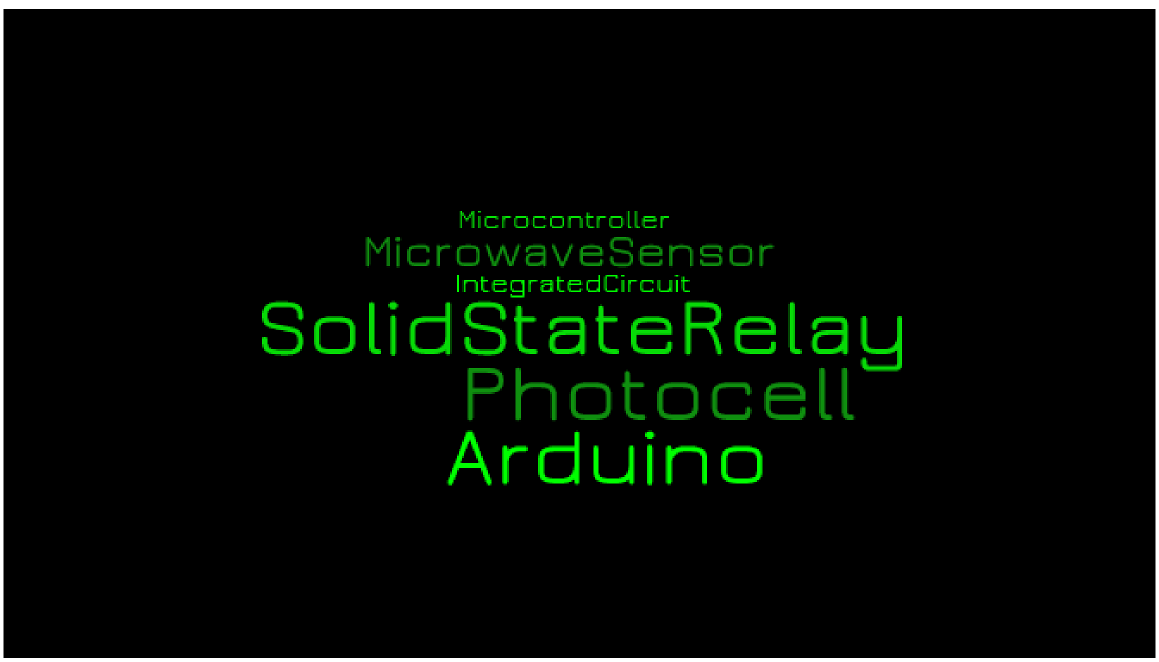


Figure 115

Word Cloud for Scenario 17 Hazards Selected by Participants

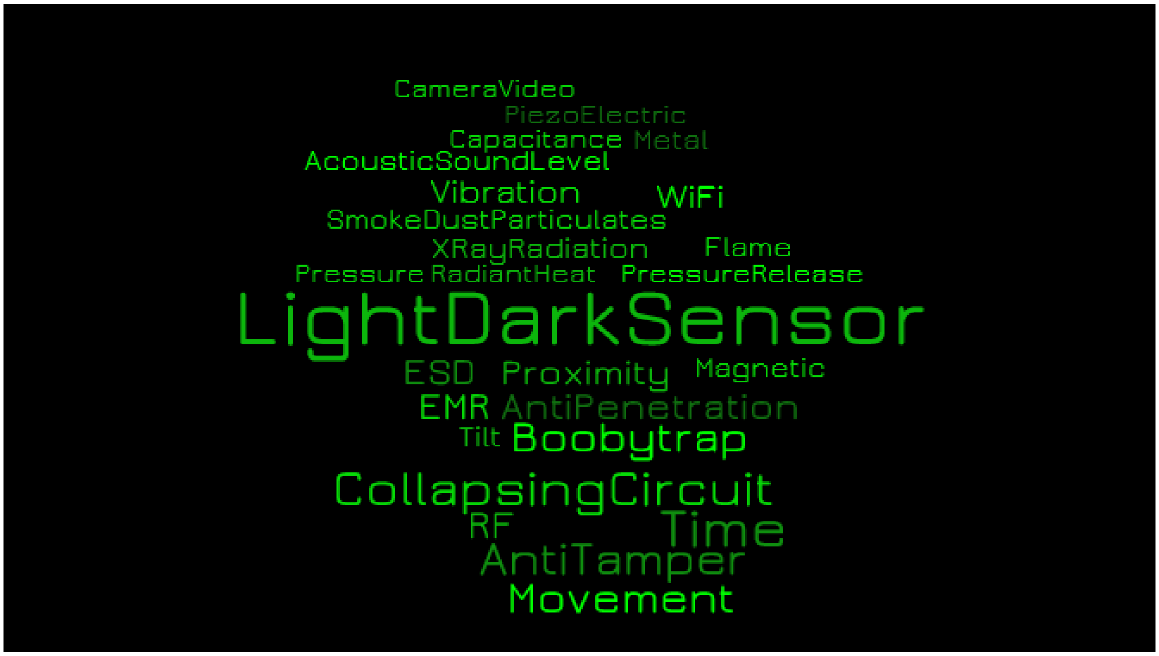
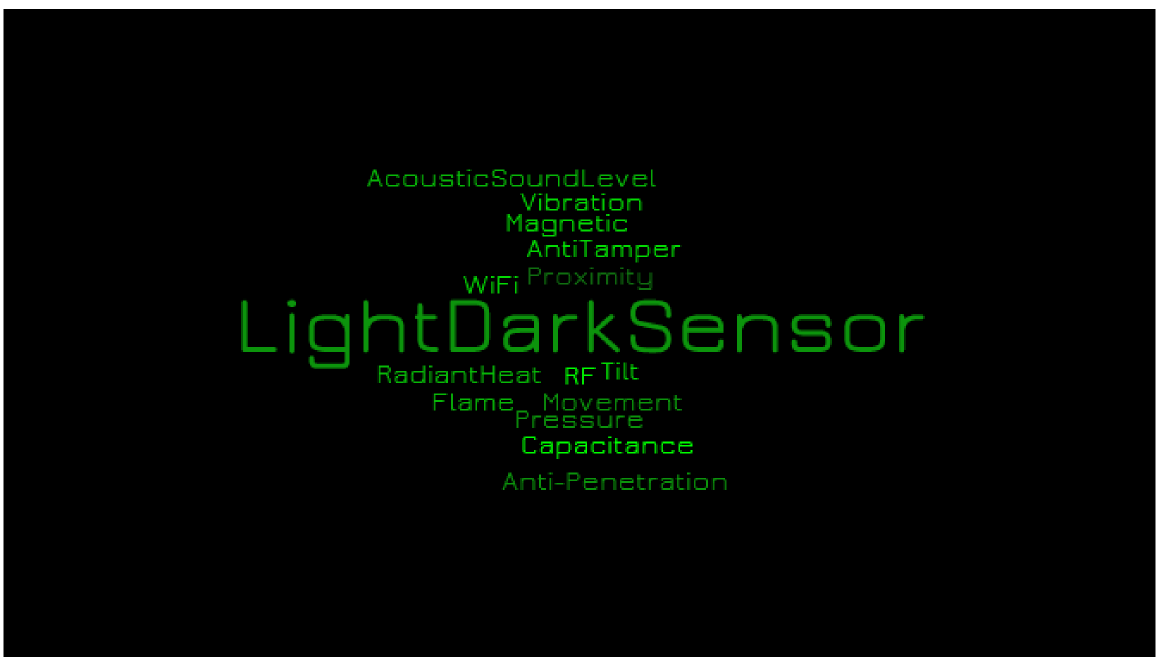


Figure 116

Word Cloud for Scenario 17 Hazards Selected by Expert Panelists



Self-Assessed Confidence Levels

There are probably few practitioners in the bomb disposal community who would argue that self-confidence is not important while performing bomb disposal operations; however, these same practitioners are likely to agree that overconfidence can be fatal. It is important to realize however, that there is a difference between the self-confidence to act in the face of danger, and self-confidence in decisions made. In the former, confidence is the ability to turn thought into action, and in the later, it is one's strength of belief that a decision made was the correct one. It is entirely possible to have the self-confidence to act, even though one believes the decision to act was in fact, the wrong one. These two forms of confidence should not be confused.

Data from this study suggests that most bomb technicians routinely over-rate their own ability to perform component identification, hazard assessments, and type-by-function determination, regardless of years of experience, bomb disposal school attended, military or public safety affiliation, and education level. This may suggest, as other researchers into diagnostic error have identified, that these errors are not caused by gaps in knowledge, but various forms of bias. Table 82-84 compares success rates to confidence levels.

Table 82

Self-Assessed Confidence Levels for Component Identification

	Success Rate	Confidence Level
Practice Scenario	1%	76%
Scenario 1	36%	87%
Scenario 2	36%	83%
Scenario 3	53%	87%
Scenario 4	26%	84%
Scenario 5	34%	83%
Scenario 6	5%	79%
Scenario 7	43%	78%
Scenario 8	26%	85%
Scenario 9	28%	82%
Scenario 10	30%	81%
Scenario 11	0%	70%
Scenario 12	4%	70%
Scenario 13	6%	78%
Scenario 14	15%	79%
Scenario 15	1%	72%
Scenario 16	13%	69%
Scenario 17	3%	75%

Table 83

Self-Assessed Confidence Levels for Associated Hazards

	Success Rate	Confidence Level
Practice Scenario	4%	75%
Scenario 1	50%	86%
Scenario 2	68%	86%
Scenario 3	51%	84%
Scenario 4	1%	77%
Scenario 5	39%	76%
Scenario 6	11%	72%
Scenario 7	1%	74%
Scenario 8	50%	84%
Scenario 9	0%	80%
Scenario 10	2%	76%
Scenario 11	2%	68%
Scenario 12	18%	70%
Scenario 13	1%	73%
Scenario 14	29%	75%
Scenario 15	4%	69%
Scenario 16	1%	64%
Scenario 17	0%	73%

Table 84

Self-Assessed Confidence Levels for Circuit Type-By-Function

	Success Rate	Confidence Level
Practice Scenario	52%	79%
Scenario 1	75%	89%
Scenario 2	89%	88%
Scenario 3	18%	85%
Scenario 4	24%	75%
Scenario 5	72%	76%
Scenario 6	35%	77%
Scenario 7	38%	75%
Scenario 8	83%	85%
Scenario 9	49%	82%
Scenario 10	54%	80%
Scenario 11	54%	71%
Scenario 12	37%	72%
Scenario 13	40%	73%
Scenario 14	49%	76%
Scenario 15	53%	71%
Scenario 16	58%	67%
Scenario 17	36%	74%

Identification of Diagnostic Reasoning Approaches

As Croskerry (2014) posits, Type 1 decision-making, "is where we make most of our decisions in the course of our daily affairs." This type of decision-making is often associated with accomplishing activities or actions mindlessly, meaning that the actions or activities being conducted have become second-nature. Type 2 decision-making on the other hand, is analytical thinking, and is a conscious activity. Anyone undertaking Type 2 decision-making is usually aware that they are undertaking the process, because Type 2 decision-making is a resource intensive activity (Croskerry, 2014).

An important note here however, is that Type 1 and Type 2 decision-making are not competing, but complimentary processes. According to Croskerry (2014), individuals may spend as much as 95% of their time in a Type 1 mode, and only undertake Type 2 decision-making or thinking when faced with new information or situations. This does not imply however, that one type of thinking is better or more productive than another, because Type 1 thinking can easily fail the user, and as Croskerry (2014) also notes, "There are occasions too when analytical reasoning may not be appropriate e.g., in an emergency where a very fast response is required," so living in a Type 2 decision mode can problematic. As Croskerry (2014) states,

> *A dichotomy certainly exists in the sense that there are two distinct ways in which people arrive at decisions, but it is false to say that human decision-making has to be one or the other…The beauty of the human mind is that it can toggle between the two systems and select which mode is most appropriate to the task at hand….*

Because it is possible to use both Type 1 and Type 2 thinking during the diagnostic process, an analysis of participant data divided results into percentage of Type 1, Type 2, and a combined approach. Tables 85 and 86, as well as Figures 81 and 82, show average and cumulative diagnostic reasoning approaches used by study participants for associated hazards and circuit types-by-function. As an average of the approach rates across all scenarios seems to suggest, bomb technicians participating in this study used Type 1 thinking approximately 90% of the time during their analysis.

Table 85

Average Diagnostic Reasoning Approaches Used by Scenario for Associated Hazards

	Established Success Rate	Type 1 Approach	Type 2 Approach	Combined Approach
Scenario 1	50%	76%	14%	10%
Scenario 2	68%	89%	9%	2%
Scenario 3	2%	95%	3%	2%
Scenario 4	1%	90%	9%	1%
Scenario 5	39%	93%	6%	1%
Scenario 6	11%	92%	4%	4%
Scenario 7	1%	91%	6%	3%
Scenario 8	50%	96%	1%	3%
Scenario 9	0%	85%	6%	9%
Scenario 10	2%	91%	7%	2%
Scenario 11	2%	94%	1%	5%
Scenario 12	18%	95%	1%	4%
Scenario 13	1%	87%	9%	4%
Scenario 14	29%	94%	5%	1%
Scenario 15	4%	93%	4%	3%
Scenario 16	1%	82%	11%	7%
Scenario 17	0%	96%	1%	3%

Figure 117

Cumulative Diagnostic Reasoning Approach Rates Used for Associated Hazards

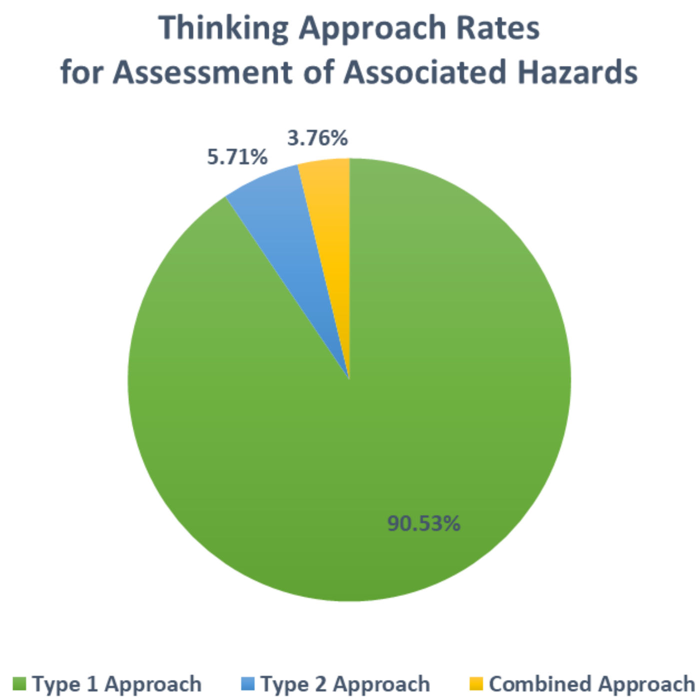


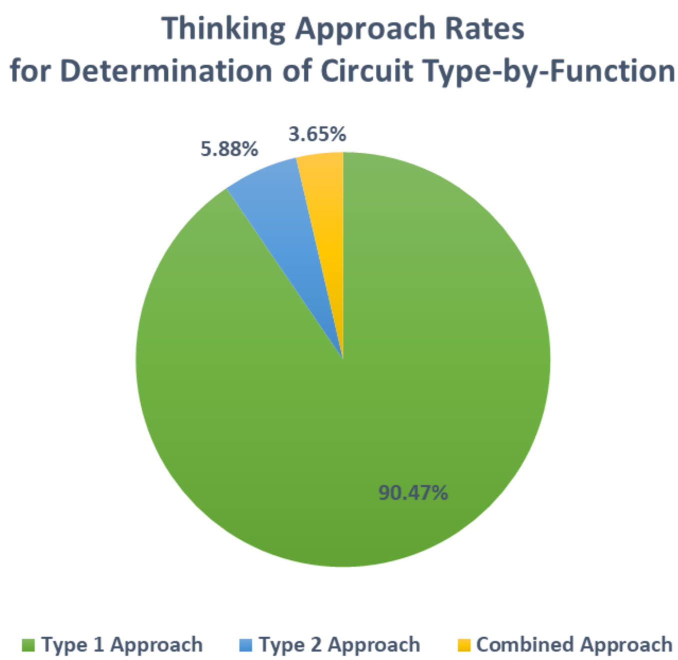
Table 86

Average Diagnostic Reasoning Approaches Used by Scenario for Circuit Type-By-Function

	Established Success Rate	Type 1 Approach	Type 2 Approach	Combined Approach
Scenario 1	75%	77%	16%	7%
Scenario 2	89%	88%	10%	2%
Scenario 3	18%	92%	5%	3%
Scenario 4	24%	87%	8%	5%
Scenario 5	72%	98%	1%	1%
Scenario 6	35%	91%	4%	5%
Scenario 7	38%	94%	4%	2%
Scenario 8	83%	94%	2%	4%
Scenario 9	49%	89%	5%	6%
Scenario 10	54%	97%	3%	0%
Scenario 11	54%	92%	3%	5%
Scenario 12	37%	88%	8%	4%
Scenario 13	40%	89%	3%	8%
Scenario 14	49%	91%	7%	2%
Scenario 15	53%	93%	3%	4%
Scenario 16	58%	86%	11%	3%
Scenario 17	36%	92%	7%	1%

Figure 118

Cumulative Diagnostic Reasoning Approach Rates Used for Circuit Type-By-Function



Driving Factors for Associated Hazards and Circuit Types-by-Function

Data regarding driving factors, or what drove participant selections, was collected as narratives in free-text fields, and analyzed using QDA Miner. The main function of QDA Miner is to allow researchers to assign codes to selected text segments of research material, and then analyze these codes. For this study, Driving Factor narratives were analyzed for patterns, such as participant analysis of components based on generic or specific component identification, or the use of specific tools or procedures. These were then added to QDA Miner as "codes" for narrative analysis. While individual driving factor percentages are shown for individual scenarios in Tables 87-121, cumulative data suggests that component identification and circuit configurations were the predominant drivers of hazard assessment and type-by-function determination (Table 87).

Table 87

Cumulative Count of Driving Factors

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	2186	20.50%	201	88.20%
	Generic Component	4802	45.10%	200	87.70%
Configurations	Specific Configuration	2413	22.70%	166	72.80%
	Generic Configuration	331	3.10%	110	48.20%
Conditions	Specific Condition	749	7.00%	123	53.90%
	Generic Condition	111	1.00%	60	26.30%
Procedures	Render Safe	23	0.20%	8	3.50%
	Disposal	1	0.00%	1	0.40%
	Tools	20	0.20%	4	1.80%
	Techniques	6	0.10%	5	2.20%

Table 88

Practice Scenario Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	173	39.40%	130	57.00%
	Generic Component	101	23.00%	67	29.40%
Configurations	Specific Configuration	96	21.90%	55	24.10%
	Generic Configuration	20	4.60%	18	7.90%
Conditions	Specific Condition	28	6.40%	21	9.20%
	Generic Condition	18	4.10%	15	6.60%
Procedures	Render Safe	1	0.20%	1	0.40%
	Disposal	1	0.20%	1	0.40%
	Tools	1	0.20%	1	0.40%

Table 89

Practice Scenario Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	194	41.30%	133	58.30%
	Generic Component	136	28.90%	85	37.30%
Configurations	Specific Configuration	80	17.00%	45	19.70%
	Generic Configuration	13	2.80%	13	5.70%
Conditions	Specific Condition	37	7.90%	24	10.50%
	Generic Condition	8	1.70%	7	3.10%
Procedures	Render Safe	2	0.40%	1	0.40%
	Disposal	-	-	-	-
	Tools	-	-	-	-

Table 90

Scenario 1 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	201	69.30%	143	62.70%
	Generic Component	29	10.00%	26	11.40%
Configurations	Specific Configuration	54	18.60%	49	21.50%
	Generic Configuration	-	-	-	-
Conditions	Specific Condition	5	1.70%	5	2.20%
	Generic Condition	-	-	-	-
Procedures	Render Safe	-	-	-	-
	Disposal	-	-	-	-
	Tools	1	0.30%	1	0.40%

Table 91

Scenario 1 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	187	61.50%	139	61.00%
	Generic Component	8	2.60%	8	3.50%
Configurations	Specific Configuration	58	19.10%	33	14.50%
	Generic Configuration	-	-	-	-
Conditions	Specific Condition	-	-	-	-
	Generic Condition	51	16.80%	41	18.00%
Procedures	Render Safe	-	-	-	-
	Disposal	-	-	-	-
	Tools	-	-	-	-

Table 92

Scenario 2 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	42	17.90%	40	17.50%
	Generic Component	171	72.80%	126	55.30%
Configurations	Specific Configuration	7	3.00%	7	3.10%
	Generic Configuration	-	-	-	-
Conditions	Specific Condition	15	6.40%	11	4.80%
	Generic Condition	-	-	-	-
Procedures	Render Safe	-	-	-	-
	Disposal	-	-	-	-
	Tools	-	-	-	-

Table 93

Scenario 2 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	3	1.20%	3	1.30%
	Generic Component	230	91.30%	157	68.90%
Configurations	Specific Configuration	11	4.40%	10	4.40%
	Generic Configuration	-	-	-	-
Conditions	Specific Condition	8	3.20%	7	3.10%
	Generic Condition	-	-	-	-
Procedures	Render Safe	-	-	-	-
	Disposal	-	-	-	-
	Tools	-	-	-	-

Table 94

Scenario 3 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	36	12.80%	30	13.20%
	Generic Component	101	35.80%	98	43.00%
Configurations	Specific Configuration	97	34.40%	66	28.90%
	Generic Configuration	-	-	-	-
Conditions	Specific Condition	46	16.30%	35	15.40%
	Generic Condition	-	-	-	-
Procedures	Render Safe	-	-	-	-
	Disposal	-	-	-	-
	Tools	2	0.70%	1	0.40%

Table 95

Scenario 3 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	30	11.10%	23	10.10%
	Generic Component	97	35.80%	92	40.40%
Configurations	Specific Configuration	111	41.00%	65	28.50%
	Generic Configuration	-	-	-	-
Conditions	Specific Condition	33	12.20%	27	11.80%
	Generic Condition	-	-	-	-
Procedures	Render Safe	-	-	-	-
	Disposal	-	-	-	-
	Tools	-	-	-	-

Table 96

Scenario 4 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	23	7.70%	23	10.10%
	Generic Component	187	62.50%	109	47.80%
Configurations	Specific Configuration	84	28.10%	56	24.60%
	Generic Configuration	-	-	-	-
Conditions	Specific Condition	4	1.30%	4	1.80%
	Generic Condition	-	-	-	-
Procedures	Render Safe	-	-	-	-
	Disposal	-	-	-	-
	Tools	1	0.30%	1	0.40%

Table 97

Scenario 4 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	27	8.00%	21	9.20%
	Generic Component	218	64.70%	121	53.10%
Configurations	Specific Configuration	84	24.90%	51	22.40%
	Generic Configuration	-	-	-	-
Conditions	Specific Condition	8	2.40%	7	3.10%
	Generic Condition	-	-	-	-
Procedures	Render Safe	-	-	-	-
	Disposal	-	-	-	-
	Tools	-	-	-	-

Table 98

Scenario 5 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	101	36.30%	82	36.00%
	Generic Component	98	35.30%	61	26.80%
Configurations	Specific Configuration	67	24.10%	42	18.40%
	Generic Configuration	3	1.10%	3	1.30%
Conditions	Specific Condition	7	2.50%	7	3.10%
	Generic Condition	-	-	-	-
Procedures	Render Safe	1	0.40%	1	0.40%
	Disposal	-	-	-	-
	Tools	1	0.40%	1	0.40%

Table 99

Scenario 5 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	98	32.10%	86	37.70%
	Generic Component	134	43.90%	76	33.30%
Configurations	Specific Configuration	68	22.30%	47	20.60%
	Generic Configuration	-	-	-	-
Conditions	Specific Condition	5	1.60%	5	2.20%
	Generic Condition	-	-	-	-
Procedures	Render Safe	-	-	-	-
	Disposal	-	-	-	-
	Tools	-	-	-	-

Table 100

Scenario 6 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	44	10.90%	29	12.70%
	Generic Component	194	48.30%	103	45.20%
Configurations	Specific Configuration	117	29.10%	48	21.10%
	Generic Configuration	23	5.70%	21	9.20%
Conditions	Specific Condition	17	4.20%	14	6.10%
	Generic Condition	3	0.70%	3	1.30%
Procedures	Render Safe	-	-	-	-
	Disposal	-	-	-	-
	Tools	2	0.50%	2	0.90%
	Techniques	2	0.50%	1	0.40%

Note: A Technique*s line was added to this table, and the table below, because of a response that contained specific techniques to counter RCIED use.*

Table 101

Scenario 6 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	38	9.70%	29	12.70%
	Generic Component	160	40.70%	80	35.10%
Configurations	Specific Configuration	113	28.80%	46	20.20%
	Generic Configuration	64	16.30%	59	25.90%
Conditions	Specific Condition	11	2.80%	9	3.90%
	Generic Condition	6	1.50%	5	2.20%
Procedures	Render Safe	-	-	-	-
	Disposal	-	-	-	-
	Tools	1	0.30%	1	0.40%

Table 102

Scenario 7 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	21	6.60%	16	7.00%
	Generic Component	166	52.20%	88	38.60%
Configurations	Specific Configuration	91	28.60%	55	24.10%
	Generic Configuration	16	5.00%	16	7.00%
Conditions	Specific Condition	23	7.20%	17	7.50%
	Generic Condition	-	-	-	-
Procedures	Render Safe	-	-	-	-
	Disposal	-	-	-	-
	Tools	1	0.30%	1	0.40%

Table 103

Scenario 7 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	15	4.50%	12	5.30%
	Generic Component	183	55.50%	100	43.90%
Configurations	Specific Configuration	86	26.10%	51	22.40%
	Generic Configuration	8	2.40%	8	3.50%
Conditions	Specific Condition	37	11.20%	28	12.30%
	Generic Condition	-	-	-	-
Procedures	Render Safe	1	0.30%	1	0.40%
	Disposal	-	-	-	-
	Tools	-	-	-	-

Table 104

Scenario 8 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	24	13.30%	23	10.10%
	Generic Component	103	56.90%	77	33.80%
Configurations	Specific Configuration	28	15.50%	20	8.80%
	Generic Configuration	4	2.20%	4	1.80%
Conditions	Specific Condition	21	11.60%	18	7.90%
	Generic Condition	-	-	-	-
Procedures	Render Safe	-	-	-	-
	Disposal	-	-	-	-
	Tools	1	0.60%	1	0.40%

Table 105

Scenario 8 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	28	13.10%	28	12.30%
	Generic Component	112	52.30%	88	38.60%
Configurations	Specific Configuration	44	20.60%	31	13.60%
	Generic Configuration	9	4.20%	9	3.90%
Conditions	Specific Condition	18	8.40%	17	7.50%
	Generic Condition	-	-	-	-
Procedures	Render Safe	3	1.40%	1	0.40%
	Disposal	-	-	-	-
	Tools	-	-	-	-

Table 106

Scenario 9 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	114	31.40%	82	36.00%
	Generic Component	99	27.30%	66	28.90%
Configurations	Specific Configuration	72	19.80%	42	18.40%
	Generic Configuration	12	3.30%	12	5.30%
Conditions	Specific Condition	63	17.40%	33	14.50%
	Generic Condition	1	0.30%	1	0.40%
Procedures	Render Safe	1	0.30%	1	0.40%
	Disposal	-	-	-	-
	Tools	-	-	-	-
	Techniques	1	0.30%	1	0.40%

Note: A Techniques *line was added to this table, and the table below, because of a response that contained specific techniques to counter activation of the PIR sensor.*

Table 107

Scenario 9 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	105	33.30%	84	36.80%
	Generic Component	100	31.70%	68	29.80%
Configurations	Specific Configuration	73	23.20%	45	19.70%
	Generic Configuration	7	2.20%	7	3.10%
Conditions	Specific Condition	26	8.30%	16	7.00%
	Generic Condition	-	-	-	-
Procedures	Render Safe	3	1.00%	3	1.30%
	Disposal	-	-	-	-
	Tools	-	-	-	-
	Techniques	1	0.30%	1	0.40%

Table 108

Scenario 10 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	91	35.00%	73	32.00%
	Generic Component	75	28.80%	53	23.20%
Configurations	Specific Configuration	60	23.10%	31	13.60%
	Generic Configuration	9	3.50%	7	3.10%
Conditions	Specific Condition	23	8.80%	18	7.90%
	Generic Condition	-	-	-	-
Procedures	Render Safe	-	-	-	-
	Disposal	-	-	-	-
	Tools	-	-	-	-
	Techniques	2	0.80%	2	0.90%

Note: A techniques line was added to this table because of responses that contained techniques to counter activation of the ultrasonic sensor.

Table 109

Scenario 10 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	86	31.60%	75	32.90%
	Generic Component	87	32.00%	63	27.60%
Configurations	Specific Configuration	65	23.90%	41	18.00%
	Generic Configuration	13	4.80%	11	4.80%
Conditions	Specific Condition	20	7.40%	18	7.90%
	Generic Condition	-	-	-	-
Procedures	Render Safe	1	0.40%	1	0.40%
	Disposal	-	-	-	-
	Tools	-	-	-	-

Table 110

Scenario 11 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	45	19.20%	42	18.40%
	Generic Component	135	57.70%	69	30.30%
Configurations	Specific Configuration	34	14.50%	19	8.30%
	Generic Configuration	12	5.10%	12	5.30%
Conditions	Specific Condition	7	3.00%	6	2.60%
	Generic Condition	-	-	-	-
Procedures	Tools	1	0.40%	1	0.40%
	Disposal	-	-	-	-
	Render Safe	-	-	-	-

Table 111

Scenario 11 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	48	16.60%	42	18.40%
	Generic Component	157	54.30%	80	35.10%
Configurations	Specific Configuration	46	15.90%	30	13.20%
	Generic Configuration	17	5.90%	15	6.60%
Conditions	Specific Condition	20	6.90%	11	4.80%
	Generic Condition	-	-	-	-
Procedures	Tools	-	-	-	-
	Disposal	-	-	-	-
	Render Safe	1	0.30%	1	0.40%

Table 112

Scenario 12 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	27	9.60%	22	9.60%
	Generic Component	156	55.70%	80	35.10%
Configurations	Specific Configuration	63	22.50%	37	16.20%
	Generic Configuration	24	8.60%	20	8.80%
Conditions	Specific Condition	6	2.10%	6	2.60%
	Generic Condition	3	1.10%	2	0.90%
Procedures	Tools	1	0.40%	1	0.40%
	Disposal	-	-	-	-
	Render Safe	-	-	-	-

Table 113

Scenario 12 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	37	11.70%	26	11.40%
	Generic Component	176	55.50%	85	37.30%
Configurations	Specific Configuration	67	21.10%	39	17.10%
	Generic Configuration	17	5.40%	13	5.70%
Conditions	Specific Condition	14	4.40%	11	4.80%
	Generic Condition	2	0.60%	1	0.40%
Procedures	Tools	2	0.60%	2	0.90%
	Disposal	-	-	-	-
	Render Safe	2	0.60%	2	0.90%

Table 114

Scenario 13 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	23	8.40%	17	7.50%
	Generic Component	150	54.50%	71	31.10%
Configurations	Specific Configuration	67	24.40%	38	16.70%
	Generic Configuration	6	2.20%	5	2.20%
Conditions	Specific Condition	26	9.50%	20	8.80%
	Generic Condition	2	0.70%	1	0.40%
Procedures	Tools	1	0.40%	1	0.40%
	Disposal	-	-	-	-
	Render Safe	-	-	-	-

Table 115

Scenario 13 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	27	10.00%	18	7.90%
	Generic Component	162	59.80%	82	36.00%
Configurations	Specific Configuration	62	22.90%	32	14.00%
	Generic Configuration	8	3.00%	7	3.10%
Conditions	Specific Condition	9	3.30%	9	3.90%
	Generic Condition	2	0.70%	2	0.90%
Procedures	Tools	-	-	-	-
	Disposal	-	-	-	-
	Render Safe	1	0.40%	1	0.40%

Table 116

Scenario 14 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component	27	10.70%	22	9.60%
	Generic Component	146	57.70%	77	33.80%
Configurations	Specific Configuration	58	22.90%	31	13.60%
	Generic Configuration	3	1.20%	3	1.30%
Conditions	Specific Condition	18	7.10%	15	6.60%
	Generic Condition	-	-	-	-
Procedures	Tools	1	0.40%	1	0.40%
	Disposal	-	-	-	-
	Render Safe	-	-	-	-

Table 117

Scenario 14 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Component		20	7.70%	15
	Generic Component		159	60.90%	83
Configurations	Specific Configuration		63	24.10%	30
	Generic Configuration		5	1.90%	5
Conditions	Specific Condition		13	5.00%	10
	Generic Condition		-	-	-
Procedures	Tools		-	-	-
	Disposal		-	-	-
	Render Safe		1	0.40%	1

Table 118

Scenario 15 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Components	62	25.80%	44	19.30%
	Generic Components	98	40.80%	43	18.90%
Configurations	Specific Configuration	63	26.30%	36	15.80%
	Generic Configuration	2	0.80%	2	0.90%
Conditions	Specific Condition	14	5.80%	8	3.50%
	Generic Condition				
Procedures	Tools	1	0.40%	1	0.40%
	Disposal	-	-	-	-
	Render Safe	-	-	-	-

Table 119

Scenario 15 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Components	68	26.80%	49	21.50%
	Generic Components	86	33.90%	41	18.00%
Configurations	Specific Configuration	73	28.70%	36	15.80%
	Generic Configuration	2	0.80%	2	0.90%
Conditions	Specific Condition	22	8.70%	17	7.50%
	Generic Condition	1	0.40%	1	0.40%
Procedures	Tools	-	-	-	-
	Disposal	-	-	-	-
	Render Safe	2	0.80%	2	0.90%

Table 120

Scenario 16 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Components	26	7.90%	22	9.60%
	Generic Components	164	49.50%	65	28.50%
Configurations	Specific Configuration	76	23.00%	36	15.80%
	Generic Configuration	4	1.20%	4	1.80%
Conditions	Specific Condition	59	17.80%	35	15.40%
	Generic Condition	1	0.30%	1	0.40%
Procedures	Tools	1	0.30%	1	0.40%
	Disposal	-	-	-	-
	Render Safe	-	-	-	-

Table 121

Scenario 16 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Components	25	9.80%	22	9.60%
	Generic Components	139	54.30%	70	30.70%
Configurations	Specific Configuration	59	23.00%	35	15.40%
	Generic Configuration	6	2.30%	5	2.20%
Conditions	Specific Condition	22	8.60%	15	6.60%
	Generic Condition	3	1.20%	2	0.90%
Procedures	Tools	-	-	-	-
	Disposal	-	-	-	-
	Render Safe	2	0.80%	2	0.90%

Table 122

Scenario 17 Driving Factors for Associated Hazards

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Components	42	14.40%	23	10.10%
Components	Generic Components	149	51.00%	78	34.20%
Configurations	Specific Configuration	66	22.60%	34	14.90%
Configurations	Generic Configuration	8	2.70%	8	3.50%
Conditions	Specific Condition	26	8.90%	13	5.70%
Conditions	Generic Condition	1	0.30%	1	0.40%
Procedures	Tools	-	-	-	-
Procedures	Disposal	-	-	-	-
Procedures	Render Safe	-	-	-	-

Table 123

Scenario 17 Driving Factors for Circuit Type-By-Function

Category	Code	Count	% Codes	Cases	% Cases
Components	Specific Components	28	10.00%	19	8.30%
Components	Generic Components	136	48.70%	78	34.20%
Configurations	Specific Configuration	50	17.90%	31	13.60%
Configurations	Generic Configuration	16	5.70%	14	6.10%
Conditions	Specific Condition	38	13.60%	24	10.50%
Conditions	Generic Condition	9	3.20%	8	3.50%
Procedures	Tools	1	0.40%	1	0.40%
Procedures	Disposal	-	-	-	-
Procedures	Render Safe	1	0.40%	1	0.40%

To summarize the qualitative data findings, study participants primarily used Type 1 decision-making in their analysis, and focused on component identification and circuit configurations in determining hazards associated with devices, and circuit type(s)-by-function. Additionally, a visual analysis of component and hazard selections using word-clouds clearly suggests that bomb technicians key in on specific components, and these components drive their analysis. Self-assessed confidence-level data also suggests that study participants significantly over-rated their ability to recognize components, assess hazards, and determine circuit type(s)-by-function.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The human brain is a complex organ with the wonderful power of enabling man to find reasons for continuing to believe whatever it is that he wants to believe.

– Voltaire

Having been a member of the bomb disposal community for some 40 years, first as a bomb technician, then as a trainer, and finally managing advanced technology development efforts for bomb disposal, it is hard not to take a more ethnographic approach to analyzing the findings of this study. Regardless depth and breadth of experience, this author was somewhat taken aback by the results of this study. However, as this author's first Committee Chair for a Ph.D. in Education advised, "Wait until your final chapter to express your opinions regarding the results of your study, because nobody cares about your opinion until they have reviewed the findings for themselves." (Dr. Rodrick Simms, Personal communication, 2006)

This author has tried to abide by that admonishment, so the final chapter of this study will not only be a summary of the findings, but this author's attempt to "make sense" of those findings, and put forth recommendations for their use. This dissertation will then conclude with other suggested research related to diagnostic reasoning and success rates in bomb disposal, as well as other topics related to curiosities identified throughout this study.

It is probably worth stating up front that this researcher was not initially considering investigating diagnostic reasoning approaches, as a label, when thinking about research topics. Instead, problem-solving or decision-making approaches was the topics under consideration; however, literature regarding bomb disposal and problem-solving, or bomb disposal and decision-making, were almost nonexistent. Even though a few researchers have looked into cognitive aspects of bomb disposal (e.g., Cooper, 1982; Hogan and Hogan, 1989; Rachman, 1990; van Wijk and Waters, 2001), it appeared that most researchers are more interested in bomb disposal robots and other technologies, than the cognitive aspects of bomb disposal, or bomb technicians themselves. As a result, for this author to find examples of appropriate research methodologies, it necessitated looking at how other communities study problem-solving and decision-making.

Having previously researched cognition in the military Explosive Ordnance Disposal (EOD) community, this author was aware of work done in the Special Operations community looking into cognition with respect to assessment and selection of Special Forces soldiers (e.g., Pleban, et al., 1988; Marquis, 2011; Picano, Williams, and Roland, 2012; Dodd, 2016). Studies into these types of soldiers seemed good candidates to for consideration, given that many special operations forces are trained in demolitions, demining, emergency medicine, chemical and biological warfare, sabotage techniques, and counter-IED operations. In addition, the special operations community has other similarities to the bomb disposal community, in that work conducted by special operations service members, whether Army, Air Force, Navy, or Marine Corps, require mastery of a disparate variety of skills, and working not only in austere environments, but under stressful conditions. Again however, no literature, at least available to the public, was found that was dedicated to assessing problem-solving strategies in the special operations community.

Fighter pilots were then considered, as this author thought they might be good candidates for problem-solving studies. It seemed a rational assumption that psychologists and military leaders would be interested in reducing the number of crashes that resulted from pilot error, and learning why a pilot's problem-solving skills might fail them during critical situations. Additionally, this researcher thought it might be a good idea to look at racecar drivers for similar reasons. Yet again, researchers, or at least those funding them, were more interested in recruitment and training of these individuals, than problem-solving or decision-making (McGlohn, et al., 1996; Meško, et al., 2013; Wang, et al., 2020).

By this point, it became clear that problem-solving and decision-making in communities that might parallel bomb disposal, and by extension cognitive research into its practitioners, was scant in the scholarly literature. This is not to say that such research does not exist, but in conducting an extensive search, with the help of information specialists at several university libraries, and through resources like Google Scholar, none were found. This resulted in this researcher having to start looking further afield for communities that might have developed programs to improve problem-solving and decision-making in their practitioners.

It seemed prudent at this point to take as broad an approach as possible in search of an appropriate community of practice. Interestingly, one of the first publications this researcher found, and the one that eventually led to the medical communities' examination of diagnostic reasoning as a suitable comparator to bomb disposal, was Holland's article, A Psychological Classification Scheme for Vocations and Major Fields (Holland, 1966). In this article, Holland discusses test instruments like Kubie's *Preconscious Activity Scale*, a *Range of Competencies* questionnaire, Foote and Cottrell's *Interpersonal Competency Scale*, and Rokeach's *Dogmatism Scale*, which measures "dogmatic and rigid thinking."

As the reader may have surmised, these seem to be some of the earlier instruments used to measure general problem-solving approaches, with the use of most of these instruments dating back to the mid-1950s (Holland 1966). A great deal of earlier literature also appeared to focus on how novices and experts process information differently, and as a result, make decisions differently. As expressed by Shanteau (1987), "experts are perceived as different from nonexperts in some potentially important ways. Experts are often seen as having an aura or mystique not possessed by others." Yet the author goes on to suggest that, at the time, experts were thought to be, "cognitively limited decision makers." The author also suggests that in addition to the categories of *expert* and *novice*, a third should be added, labeled as *naive decision makers*. To this researcher, and someone who is intimately familiar with the bomb disposal community, this seemed an appropriate label, even though not used during the current study.

Shanteau's article (Shanteau 1987) put this researcher on a path of looking at the medical community and their approach to diagnostic reasoning. In his article, the author suggests there may be a fallacy to expertise, noting that one-third of *experts* involved in his study, misjudged samples, and that these same judges graded samples differently when judged a second time. The author also identified several other studies, such as those conducted by Goldberg (1959), Trumbo (1962), and Einhom (1974), that investigated heuristics and bias in decision-making. Each of these suggesting that experts are often unaware of their own shortcomings. This seemed particularly true for medical doctors, which prompted this researcher to look further into decision-making (i.e., diagnostic reasoning) research in the medical community.

Finally, this researcher wants to remind the reader that his use of the medical community is not based solely on the belief that there are similarities between the medical and bomb disposal disciplines from a cognitive perspective, but rather, that the medical community offers a wealth of information on decision-making and problem-solving, as well as methodologies for conducting research into decision-making. According to Yazdani and Abardeh (2019), the medical community has been investigating diagnostic reasoning since the 1980s, but even after undertaking several decades of research, "Clinical reasoning is a challenging, promising, complex, multidimensional, mostly invisible, and poorly understood process." This feeling may very well be, on some subconscious and visceral level, why this author was drawn to diagnostic reasoning as an analog for research into the bomb disposal community, since this statement also typifies the bomb disposal profession as this author has experienced it.

General Conclusions

In addition to being a current or former bomb technician, the "typical" participant in this study was from the United States, and works in the public safety sector (i.e., not a military bomb technician). The average participant had 1-5 years of bomb disposal experience, attended initial bomb disposal training at the FBI's Hazardous Devices School, and spent approximately 8 weeks in initial training as a bomb technician. In addition, the average participant rated themselves as having an "Intermediate" knowledge level regarding IED electronics, has had specialized training in the subject, but has had no "formal" education or training in electronics, meaning they had not taken vocational or other academic electronics courses, even though they did have a bachelor's degree or some college. The typical participant also had no experience training other bomb technicians on IED electronics.

It was assumed in this study that approaches used to study diagnostic reasoning in the medical community would have similar usefulness in the bomb disposal community, and that the data collection instrument used for this study, was capable of capturing information relevant to the diagnostic reasoning approaches used by individual bomb technicians. It was also assumed that the circuits used in this study are representative of those that could be encountered by bomb technicians in the field, and an expert panel was used to validate these circuits.

With respect to study participants, it was assumed that terms used in this study for components, hazards, and circuit types-by-function, were similar enough internationally, that a non-American English-speaking bomb technician from another country would be able to recognize the terms used. Because participation in this study was voluntary, it was assumed that bomb technicians who have a personal interest in IED electronics would constitute the majority of participants in the study, and that participants completed the scenarios without assistance from fellow bomb technicians or subject matter experts.

Quantitatively, the average success rates for study participants, by independent variable, showed no statistically significant differences, except for participants who attended very specific bomb disposal schools for their initial training, and only for circuit type(s)-by-function determination. The data suggests that no other variables assessed had any effect on a bomb technician's ability to successfully perform component identification, assessment of associated hazards, and determination of circuit type(s)-by-function. Average success rates for study participants were 20% for component identification; 16% for associated hazards; and 51% for circuit type-by-function.

Qualitatively, study participants primarily used Type 1 decision-making (i.e., pattern matching) for their diagnostic reasoning approach, and focused on component identification and circuit configurations in determining hazards associated with devices, and the circuit type(s)-by-function. Additionally, a visual analysis of component and hazard selections using word-clouds clearly suggests that bomb technicians key in on specific components, and these components drive their analysis. Self-assessed confidence-level data also suggests that study participants significantly over-rated their ability to recognize components, assess hazards, and determine circuit type(s)-by-function.

It is worth reminding the reader that these are broad characterizations of the findings, with some respondents fairing significantly better on some circuits than others. Conversely however, there were participants that did very poorly across the spectrum. This is to say that before generalizations are made based on this study's findings, it is incumbent on the individual doing the analysis to review all of the data presented in this report, rather than taking the above summary as conclusive.

Circuits and Success Rates

While improvised explosive devices (IED) existed before the age of electronics, IEDs in the pre-electronics era commonly were simple creations, using a trail of black powder or burning time-fuse to initiate an explosive- or incendiary-filled device. These crude firing trains could be ignited with either a common match, or black powder impregnated or filled igniter, meaning that most devices were either *Command*, or *Time* type-by-function, even though the occasional *Victim Operated* device might have been constructed. Regardless of the ignition system however, it is safe to say that the vast majority of homemade bombs (i.e., IEDs) were mechanically initiated rather than electronically initiated, at least up to the late 1950s or early 1960s, simply because batteries up to that time were not particularly reliable, nor could they be easily transported and concealed because of their size. Additionally, while electronic components were used in industry, they were not commonly available to hobbyists, with the earliest available components being offered through companies like Heath, which offered kits to build audio and radio equipment. Publications like Popular Electronics were also not available until the mid-1950s, so information on how to build electronic circuits was not readily available through any channels other than formal education and training, either by academic institutions, trade schools, or the military.

Today however, the availability of electronic components, and information about how to assemble these components into functioning circuits capable of initiating an IED, is staggering. Today it is possible to order electronic components from parts distributors or drop-shippers from all over the world, and have them delivered to your doorstep in days at almost trivial expense. To put this in perspective, the first hobbyist electronic kit offered by Heath in 1947 was an oscilloscope, costing approximately USD $50, or just over the equivalent of USD $600 today. A quick internet search at the time of this writing – February 2023 – identified numerous oscilloscope kits for sale to amateur hobbyists for less than USD $10.

Additionally, information for building electronic circuits is readily available, with not only literally thousands of videos being available online to walk hobbyists through a build, but K-12 education programs now exist to teach children basic electronics using systems from companies like LEGO and Arduino. This author's own daughter works for just such an after-school education company, that offers electronics and robotics programs for K-12 students throughout New York and New Jersey.

All of this is to say that if children and hobbyists have access today to this type of instructional material, as well as the ability to purchase components so easily, then so do potential bomb builders. Projecting this slightly into the future, if the children of today have such ready access to courses that teach them how to build electronic devices using programmable circuits and sensor modules, then it only stands to reason that the devices bomb technicians will encounter in the future are likely to be significantly more complex than the simple devices they encounter today. This would suggest, by extension, that there is a growing need for bomb technicians to recognize and understand the functioning of more-and-more complex components, as well as circuits that can be built from those components, as they become readily available to hobbyists and K-12 education programs through the global market.

In short, if the firing system of an IED only consisted of a battery and an electric blasting cap, then the only items of concern to the bomb technician, and the only ones that a bomb technician would need to be able to identify, or have a functional understanding of, and familiarity with, are electric blasting caps and batteries, ignoring of course the explosive or incendiary load, which may have physical characteristics that make them sensitive to initiation by electrostatic discharge (ESD) or other influences. Along those same lines, if all render safe procedures only required the bomb technician to either remove a battery or blasting cap manually by cutting it out, or removing it dynamically with an explosive or percussion actuated tool, then there would be no need for understanding any electronics other than the simple circuit configurations involved in connecting the battery to the initiator.

Extending this thought process logically forward however, it is easy to see that rather than all devices being *Command* detonated, where the bomber has only to create a simple circuit with a battery connected to an electric initiator, bombers have an almost infinite number of circuits variations available for *Command*, *Time,* or *Victim Operated* initiation, simply through the addition of what is almost universally called a *switch* in the bomb disposal field. In reality however, switches are usually just an electronic circuit of some varying level of complexity. By placing one extra thing (i.e., a switch) into a device's firing train, the bomber has added another level of complexity, and one that might make it impossible for a bomb technician to simply cut out, or otherwise dynamically remove a battery, or electric initiator.

To explain this further, regardless of whether a switch is considered simple or complex, the circuit will usually contain at least some relatively common components, meaning components like resistors, diodes, capacitors, and transistors; or even at a slightly higher level, integrated circuits, which are in reality tiny individually packaged circuits unto themselves. Specific components have certain effects in the circuit, with components like resistors impeding the flow of electrical current, diodes only allowing current to flow in a given direction, and transistors acting as tiny switches unto themselves (Scherz and Monk, 2013).

Specific components placed in combination and in a specific pattern in a circuit, produce specific conditions within that circuit based on the flow of electricity to those combinations. For example, two resistors can be placed in a simple, yet specific configuration known as a *voltage divider*, where the output voltage from that configuration is a fraction of the input voltage (Platt, 2012). Another example, and one that might seemingly be more pertinent to bomb disposal at first approximation, is the *Resistor/Capacitor*, or *RC circuit*. This should not be confused with an *RC device*, where in the U.S., at least to the larger bomb technician community, this stands for a *Remote/Remotely* or *Radio Controlled* device. With respect to circuits, an RC circuit can be used for a number of functions, but the one most widely recognized in the bomb disposal field is to place a resistor in-line with a capacitor to restrict the flow of electricity into that capacitor in such a way that it takes a specific amount of time to charge the capacitor, depending on the size of the resistor and capacitor, and the voltage of the power source (Whitaker, 2018). By knowing these factors, you can calculate, with a relatively high degree of accuracy, how long it will take the capacitor to charge to a desired voltage.

By recognizing what the configuration of an RC circuit looks like, even if used inside another circuit, a bomb technician should be alerted to the fact that the circuit being viewed is potentially a timed device. However, if the resistor/capacitor combination is not configured in this way, or the capacitor is used in conjunction with a different component, the effect produced could be totally different, and the bomb technician could be faced with a collapsing circuit that uses a capacitor in place of the second battery, which is the configuration commonly used in a *classic* collapsing circuit. Although both of these are very recognizable configurations, if a bomb technician has never been exposed to one or both of these types of circuits, it is unlikely they will recognize them, or understand the hazards that they present, or how they might impact a planned RSP.

Initial certification and training of new bomb technicians usually focuses on the types of devices that it's expected graduates will see in the field, so a question that is often asked is, "Do bomb technician need to be able to recognize components and circuits beyond those they are likely to encounter?" In this author's opinion, the answer is probably "No" if you are certain the devices you will encounter over the span of your career will never be more sophisticated than those taught to you during your initial training and certification, and/or you will never be required to formulate a render safe procedure for a more complex or sophisticated device.

Since in the U.S. almost all render safe procedures are conducted remotely, usually by dynamically tearing the device apart either with a disruptor or robotically, the contention is that even more sophisticated devices do not warrant detailed analysis before disruption. Where this approach becomes problematic however, is when a device is encountered that, either because of location, target, or device construction, a dynamic render safe procedure cannot be used. In such instances, where a bomb technician may be called to manually render safe a device, it would probably behoove the bomb technician to be able to recognize components and circuits beyond the “basics,” and understand the ramifications for relevant component configurations. While a bomb technician can be the best in the world at calculating circuit speeds, or doing cap diagnostics, it is still possible to suffer a catastrophic failure during a render safe procedure if the bomb technician does not recognize that these “advanced,” or “specialized” techniques will simply not work on some types of circuits.

It would be disingenuous to think however, that bomb technicians depend solely on information learned during initial training and certification, or that some do not attempt to educate themselves and their fellow bomb technicians on potential threats, components, and circuitry. In addition to self-education, there are both formal and informal mechanisms in place to bolster the knowledge and skill of bomb technicians, in both the public safety and military sectors, on electronics. Unfortunately, there is little “required” training in place, and no real means to address disparities in access to advanced or professional development training on the public safety side, even though there are a dearth of courses and training opportunities available from state and federal organizations, as well as associations, academia, and commercial entities.

The numbers and types of components and circuits taught to bomb technicians during initial training vary from country-to-country and school-to-school. In some countries, the IED electronics training during initial certification is longer than the entire initial bomb technician certification course of others. In the U.S., the FBI and bomb squad commanders, through the National Bomb Squad Commander’s Advisory Board (NBSCAB) publishes an annual document titled, Guidelines for Bomb Squads (U.S. Department of Justice, 2023), hereafter referred to as the Guidelines. This document is intended to "set the standard for professionalism and safety" for the public safety bomb technician (PSBT) community, and "sets forth standards for individual certification of PSBTs and accreditation of Public Safety Bomb Squads (PSBS) operating within US public safety agencies." Included in this document is a section titled the Special Program Area Annex, which focuses on specialty programs identified as warranting "advanced training and certification beyond the traditional PSBT certification requirements" (U.S. Department of Justice, 2023).

Interestingly, this document states, "It is noted that the scope of responsibility for every PSBT includes response to all hazardous devices, as set forth in this doctrine, regardless if they fall under one of these special program areas" (U.S. Department of Justice, 2023). According to the Guidelines, a "competent PSBT" will be "trained and proficient in" tasks such as:

- Investigating and rendering safe "suspected hazardous device(s), explosives, explosive materials, pyrotechnics, and ammunition"
- Investigating, and performing diagnostics and "potential render safe operations in chemical, biological, radiological, nuclear, and explosive (CBRNE) events"
- Conducting post-blast investigations
- Provide "technical support" to special operations
- "Prepare and participate in explosive related training programs"
- Prepare and report "technical data" to the Bomb and Arson Tracking System (BATS)

As the reader may have noted, this is an extensive list, even though it is not an all-inclusive list of things required, just for a PSBT to be "competent." And how are PSBTs supposed to accomplish this? According to the Guidelines (U.S. Department of Justice, 2023), a PSBT will go through the HDS Bomb Technician Recertification Course every three years, and “Complete a minimum of 288-hours per year of practical exercise/training at the unit level for sustainment of basic skills.” The Guidelines also requires that a PSBT completes “a minimum of 40-hours of additional external explosive related training, seminar, exercise, symposium, or conference annually.”

Given the list of tasks required for a PSBT to remain proficient, it is hard for this author to imagine how this is possible through what averages out to be 24 hours a month of unit-level training, and 40 hours of external training a year. In addition, given that training is usually funded internally through departments and agencies, and for 80% of PSBTs that being a bomb technician is a collateral duty (i.e., not a full-time job), dollars are short for improving the skills of PSBTs beyond what they may have learned during their initial certification course.

On the formal side of the house, both the FBI and ATF have professional development training related to a number of the Special Program Areas identified in the Guidelines. Many of these courses are provided at no-cost to a bomb squad, or an individual bomb technician, but time to attend such courses still falls on departments and agencies, so is less appealing than mandatory attendance courses like the Bomb Technician Certification and Bomb Technician Recertification courses. Other courses are made available via webinars and computer-based training, most of which will provide a certificate with numbers of contact hours included so bomb technicians can count these toward their requisite 288-hours of sustainment training.

Commercial courses are also available to teach specialized skills. Unfortunately, the number of courses that are available to military and public safety bomb technicians by commercial entities are far more numerous and diverse than many of those offered by federal entities. Because of their expense however, it is usually members of full-time or fiscally well-endowed squads who receive this training, creating an even greater stratification in knowledge levels within the PSBT community. Additionally, there is no control over what these companies are allowed to teach, nor are they held to a particular standard. This is not to say that the courses offered by any particular company are flawed or dangerous, just that there is no real oversight to ensure that curricula is accurate, or in keeping with the training being put out at official schools.

At this point it is worth stating that training is not the same thing as education, and bomb disposal is one of many professions where, upon graduation from initial *training*, students are conferred the status, at least to the uninitiated, of an expert in that field. Woodington (as cited in Saylor, Alexander, & Lewis, 1981) states that training should provide students with new knowledge and skills in order to *do a job*, *improve poor job performance*, or *develop specific competencies*. These are all functions that are attempted to be accomplished through *initial*, *recertification*, and *advanced bomb disposal training* programs. However, education may also be being accomplished, if we use Saylor's definition (Saylor et al, 1981), which states that education is "the acquisition of the art of the utilization of knowledge." This is supported by Schreiber and Berge (1998) who assert that *training* "responds to organizational processes and job functions," while *education* "aims at enriching and expanding the role of an individual within a profession or society." Schreiber and Berge also note that the focus of training is *performance outcomes*, while education focuses on the *acquisition and application of knowledge*.

Because there is a difference between training and education, it is important to recognize academic institutions like Oklahoma State University, Eastern Kentucky University, and the University of Rhode Island, just to name a few, who provide educational programs that afford bomb technicians an opportunity to advance themselves personally and professionally. Irrespective of how they are viewed by practitioners in that field, credentials, such as academic degrees, help provide legitimacy to a discipline. This is usually achieved by practitioners of that discipline participating in research-based and academic programs, where they help advance a body of knowledge relevant to that discipline. Even though participation in an academic program is likely most onerous on bomb technicians and their families with respect to time, money, and emotional energy, then it is to his or her employer, it is rare to find a bomb technician who has been through an academic program to say it was not worth the effort, or that it did not help them grow both personally and professionally. It is this author's sincere belief that current and former bomb technicians participating in academic programs, is the most essential and certain way to ensure the continued survivability and credibility of bomb disposal as a discipline.

How types and varieties of education and training available relate to this author's research into diagnostic reasoning approaches and success rates, is that a total of 18 circuits at varying levels of complexity were used in this study; some similar to those taught during initial training, and some that are likely to only have been learned during advanced training or education. Since, at least to the best of this author's knowledge, no two bomb disposal schools, educational institutions, or commercial courses teach exactly the same curricula with respect to IED electronics or circuitry, it is likely that few participants in this study have been exposed to all of the circuits or components used, necessitating the use of cognitive processes beyond simply recall.

The collection of 18 circuits used in this study were not selected at random, but were culled out of a collection of 52 circuits taken from various sources on IED electronics, and represent varying levels of complexity. The final list of circuits was selected by a panel of six IED subject matter experts (see Appendix E), all but one of which were bomb technicians, with the outlier being a well-recognized IED electronics expert with an advanced degree in electronics engineering, and years of experience conducting IED exploitation of devices from all over the world. Two of the panelists were non-U.S. bomb technicians, and were selected by this researcher to ensure that the final circuits used in the study represented devices that might be encountered in countries other than the U.S. The circuits selected by the panel ranged in levels of complexity from what the panelists classified as *Very Easy*, *Easy*, to *Difficult*, and *Very Difficult*.

With respect to complexity, the easiest of the circuits included in the study, and perhaps the most widely recognized circuit in the bomb disposal field, is a classic collapsing circuit, which consists of only three common electronic components, in addition to at least two power sources and the initiator. This circuit is part of every bomb technician's initial training that this researcher is familiar with. The number of components should not be used solely as a measure of complexity however, as many of the circuits in this study consisted of only four or five components, even though some of these components were less than common. Perhaps the most complex circuit included in the study, from a recognition and identification perspective, contained only four components other than a power source and initiator, but one of these components was a sophisticated, although inexpensive microcontroller-enabled hobbyist development board, and one of the other components a microwave sensor module. Even given this span of complexity, there were study participants that were able to identify almost all of the components in most circuits.

Somewhat surprisingly, where identification errors occurred for some participants was when they attempted to be overly specific in selecting a component type. For example, calling what might be referred to as a common diode (i.e., a rectifier diode), either a Zener diode or a Schottky diode, each of which has a unique construction, and different effects when used in a circuit. Even though these diodes can be used interchangeably in some circuits, depending on need, they are different diode types. Another example of this common type of error occurred with labeling what could simply have been called a *capacitor*, and incorrectly labeling it an *electrolytic*, *ceramic*, or *film capacitor*, when it was one of the other types.

Additionally, of the 18 circuits used in this study, it is not a stretch to say that at least half are seen at bomb technician initial certification and training courses in the U.S., and may have been constructed by students at these, or other courses. For example, *collapsing circuits* are usually constructed during electronics training at both the FBI's Hazardous Devices School (HDS), and Naval School Explosive Ordnance Disposal (NAVSCOLEOD). The same is true for circuits using a *digital timer* to activate a circuit, whether using a *transistor*, or *silicon-controlled rectifier* (SCR). Constructing *tilt switches* are also common at both schools, whether using a *ball* or *mercury switch*. As stated earlier, other types of circuits are used in bomb response scenarios at these schools, but types vary greatly depending on whether a bomb technician is attending HDS or

NAVSCOLEOD, simply because these two types of bomb technicians, while having some commonalities, usually conduct operations in different types of locations under different conditions. HDS graduates typically work domestically in urban environments, and usually encounter devices common to the domestic threat. NAVSCOLEOD graduates on the other hand, are trained for deployment to overseas locations, where they will face a regional, or more global threat, and operations might be conducted in either urban or rural environments, and potentially under fire from enemy weapons.

Both the FBI and NAVSCOLEOD provide advanced training in IED electronics to their graduates, as well as select international partners. While the *current* threat, or devices being seen most often domestically, or in the theater of operation where military bomb technicians are currently deployed, will greatly influence the types of devices trained on, these devices are usually relatively simple, unsophisticated devices, and are meant to familiarize trainees with how a given device functions. This functionality is usually conveyed to students through device type-by-function, or said another way, how the device is intended to be initiated by the bomber (i.e., *Time*, *Command*, or *Victim Operated*). Unfortunately, this same *Type-by-Function* approach is used during advanced training as well, which is why you often find bomb technicians during training exercises asking questions that might lead to establishing a type-by-function, rather than performing an analysis of the construction of the device.

Using a type-by-function approach reduces, or almost eliminates the necessity for, or cognitive burden associated with a full device analysis. In essence, what bomb technicians are taught to do is broad-category, device-type *recognition* (i.e., Type 1 thinking, or pattern matching), rather than being taught to conduct an assessment/analysis (i.e., Type 2 thinking) of the specific hazards being faced, based on the firing circuit/trigger/switch. This is not to say that a device type-by-function recognition approach is either good or bad, only that the first case leads to the broad use of general render safe techniques, with the latter likely leading to a device-specific render safe plan. By not *educating* bomb technicians on *component recognition*, *circuit construction*, *device principles-of-operation*, and *hazard analysis*, courses are unwittingly forcing bomb technicians to select *remote general disruption* as *the* default render safe procedure (RSP) of choice.

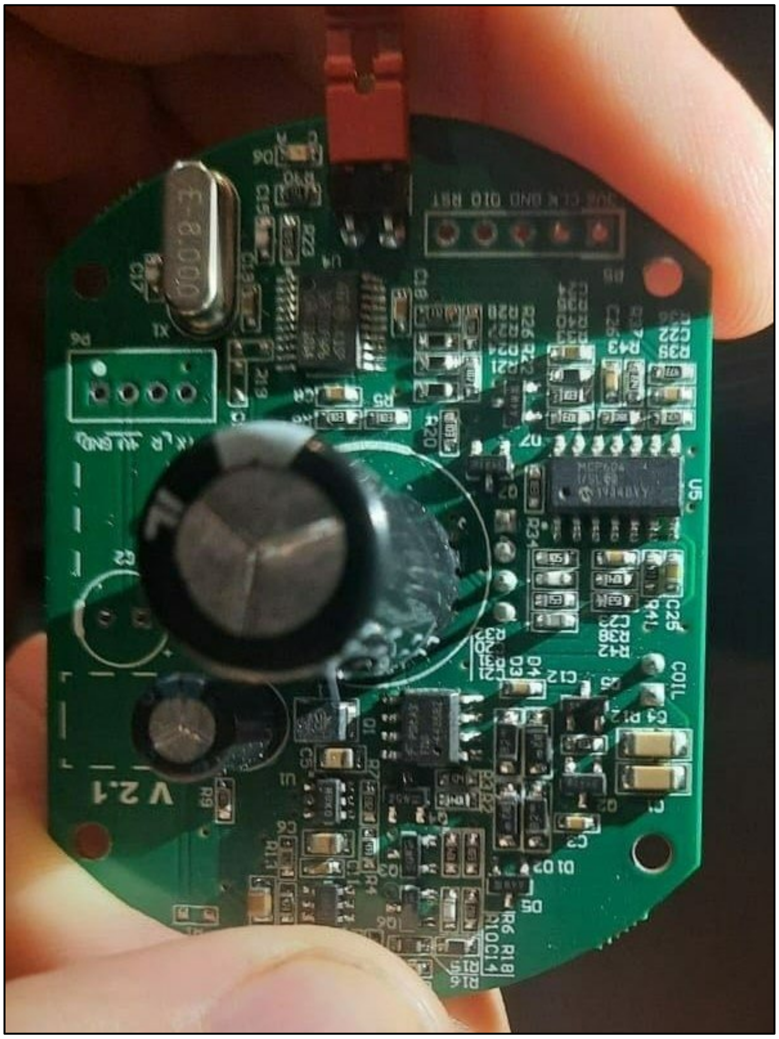
It will likely be argued by some in the bomb disposal field that *remote general disruption* should always be the RSP of choice, even though techniques like *grid-aim*, *precision disruption*, and *manual entry* seem to be highly prized skills among bomb technicians. These are considered *specialized* or *advanced* skills, and are generally only taught in *professional development* courses, where the focus is on specialized techniques to precisely target specific components, power sources, or initiators, and remove them from a device's firing train. The fact remains however, that certain types of components will function a device if the primary power source is removed, and switches exist that can make it almost impossible to disrupt them using the tools commonly available to bomb technicians. This author was admonished recently by a bomb technician, that he did not need to be worried about these "Hollywood" devices, even though realization of actions that cannot be taken on a circuit or device, is just as important as, if not more critical than, knowing those that can.

A lack of training on components and circuits ultimately also leads to inaccurate reporting, which in turn leads to incorrect threat analysis, and ultimately poorly targeted research and development efforts and training curricula. This author has personally reviewed reporting penned by bomb technicians domestically, where I/O ports are clearly visible on actual (i.e. explosively viable) devices that had been rendered safe, which suggests that a microcontroller, and/or microsensor was present, but no mention of a microcontroller or microsensor was made in the report. This further suggests that rather than there being a lack of sophisticated devices being made or used in the U.S., it is just as likely that our bomb technicians are simply not recognizing that they are being used. This lack of recognition can only be corrected by better education and training, even if only through self-study courses.

It seems prudent to add however, that there will also be cases where nothing short of device exploitation at an established laboratory like the Terrorist Explosive Device Analytical Center (TEDAC), will help a bomb technician identify a circuit or sensor module when they see it for the first time. A recent example of this appeared on Facebook, in a "bomb technician only" group. The poster was asking fellow technicians if they could help identify a recovered circuit (see Figure 119) from a device used in an ongoing conflict. Perhaps the most useful response, because it was not based on pure speculation, came from Russell Szczepaniec, a bomb technician who is well known for his electronics expertise. Russell stated, "Realistically, this is a threat assessment problem to figure out. Gone are the days of looking at circuits and having a reasonable chance of figuring them out. There is a coil and a unique shape to the board. Those are probably the best clues outside of application notes." (Quote used with author's permission)

Figure 119

Circuit Recovered from an Air-Dropped Improvised Device



Note: Image from Facebook post dated February 9th, 2023.

Problem-Solving and Decision-Making in Bomb Disposal

As defined by cognitive scientists, *diagnostic reasoning* is simply the process that individuals use when problem-solving (Flavell, 1976; Tversky and Kahneman, 1985). Although it may seem counterintuitive, research suggests that problem-solving approaches in the general sense, and strategies to achieve general problem-solving, in the broader sense, cannot be taught or learned through classroom instruction (Gaeth, 1980; Elstein, Shulman, and Sprafka, 1990; Mandin, Jones, Woloschuk, and Harasym, 1997; Coderre, Mandin, Harasym, and Fick, 2003). Additionally, research suggests that being able to solve problems in one area, does not guarantee being able to solve problems in another, nor are good general problem-solving skills an indicator of expertise (Post, 1979; Eva, 2003; Carol-Anne, Regehr, Mylopoulos, and MacRae, 2007; Masicampo and Baumeister, 2008). Similarly, results from this study suggest, that many individuals who self-assessed as experts, or who had attended advanced training courses, and/or had over 10 years of experience, were no better at diagnostic reasoning than novices (i.e., those with limited experience, no additional training, and self-assessed as novices).

In any complex domain, such as bomb disposal or medicine, expertise is not monolithic, and there will inevitably be specialization. In most disciplines, it is rare to find practitioners who perform at an expert level in all areas of that discipline. The literature also suggests that expert knowledge tends to be organized functionally, and in such a way to support specific reasoning tasks, rather than a single approach supporting all reasoning tasks. This is why performance differences can be seen between two individuals who are both called bomb technicians, but one is military, and the other public safety. While military bomb technicians, just like public safety bomb technicians, are responsible for rendering safe improvised explosive devices (IEDs), the conditions and locations in, and under which they perform this task may be very different. This creates functional differences, and therefore differences in reasoning strategies.

Additionally, within domains there may be sub-specialization, which is why one individual on a bomb squad may be thought of as the “expert” in electronics, or homemade/improvised explosives, or hazmat-related issues. Because of this, it is best to view expertise within complex domains as a continuum, where individuals exhibit different levels of performance in different sub-specializations. The practitioner who is commonly referred to as a *novice*, simply lacks the domain-specific knowledge and performance characteristics of the *expert*, who has mastered the same domain-specific tasks, and has reorganized the material in such a way as to make it readily accessible for use. In other words, the expert has undergone an evolution in knowledge structures that allows them to easily recognize characteristics and conditions within a problem-set, and can access that information in such a way that it allows them to solve a problem in that domain more quickly and efficiently than the non-expert (Chase and Simon, 1973; Larkin et al., 1980; and Chi, Feltovich, and Glaser, 1981).

Diagnostic Reasoning Approaches

Interestingly, in Section 3.2. of the *National Guidelines for Bomb Squads* (U.S. Department of Justice, 2023), it states,

> There is a significant correlation between psychological health/physical well-being and the successful performance as a PSBT…The *effective* PSBT is a risk taker:
>
> - Relies on calculation.
> - Assesses the unknown.
> - Innovates within organization rules based on experience and training.
>
> The *ineffective* PSBT is a chance taker:
>
> - Relies on luck.
> - Challenges the unknown.
> - Reacts from a gut reaction based on experience and perception.

This appears contradictory to the most current school of thought on decision-making and cognitive psychology, which is *Dual Process Theory.* This theory points to a concurrent use of Type 1 and Type 2 decision-making approaches, and according to Croskerry (2009), Type 1 decision-making is a much more intuitive, heuristic approach, depending on a user's accumulated knowledge and experience, or if the reader will, "gut reaction based on experience and perception." Researchers in cognitive science also contend that Type 1 decision-making is typically associated with more experienced practitioners in a field, and that Type 2 decision-making is associated with a more *novice* approach. It is also noted by these researchers that during Type 2 decision-making, a systematic, analytical process is used, or if the reader will, the decision maker "relies on calculation."

Looking more at the roots of *Dual Process Theory*, Croskerry (2009) provides a comparison of intuitive and analytical approaches that are subsumed by Type 1 and Type 2 decision-making. These are:

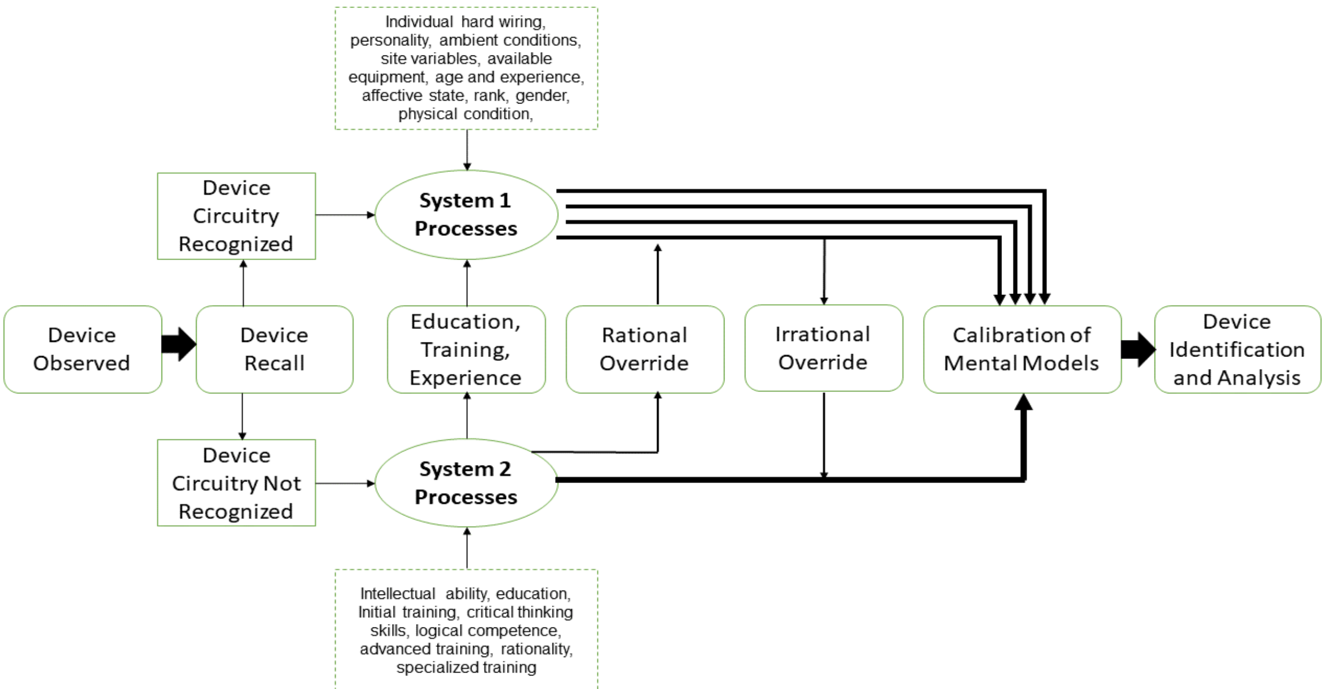
<u>Type 1: Intuitive</u>
- Experiential-inductive
- Bounded rationality
- Heuristic
- Gestalt effect/pattern recognition
- Modular (hard-wired) responsivity
- Recognition-primed/thin slicing
- Unconscious thinking theory

<u>Type 2: Analytical</u>
- Hypothetico-deductive
- Unbounded rationality
- Normative reasoning
- Robust decision-making
- Acquired, critical, logical thought
- Multiple branching, arborization
- Deliberate, purposeful thinking

Borrowing from Croskerry's model (Croskerry 2009) of how Dual Process Theory works in a clinical diagnostic setting, this author has put together a model (see Figure 84) of how this type of diagnostic reasoning approach might work during an IED response. In theory this process would be used whether a bomb technician was simply identifying the components in a firing circuit, analyzing hazards associated with the device, or making a device type-by-function determination.

Figure 120

Bomb Response Using a Combined Type 1/Type 2 Decision-Making Process



In this model, the decision-making process runs linearly from left to right, and starts with a device or suspected device being observed by the bomb technician. The device is either recognized or not by the bomb technician, and if recognized, the fast, parallel, automatic processes of System 1 are engaged. If the device is not recognized, the slower, analytical processes of System 2 are engaged instead. Factors that aid in making decisions during System 1 and 2 processes are shown in the dotted-line boxes above and below Systems 1 and 2 respectively. If information gathering and deductive processes used during the System 2 process leads to recognition of the device, System 1 processing will again be engaged. If unknown variables and/or external factors cause self-doubt, thinking will default to System 2 processing. Either system may override the other at any time during an incident, but eventually, a new mental model will be formed, or an old model strengthened. The result is a final decision regarding the device that will be acted upon by the bomb technician.

When referring to *diagnostic reasoning* in the traditional sense, meaning, as it is used by cognitive scientists, bomb technicians receive no *formal* diagnostic reasoning training, and any *informal* diagnostic reasoning training is not conducted as a conscious part of the training. This is not to say that diagnostic reasoning does not occur in the bomb disposal discipline, only that it is not known as such, and there has not been, to the best of this researcher's knowledge, any attempt to develop or implement diagnostic reasoning training in the bomb disposal community, in any way. Even if formal training were to take place however, *decision-making training* has yet to be proven effective. While Pitz and Sachs (1984) point out that "The final test of an understanding of judgement and decision-making processes is to develop procedures for helping people make better decisions." Gaeth (1980) points out that the reality of the situation is that most early attempts at training people to make better decisions, was largely unsuccessful.

Even though teaching decision-making may be a questionable approach, if we look at the importance of diagnostic reasoning to bomb disposal, and how bomb technicians are taught during *initial*, *professional development*, and *advanced training*, it should be clear that there is a need to have trainees perform diagnostic reasoning tasks at an ever-increasing level of complexity during all training evolutions. It is one thing to have bomb technicians do common domain tasks like assemble and use an x-ray or disruptor, or even putting on a bomb suit and doing work down-range for a traditional scenario, but quite another to give a bomb technician a complex, multi-part problem that requires accessing and using *domain specific knowledge* and tapping into *knowledge structures* in such a way that it improves a bomb technician's ability to *easily recognize characteristics and conditions within a problem-set,* and solve *complex domain specific* (i.e., bomb disposal) problems. If we are not requiring this in professional development, or advanced training courses, then the bomb disposal training community is probably failing our technicians with respect to improving their diagnostic reasoning skills.

To underscore why it is important to train our bomb technicians to better conduct diagnostic reasoning, it is fairly well understood by most people that almost any action or activity can be practiced to the point where it becomes second-nature. In terms of diagnostic reasoning, for situations requiring these learned actions or activities, Type 1 decision-making will naturally come into play, and be used without conscious thought. For example, a gymnast, dancer, or martial artist can practice a movement to the point where it becomes effortless, even though initially performing those movements were stilted, and seemed unachievable. Also, a surgeon can practice a procedure until it is done almost unconsciously, and unless something unusual occurs during the procedure, it is considered "routine" by the surgeon, and anything but, to outside observers.

It stands to reason that these same cognitive processes will express themselves during every-day bomb disposal operations, as long as the practitioner has spent sufficient time in the field to develop the neural pathways and connections necessary to accomplish specific tasks routinely. Inexperienced EOD technicians are often mystified at how easily a seasoned EOD technician can identify things like the almost imperceptible signs of a buried mine, or the presence of a tripwire, but in actuality, the only reason this is achievable is because past experience has made detecting and identifying the signs and signatures of disturbed earth, or the probable locations of tripwires, a subconscious activity. The same can be achieved for all skill-sets in bomb disposal, with the proper training.

It is inevitable that Type 2 information gathering, processing, and decision-making will be required at some point during an incident response in bomb disposal, regardless of how much training is done to achieve Type 1 thinking. It also stands to reason that Type 2 thinking will be the *dominant* mode of thinking during an incident, simply because almost every situation a bomb technician faces in the performance of their duties will involve gathering and processing new information, as well as having competing sources of attention, and degrees of *unknowns*. This is not to say however, that Type 1 thinking will not be engaged while routine tasks are being performed, but if a thorough analysis of the device or situation is required, Type 2 reasoning will most likely take the dominant role. This is the primary reason developers of new technologies intended to aid bomb technicians in accomplishing their mission are always concerned about the cognitive burden that any new technology will place on the technician, because the use of this new tool or technology will require extra attention by the operator, and may override reflexive actions.

The Problem with Type-1 Thinking

The reader has only to look at circuits used in this study to see where Type-1 thinking is most prevalent. The highest success rates for component identification, hazard assessment, and type-by-function determination were for the Adjustable Light Circuit; SCR Kitchen Timer; Two-Battery Collapsing Circuit; Collapsing Circuit with Capacitor; and the Radio Squelch Circuit. These are all common circuit configurations used in bomb disposal training, and are therefore heavily fixed in the minds of most bomb technicians, so recalling what these circuits look like is a somewhat trivial task. However, this author contends that while bomb technicians may recognize these circuits, most would be hard-pressed to build these circuits if only provided the components to do so, because recall is pattern-matching (i.e., Type-1 thinking), but knowing how to assemble a functional device will likely, unless done enough, require conscious thought, or Type-2 thinking.

As stated earlier, Type 1 thinking, or heuristics, was the dominant mode of problem-solving and decision-making used by participants in this study. While heuristics can fail catastrophically, they generally only fail when our mental models are either inaccurate, or inadequate. This was as true for this study, as for any other situation where the use of heuristics has gone wrong. For example, anyone who has seen a classic mechanical relay on more than one occasion, generally recognizes the boxy shape instantly, and if the relay is of the five-pin variety, most bomb technicians in the U.S. will recognize it immediately, primarily because it is the variety that is most often used in training. Seeing these components and circuits in early training, along with their distinctive features, or combinations of features, allows the bomb technicians to easily use pattern matching (i.e., heuristics) to identify them. This is what makes this, and a few types of other components and simple circuits, easy for bomb technicians to recognize.

That said, the role mental models play in heuristics should not be understated, as they are used in all aspects of daily activity, from identifying objects and predicting outcomes, to developing effective action plans. Accurate mental models are critical to any activity that requires rapid decision-making, and if a bomb technician lacks either sufficient or accurate mental models upon which to base their decisions regarding IED circuits, their mental models will likely lead them to flawed assumptions regarding the hazards presented by specific types of circuits or components, as well as creating a flawed analysis of how a device functions. For example, if a bomb technician's mental model of a mechanical relay is based solely on the boxy, five-pin mechanical relay used in most bomb technician training courses, encountering a relay with seven, eight, or ten pins, or even those with cylindrical shapes, may lead that bomb technician to believe they are dealing with a totally different, unknown component.

In simplest terms, a mental model is a representation of reality that a person uses to understand his or her world. Norman, as citied in Gentner and Stevens (1983) explains it as follows:

> *In interacting with the environment, with others, and with the artifacts of technology, people form internal, mental models of themselves and of the things with which they are interacting. These models provide predictive and explanatory power for understanding the interaction.*

Johnson-Laird (1983) supports the concept of internal representations in the thinking process, and connects mental models to the basic structure of cognition. She states,

> *…mental models play a central and unifying role in representing objects, states of affairs, sequences of events, the way the world is, and the social and psychological actions of daily life.*

Since forming new mental models involves an active mental process, learners, bomb technicians in this case, must put new information into an existing mental framework. If the new information does not fit logically into the existing framework, a learner will attempt to modify, or reconstruct their existing mental model, creating a new one. Over time, the learner will test this new mental model, further refining the model as new information is acquired. Eventually, the learner will settle on the new mental model they believe most accurately reflects all available information, even though some anomalies may still exist. The latest, or most newly formed mental model, will survive and remain active until some new piece of information or experience significantly alters or destroys their existing model.

Unfortunately, unless altered by some newer, more accurate piece of information, an inaccurate mental model may endure indefinitely. This is one of the reasons some bomb technicians who have learned an incorrect bit of information during initial training, or early in their career, but have had no exposure to new information or an experiential event to correct that misperception, will retain an inaccurate mental model their entire career, and perhaps worse, pass that inaccurate mental model on to others. This is how "old wives' tales," or flawed heuristics, become entrenched in a community of practice, and cause the perpetuation of myths regarding techniques and procedures, that have no basis in fact.

Circling back to heuristics, it is not unkind to say that most bomb technicians are unaware of the term heuristics, even though they use them regularly. As Croskerry (2002) notes, it is important to understand that the use of heuristics during the decision-making process can be either beneficial or detrimental, and not unlike the act of breathing, we are most acutely aware of the importance of heuristics, when they fail us. Trowbridge (2008) points out that there are 3 major types of heuristics that can be detrimental if used during the decision-making process: *availability*, *anchoring*, and *representativeness* heuristics.

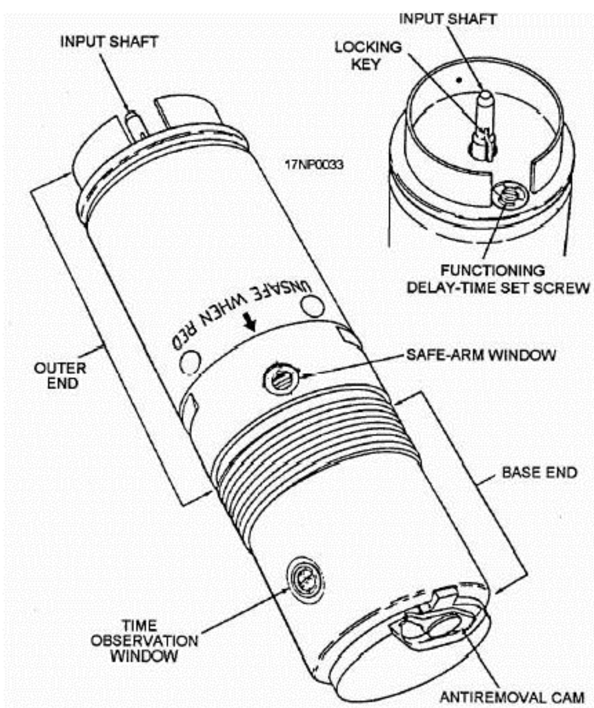
According to Croskerry (2002), an *availability heuristic* results in making decisions based on easily accessible information, for example what the decision maker can recall, rather than what is most probable. Drawing conclusions in a specific type of setting is a good example of this, and includes situations where decisions are made because of a particularly notable past incident, such as the conditions in which a similar device was encountered (e.g., a bank, synagogue, Planned Parenthood clinic, or warzone). These types of locations or situations can draw bomb technicians toward erroneous conclusions about the nature, purpose, and construction of a device, even though observables would suggest otherwise.

The second heuristic, *anchoring*, is closely akin to *confirmation bias*. Many times bomb technicians will make decisions regarding a device early in the reconnaissance phase, and often become *anchored* to those decisions. This type of anchoring may manifest as conclusions about the type of circuit being used, what a particular component is, or how the device is initiated. For example, one of the circuits used in this author's study contained a microwave sensor module that included a very prominently displayed light dependent resistor (i.e., photocell). The vast majority of bomb technicians participating in the study readily identified the photocell, but even though this component played a minor role in the circuit overall, almost all study participants concluded that the primary function of this circuit was as a *light-activated circuit*, even though numerous other indicators suggested otherwise. Because study participants were *anchored* to the photocell, they discounted all other highly-visible features that would have helped in identifying how this circuit functioned.

If we look back at the boxy five-pin mechanical relay discussed earlier, we can see that *representativeness* is another category of detrimental heuristics found in study participant responses. Like other people, bomb technicians rely on cognitive short-cut such as pattern matching in the performance of their duties, especially in time sensitive, or emergency situations. In the military bomb disposal community, *immediate action drills* are practiced for certain types of ordnance, such as a *clockwork-fuze*. A clockwork-fuze that was once, and possibly still is, commonly found in the U.S. inventory, and the one routinely used in practicing immediate action drills, is the MK 346 MOD 0 Mechanical Long-Delay Tail Fuze (see Figure 121).

Figure 121

The MK 346 MOD 0 Mechanical Long-Delay Tail Fuze



(Retrieved on 23 February 2023 from https://www.tpub.com/aviord321/5.htm)

Not unlike the boxy five-pin mechanical relay, the standard MK 346 MOD 0 has become *the* example for clockwork fuzes. Fortunately, if an EOD technician runs across this fuze, they will likely recognize it *immediately*, and know what actions to take. However, while immediate recognition might be a very useful process in this instance, and is just the type of pattern recognition that is needed for rapid-fire decision-making, what happens if the bomb technician runs across an atypical clockwork-fuze? Where *representativeness* now has the potential to take the decision maker astray, is by causing the EOD technician to believe that all clockwork fuzes *should* look like a MK 346 MOD 0, or that anything closely resembling a MK 346 MOD 0, must be a clockwork fuze. Conversely, anything that does not look like a MK 346 MOD 0, cannot be a clockwork fuze. As identified in this study, when a boxy, five-pin mechanical relay was used, it was *labeled correctly* close to 100% of the time, but when a mechanical relay with more pins was used, it was *mislabeled* almost 100% of the time. There were many more examples of this, so bomb technicians should always consider that atypical and analogous presentations of a component are possible.

One of the most common diagnostic reasoning errors this researcher found in his study, and one that is often seen in the medical community, according to the literature, is known as *premature closure*. In the medical community, premature closure is considered to be the condition of stopping the diagnostic reasoning process before all of a patient's signs and symptoms have been considered, or basing a diagnosis on some easily recognizable clinical feature encountered early on in the diagnostic process. In this study, it was not uncommon to see study participants basing decisions about component identification, assessment of associated hazards, or determination of circuit types-by-function, based on some easily recognized feature or combination of features. For example, more commonly than not, study participants indicated that a circuit having two batteries was a collapsing circuit, or that the presence of both resistors and capacitors meant that a circuit must be a timed device.

According to Graber, Gordon, and Franklin (2002), one of the tools to help practitioners overcome errors involving *early closure*, is to look for signs and symptoms that do not fit the *typical* diagnosis, and ask 'What can't we explain?' Similarly, Croskerry (2003) suggests that diagnosticians look deeper into anything that does not match, or cannot explain the presence of a finding. This author was pleasantly surprised to see a form of this error countermeasure being used by several study participants in their own analysis, and thinks it a valuable approach that other bomb technicians might want to adapt. It is undoubtedly also a skill that instructors in bomb disposal, or almost any discipline for that matter, should encourage, and worked into practical exercises if possible.

Confidence and Bias

It should be reiterated that diagnostic error is characteristic of both novices and experts, especially when faced with unfamiliar tasks, or tasks that require making sense of new information outside the knowledge domain of either. Overconfidence is also characteristic of both the novice and expert, but it is more likely that what appears to be overconfidence in an expert, is confidence being expressed in their own domain-specific knowledge, and the use of decision-making skills related to problem-solving in that domain. It is also within reason to assert that the more knowledge and training an individual has, and the more specific it is to the problems a given practitioner will face in a given domain, the more a practitioner's level of confidence can be believed.

While overconfidence is widely noted in the academic literature, and diagnostic error has been shown to have a direct correlation to overconfidence, overconfidence is a common trait shared by both novices and experts, regardless of the discipline. It has also been widely noted by cognitive psychologists, going back to the early days of research into expert decision-making (e.g., Nagy, 1981; Krogstad, Ettenson, and Shanteau, 1984; Shanteau, 1987; De Groot, 2014), that experts have,

- highly developed perceptual/attentional abilities,
- a sense of what is relevant and irrelevant when making decisions,
- an ability to simplify complex problems,
- strong outward confidence in their decision-making ability, and
- extensive and up-to-date content knowledge

Irrespective of experts having some common beneficial characteristics in their decision-making abilities, they may still be prone, as all humans are, to suffer from what cognitive psychologists call, *illusory superiority* (Dunning, Heath, and Suls, 2018), believing they know more than they actually do, or that they are more skilled than others at a particular task. It is believed that *illusionary superiority*, more commonly referred to as *overconfidence bias*, is caused by a tendency to act on *incomplete information* or *intuition*, which may appear similar to heuristics, but is different in that the individual suffering from overconfidence bias lacks the up-to-date *content knowledge* and *information retrieval structures* necessary to make accurate, effective decisions using Type 1 thinking.

Overconfidence bias was formally described by psychologists David Dunning and Justin Kruger in 1999 in a paper titled, Unskilled and Unaware of It: How Difficulties in

Recognizing One's Own Incompetence Lead to Inflated Self-Assessments (Kruger and Dunning, 1999). Since then, study after study has found that what is known now as the *Dunning-Kruger Effect*, is alive-and-well in modern society. Perhaps understandably, no one wants to think of themselves as *average*, even though statistically speaking, 50% of the population is *below-average*, and the same is true for practitioners in any given profession. This does not mean however, that for any particular craft, that individuals in that craft are *below-average* intellectually, or with respect to problem-solving skills. Being a neurosurgeon, nuclear physicist, explosives chemist, bomb technician, or even a concert pianist might very well indicate that just by being a member of that community, you are above average with respect to the general population. Regardless, what the Dunning–Kruger effect implies, is that *below-average* people who have a limited amount of *domain specific knowledge* in a particular subject area, are "too ignorant to appreciate their own ignorance" (Howard, 2019b).

Another element that affects overconfidence, and the perception of overconfidence in bomb disposal, is when bomb technicians use a small number of data points from personal experience to draw broad conclusions, or even worse, hear anecdotal evidence provided by other bomb technicians, many of whom are perceived as older-and-wiser bomb technicians, and take that anecdotal evidence at face-value. The listener will then pass on those anecdotes as truth. Psychologists classify using anecdotes in the decision-making process as an *informal logical fallacy*, or *hasty generalization*; this is also known by statisticians as *the law of small numbers*. It is important to understand however, that anecdotes consistent with evidence-based practices and scientific knowledge are critical, especially to novices, as they try to make sense of the world. They are extremely detrimental however, when they are contrary to such knowledge, or are just wrong or incomplete. (Howard, 2019a)

True expertise, as defined by Einhorn (1974), is “a set of improvements in cognitive functioning (most notably: problem-solving and reasoning) that develop as one progresses deeper and deeper into a given domain.” The author goes on to say that this set of improvements allows for *stability* and *reliability* in the expert’s judgments. Ericsson and Lehmann (1996), say that it is possible for an expert in a discipline to achieve extremely high performance levels for tasks within their specific domain, in the order of two-standard-deviations above that of an average practitioner, which is quite significant. Experts can almost casually retrieve information in their long-term memory subconsciously, and as long as the material needing to be recalled is in their *scope of practice*, an expert’s recall and problem-solving ability is extremely high (Allard, Graham, Paarsalu, 1980; Starkes, Allard, Lindley, and O'Reilly, 1994).

The down-side to this however, according to Necka and Kubik (2012), is that expertise tends to be bound to specific domain, meaning that being an expert in one domain does not automatically confer expertise in another, even when the two domains are closely related. For example, a cardiologist is not automatically considered an expert in pulmonology, even though both are medical doctors, and the heart and lungs are co-located in the body. This is not to say that general medical knowledge about both systems, as well as knowledge of how the two systems interact, are not shared by both, but the overlap may be very limited, depending on the domain. Still, according to Necka and Kubik (2012), experts tend to be more *mentally flexible* than novices, and resist cognitive rigidity (i.e., close-mindedness). Even though, when a problem is outside an expert's scope of practice, or rules and procedures need to be altered because the context of the problem has changed, experts appear more rigid, and therefore, less flexible and capable.

According to Necka and Kubik (2012), an expert's *domain specific* advantage can be nullified very quickly by "an alteration of the rules, change of the context, or shift of the procedures." The authors state that when such changes occur, experts don't perform any better than the average practitioner, and sometimes not even at the same level. As demonstrated by research into bushfire prediction by expert firefighters, Lewandowsky and Kirsner (2000) found that expertise has *contextual* limitations, meaning that experienced firefighters were only able to achieve exceptional performance level when they were familiar with a particular situational settings. Similar decreases were observed when experts were forced to use procedures not usually employed. It is this researcher's belief that this is one of the reasons that accuracy of foundational knowledge, as well as depth and breadth of experience, is so critical in bomb disposal. This is true simply because of the improvised nature of an IED, which makes the device, and by extension its render safe procedure, tantamount to being non-domain specific.

In short, experts store knowledge and procedures in long-term memory in such ways as to retrieve that knowledge and accomplish rapid problem-solving in a much more effective way than novices (Ericsson, Patel, and Kintsch, 2000). It may be easy to perceive this as rigidness in an expert's knowledge structures, but according to Cattell (1946), there are two forms of detrimental rigidity commonly seen in experts: 1) *perseverance*, which connotes using a technique or strategy that is no longer applicable; and 2) *difficulty learning new patterns of reaction*, or "teaching an old dog new tricks."

According to Chi, Glaser, Farr (1988), as well as Anders, Charness, Feltovich, and Hoffman (2006), it is one or both of these types of rigidity that impede an expert's problem-solving ability, not the knowledge-structures themselves.

Cognitive bias plays a significant role in decision-making. As Croskerry (2014) suggests, the human mind cannot escape being influenced by the remembrances and impacts of past events, and we must accept that these influences can impact decision-making in both positive and negative ways, or in the parlance of cognitive psychologists, *bias* us in a given direction. To quote Croskerry (2014), "*Bias is so widespread that we need to consider it as a normal operating characteristic of the brain.*" Croskerry (2014) also notes, referring to Type 1 and Type 2 decision-making, that "…it is not one mode or the other that enables well-calibrated thinking but the discriminating use of both. A pivotal role for analytical thinking lies in its ability to allow decision makers the means to detach from the intuitive mode to mitigate bias."

Croskerry (2014) also suggests there are two specific biases to be especially cognizant of when evaluating decision-making; these are *blind spot* and *myside bias*. According to Pronin and Ross (2002), *blind spot bias* is "an asymmetry in assessments of one's own versus others' susceptibility to bias." In plain language, this is the belief by a decision maker that any conclusion they reach is free from bias, and that their decisions are based solely on current and reliable information, or only the evidence being presented. The individual experiencing blind-side bias believes their decisions are free from influenced by past events, extraneous factors, or outside influences of any kind. Taking this one step further, any decision maker under the influence of *blind side bias*, will also believe that any decision contrary to their own must, in some way, be biased, and that this bias has kept the other decision maker from drawing the same conclusions.

Croskerry (2014) frames *blind side bias* in terms of an impediment to awareness and understanding, because it creates a perception of invulnerability in the decision maker. He states, relative to physicians and clinical judgement, “Even where awareness does exist, physician hubris, bias blind spot, overconfidence and lack of intellectual humility may deter them from accepting that they are just as vulnerable as others to impaired judgment through bias.” One does not need to look too deeply into the bomb disposal community to see this bias at play. A good example of this in the current study came from a particularly knowledgeable participant who contended that, regarding a specific circuit,

> *There is a fatal flaw with this circuit; the output current for the Arduino Pro Micro (and similar models) is around 50 mA, where the required coil amperage for the relay is 100mA at a minimum, and the accepted firing threshold for initiators is more than that. As such, as-built, this circuit could not function an initiator without some kind of step-up amplifier or transistor (OPAMP, SCR, MOSFET, transistor, etc.). This is a bad device.*

Even when provided a data sheet on the component in question, identifying that the specifications of the relay used would allow this to be a functional device, and being told that this author had built this circuit to test its functionality, the participant was steadfast in his contention that the circuit would not work. The participant was biased by his past experience, even though that experience was based on using a component that was different than the one being used in this study’s scenario, and was unwilling to acknowledge the possibility that his analysis was flawed, even though presented with evidence to the contrary.

According to Croskerry (2014), *myside bias* occurs when a decision maker evaluates or favors information that supports their own preconceptions and beliefs. The author notes that it is a form of, and closely akin to *confirmation bias*. The author also notes that the strength of this bias tends to increase as situations and issues become more polarized. Taking this down to an on-scene, operational level, *myside bias* can result in what is commonly called group-think or tunnel-vision. Group-think and tunnel-vision can cause signs and indicators on-scene at an incident site to be ignored, especially if brought to the bomb technician's attention by someone outside of that technician's inner circle. After-action reviews and incident/accident reports are often skewed to a particular department or agencies interpretation or perspective because of myside bias, and in the end, the entire community suffers.

This bias, like blind side bias, also appears to be actively at play in the bomb disposal field, with issues like *end-cap removal*, and *fast-attack bomb response* vs. *remote operations*, etc., causing polarization between *old-school* and *new-school* bomb technicians. Even for this study, polarization along two lines of thinking became increasingly evident as early success rates were released: one group being those that believe electronics knowledge, and the ability to analyze circuits, is an essential skill for a bomb technician, and the other being those that say these are unnecessary skills. However, even for those bomb technicians believing circuit analysis a necessary skill, there was still hesitancy to accept that the community had such low success rates overall, or that, for those participants from the U.S., that other countries performed better.

Bomb Disposal and Expert Testimony

Based on data collected during this study, a question has been posed to this researcher as to whether a bomb technician's testimony regarding the technical makeup or functioning of a device can, or should, be treated as expert testimony. Additionally, should this testimony be held to the same threshold standards as other Daubert inquiries? Where this distinction becomes important is that while the *physical makeup* of a device presented as evidence during a trial may not be called into question, the *viability*, *functioning*, and *effects* that could have been produced by that device could be, if not confirmed through scientific testing. Without testing, *viability*, *functioning*, and *effects* are open to interpretation, even if provided by a bomb technician. It is this technical opinion, proffered in the form of expert testimony, which is still subject to a *Daubert Inquiry*.

Unlike tests conducted for academic, commercial, or even government research and development, where researchers, rightly or wrongly, may be able to pick-and-choose what results to provide as evidence for their position, the same is not true for forensic testing, to include device reconstruction and testing. As a current FBI Special Agent Bomb Technician (SABT) recently remarked in a discussion forum for an academic course in Identification of Destructive Device Fuzing Systems,

> *There is always that discussion of "would that device work? was it viable"? In the federal government, we are hesitant to recreate the exact device and test it. Any tests are discoverable and can be hurtful to the prosecution/sentencing if they do not work. In federal law, we do not have to show that the device would have functioned, using a recreation.*

Fortunately or unfortunately, depending on your perspective, few bomb technicians have the equipment or expertise necessary to accomplish more than basic evidence collection or forensic procedures, or even effects testing on a device to determine the presence of explosives, blast effects, etc. While the same bomb technician may be able to speak effectively to the construction and functioning of a simple pipe-bomb, the results of this study seem to suggest that the average bomb technician would be getting into questionable technical territory if asked to testify to the viability or functioning of even a moderately sophisticated electronic firing system. This is not to denigrate this researcher's fellow bomb technicians in any way, but it has become increasingly clear to this author, just how little bomb technicians really know about the technical aspects of the devices they work on.

Regardless, some courts still use the general acceptance test when weighing evidence related to arcane disciplines like bomb disposal, but for federal crimes, Federal Rules of Evidence (FRE) 702, *Testimony by Expert Witnesses* (U.S. House of Representatives, 2015) still applies. FRE 702 states that a witness who is qualified as an expert by knowledge, skill, experience, training, or education may testify in the form of an opinion or otherwise if, a) the expert's scientific, technical, or other specialized knowledge will help the trier of fact to understand the evidence or to determine a fact in issue; b) the testimony is based on sufficient facts or data; c) the testimony is the product of reliable principles and methods; and d) the expert has reliably applied the principles and methods to the facts of the case. Still, for those with more than a passing familiarity with the research and development of tools, techniques, and procedures (TTPs) used by the bomb disposal community, it is easy to see how this might be problematic, as the general standard for acceptance of a TTP in the bomb disposal community, tends to be, any successful outcome, not reliability or repeatability.

With respect to expert testimony however, bomb technicians have generally been given a great deal of latitude by the courts in the past, and *deference* exercised with respect to a bomb technicians credibility as an expert witness. This is true for a number of reasons, but primarily because before the U.S. conflicts in Iraq and Afghanistan, which caused the term improvised-explosive-device (IED) to become a household word, few people other than bomb technicians had ever been exposed to the effects of IEDs, their use as a weapon, or the physical and psychological damage they could cause. Before this time, non-bomb technicians in law enforcement, the government, and the courts simply believed that what they were being told by bomb technicians regarding the building and use of a device, was just fact. Today however, every sector in business and industry in the U.S., as well as the government and Congress have workers, many in leadership positions, who have suffered post-traumatic stress disorder (PTSD), traumatic brain injury (TBI), or amputations or other injuries from IED attacks while serving in the military. As such, there is an expectation that those who are charged with rendering safe IEDs will actually be experts in all aspects of IED fuzing and functioning. Unfortunately, as the results of this study suggest, bomb technicians are not the IED experts the public or courts expect them to be, and it is far too easy for a defense attorney, member of a jury, or a judge to Google-check something being claimed by a bomb technician giving testimony about the construction, functioning, or use of a device.

So where does this leave bomb technicians with respect to expert testimony? With few exceptions, bomb technicians are not scientists, nor, as far as this author has been able to ascertain from published documents, were they ever expected to be. If they had been, they would receive far more training in the scientific principles underpinning TTPs used in their profession, as well as technical aspects of the fuzing and functioning of improvised explosive device firing circuits, the chemistry of explosives, and blast effects. So this comment is not misconstrued, it is not this author's intent to say that bomb technicians are not functionally literate in the workings of their tools and equipment. However, generally speaking, bomb technicians in the U.S. are neither scientifically nor technically literate to a level that would give them sufficient scientific or technical knowledge to testify as to the veracity of tools and techniques used in their profession; this author included.

It is worth remembering that the average public safety bomb technician in the U.S. is a mid-career public servant in a municipal law enforcement agency, that only conducts bomb disposal as a collateral duty, meaning in addition to some other job within their organization. The exceptions tend to be in fire departments with bomb squads, or Special Agent Bomb Technicians that work for federal agencies. Irrespective of this, all public safety bomb technicians (PSBTs) graduate from the same initial training, from the same bomb disposal school, so any scientific knowledge gained about the TTPs used in bomb disposal would either come from that initial training, or from professional development courses. Even factoring for bomb technicians who may have come into bomb disposal with technical degrees, or who may have had vocational training of a technical nature, the literature is clear that knowledge tends to be domain specific, and not easily transferable from one discipline to the next.

According to the *National Guidelines for Bomb Squads* (U.S. Department of Justice, 2023), anyone graduating from the Hazardous Devices School, the only school in the U.S. authorized to certify bomb technicians, "…PSBTs will be able to perform the following competencies,"

- Explosive Demolition Operations
- Disrupter Operations
- X-ray Operations
- Conduct Disposal Operations
- PPE Use
- Robotic Operations
- Explosive Tool Use
- Remote Rigging Set-up
- WMD Response

While Weapons of Mass Destruction (WMD) response might seem the outlier here with respect to being more technical than the rest, this too has been reduced mainly to tool use, and wearing of appropriate PPE. Also note that the verbiage does not imply that a bomb technician is to understand technical or scientific aspects of these operations or equipment, but rather simple use these tools, or performing these operations competently.

The way bomb technicians are currently trained, at least in the U.S., leads to an interesting intersection between the level of training needed to provide expert opinion on scientific principles, and what constitutes subjective opinion. This distinction is less important if a bomb technician is only attempting to explain what procedures they took while rendering safe a device, or even with respect to what observable outcomes were produced. Instead, where this becomes more important, if not critical, is when a bomb technician goes beyond testimony regarding procedures and attempts to explain principles and functions of a technical or scientific nature. The former is well within the scope of current training, while the latter is not, even though it arguably, should be. As Feldbaum (1997) states,

> *…it is incumbent upon the vocational expert to understand thoroughly and articulate persuasively the scientific, technical, and other specialized knowledge that serve as an appropriate court-defensible foundation for their expert testimony....all of us are compelled to move with greater urgency in that direction.*

At a minimum, it would be prudent for bomb technicians to stop thinking of themselves as, or claiming to be technical experts on IEDs, unless of course, they have the knowledge, training, skills, and experience to be classified as such.

Of course in the U.S. there is no standard set for what constitutes an expert in the bomb disposal field, so it is incumbent on a bomb technicians to recognize and acknowledge the limits of their own scientific and technical knowledge, as well as strengths and weaknesses related to technical issues. Bomb technicians need to be realistic in assessing their own knowledge regarding scientific and technical matters related to IEDs, and refrain from proffering testimony that exceeds the scope of that knowledge and training, or even experience, and be willing to admit when they have reached the limits of their expertise.

Of course more robust education and training programs in the sciences, as they relate to improvised explosive devices, would help combat this shortfall. This is not likely an endeavor that organizations conducting initial training and certification of bomb technicians will, or even should, undertake, since government-sponsored academies and academic institutions are much better suited for addressing this type of curricula. However, even academies and institutions would need to recognize that the scope of knowledge and skills required to bring practitioners in the bomb disposal field up to a technical- and scientifically-literate level, is likely to be a daunting task. Compound this with the sheer number of disciplines touched on in the bomb disposal field, and it can easily be seen that becoming what could be called a true expert on IEDs, would require academic courses in explosives chemistry, and electronics.

If a practitioner wanted to expand their scope of expertise to bomb disposal in general, additional courses would be needed in such fields as detonics, blast effects, structural engineering, material science, and forensics, to name just a few. Such an individual would also likely need an in-depth understanding of, and be able to articulate the principles behind many of the test apparatuses and methods used in device exploitation, or field testing of explosives and explosive effects. This, in-and-of itself, is a salient argument for academic specialization at both the undergraduate and graduate level, for bomb disposal as a discipline.

Further Research

IED electronics was just one potential area within the bomb disposal discipline that lent itself well to looking at diagnostic reasoning approaches. Like IED electronics, many other tasks within the discipline have varying levels of domain specific knowledge, and individual technicians are often recognized, or even self-assessed as being novices or experts in those domains. This researcher's study could just as easily have used x-ray interpretation, homemade/improvised explosives (HME/IE) identification, military ordnance, or VBIED response for this study, even though these would require looking at a whole different set of domain specific knowledge. Conversely, disruption techniques for pipe-bombs would not lend itself well to a diagnostic reasoning study, because the procedures used are relatively static, and technicians are taught to use very specific techniques regardless of the pipe bomb's configuration. As such, even though some practitioners might argue differently, little problem-solving, and therefore little diagnostic reasoning is needed to perform this type of disruption.

The difference between the previous areas mentioned (i.e., IED electronics, x-ray interpretation, HME/IE identification, military ordnance, and VBIED response) and disruption of pipe bombs, is the amount of domain specific knowledge regarding the topic area available to, and required to be learned by the practitioner; the amount of unconstrained information required to be gathered during an incident to make a proper assessment/evaluation; and the variability of actions that can be taken, or conclusions that can be drawn based on a participant's analysis/assessment. In short, if the decision-making process only offers one or two outcomes, the topic area will likely not be suited to diagnostic reasoning research.

While this author has seen far too many research efforts that claim to be the last word on a subject, especially when related to bomb disposal, it would be hubris to claim that this study is by any means a definitive treatise on diagnostic reasoning for this community. That said, this author suggests the following areas of research as follow-ons to this study:

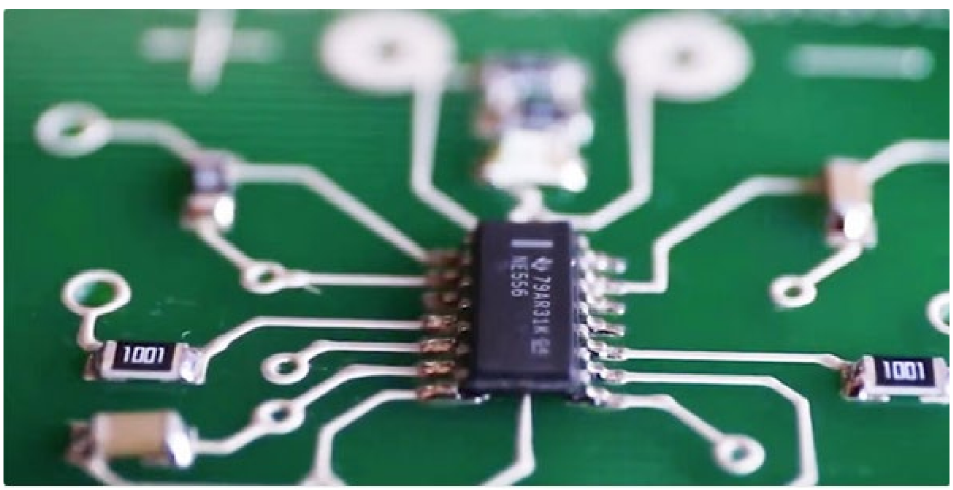
- A confirmation study of this research – As stated earlier, there are certainly things that this author would change about his research approach and methodology, and better ways to elicit and collect information. For example, it could have been informative to collect and analyze information regarding a participant's full- or part-time status as a bomb technician. Additionally, even with the use of an expert panel to develop what "right looks like" regarding components, associated hazards, and circuit types-by-function, there was too little interrater reliability amongst the expert panel for this author's taste.

- X-ray Interpretation – Since x-ray interpretation requires many of the same skill-sets as IED electronics analysis, this seems like a subject area that would lend itself well to being a conduit for diagnostic reasoning research. Not only does it have some of the same target items as in this study (i.e., components and circuits), but is a visual media, and has varying levels of complexity. Additionally, during this study, several participants stated that if these were x-rays, they would have been able to trace component connections, and differentiate between components like MOSFETS, SCRs, and BJTs, thereby improving their success rates for component identification. This should be put to the test.
- HME/IE Identification – While it may seem the height of folly to some to suggest HME/IE identification as a research area for diagnostic reasoning, many study participants suggested using HME/IE, rather than IED components and circuits. In their opinion, HME/IE identification is much more relevant to the field, than IED electronics. Additionally, it is not uncommon for bomb technicians to claim, unequivocally, that they are able to identify HME/IE just by its appearance. This ability should be validated or disproven, and success rates quantified.
- Finally, circuit identification rates using "newer" circuit construction techniques and methods needs to be considered. According to Falconer Electronics (n.d.), the use of Surface Mount Technology (SMTs) dates back to the 1960s, and now accounts for the vast majority of circuit manufacturing for the military and commercial applications. I could be argued however, that our

bomb technicians are stuck in a "through-hole" world, and even if good at recognizing a circuit constructed using through-hole and solder techniques, would not recognize the same circuit using SMT circuit construction. How well bomb technicians can recognize simple circuits using SMT construction techniques should be investigated, and success rates quantified. This particularly important now that conductive-ink prototyping machines like the Voltera V-One and NOVA systems are available to produce custom-built SMT circuits (see Figure 122).

Figure 122

Circuit construction using SMT and conductive-ink printing



(Source: Voltera)

Additional Areas for Consideration

Additional topics identified that bear consideration, are not limited to diagnostic reasoning approaches and success rates. Most stem from claims made by study participants regarding causal relationships between their identification of components, and assessment of hazards presented by those components, and the circuit type-by-function based on those hazards.

It is unclear to this researcher, whether some of the disparities with respect to component identification and hazard selection are being seen because of a lack of knowledge, or simply a difference in use, or a misuse of terminology. In the first case, meaning a lack of knowledge, this can be fixed through either formal education and training, or self-learning. The second condition is more problematic, in that terms, and their appropriate use, are generally domain specific, and the product of formal processes, such as initial training and professional development. In an education and training environment, the misuse of terminology usually stems from not understanding, or misunderstanding what was being conveyed by course material or instruction. This problem becomes further amplified if different instructors for different classes use different terminology, or are in the habit of using imprecise language or descriptors for subject matter.

This is not an issue peculiar to this study, in that this author noted similar issues in other projects undertaken with the bomb disposal community. Terms like anti-tamper, anti-penetration, movement, and vibration, to name a few, seem to have very different meanings depending on the bomb technician discussing that particular hazard, as well as what effect those hazards have in type-by-function determination. This would, at least to this author, suggest that there is a lack of standards, or insufficient adherence to standards, for the use of terminology during bomb disposal training.

As this author commented to his Dissertation Committee in the oral defense of his Comprehensive Examination, “The good news is, the problem can be fixed. The bad news is, you really have to want to fix it." Given that, it would be this author's suggestion that an international round-table or working group be formed to develop, at a minimum, a common lexicon to define terms related to hazards presented by potential IED components and circuits. Because some lexicons already exist, the difficulty with forming and producing results from such an effort are likely to be one of personality, not practicality or participation. At a minimum this will require working group participants to sign-on to new or existing standards that may not be being used in their respective countries.

For countries that have long-standing bomb disposal training programs, this will also require those countries to be willing to change curriculum if terminology changes, and reeducate their instructors and existing practitioners as to the benefits and necessity of change for the betterment of the community as a whole. The importance of change can be explained in the following way: If terminology used during training is imprecise, the use of terminology among practitioners will be imprecise; if terminology used by practitioners is imprecise, reporting will be imprecise; and if reporting is imprecise, the analysis of data related to IEDs and IED responses will not be accurate. This will ultimately result in data related to IEDs inevitably being flawed, and it will be impossible to know or understand the types and quantities of IEDs being used against our citizenry, or improve ways to defeat them.

Finally, two items commonly used in IEDs that seem to give bomb technicians a great deal of consternation, are mechanical relays and digital timers. The mythos and hazards assigned to these two components are weighty, and it was unclear to this author whether these concerns were warranted or not. Perhaps research has been conducted that validates these concerns, but in reviewing the literature, and speaking with individuals who could be considered not only experts in bomb disposal, but electronics as well, claims made during the study seem to be unfounded. Each will be covered individually.

Mechanical Relays

Mechanical relays are specified here, as opposed to all relays, because many of the hazards assigned to mechanical relays would not be ascribed to solid-state relays, even though some could be attributed to reed relays or some of the other twenty or so types of relays common to industry. The point about there being some twenty or so types of relays used in industry, is not an esoteric one, because it became clear during this study that unless the relay being used was a five-pin, single-pole single-throw (SPST), electromechanical relay, the one commonly used in training, it went unrecognized by study participants.

The issue of concern here however, is less one of recognition, and more one of the responses when a relay was recognized. While this author is very familiar with the concept that a relay, or other components in a circuit, *may* drain a battery, and this will *eventually* trip a relay, until this study, this author never considered it a significant enough phenomenon to warrant assigning a "time, "movement," or "anti-disturbance" hazard to a circuit, simply because a relay was present. This however, does not appear to be the current line of thought in the community, with logic like the following being offered:

> *There is a time issue. When one battery decays as it drains current across the relay coil, it will eventually reach a low enough voltage that will cause the relay to drop out (drop out voltage - which is lower than the pickup voltage). When that happens, one of the mechanical switches is connected to the initiator and another 9V battery functioning the blasting cap. This circuit can also be an anti-tamper/boobytrap (depending on your definition of a boobytrap). When the*

voltage of the battery draining across the relay coil is low voltage, it is barely holding the coil energized. At that point, if you hit or shake it, it can cause the lever to drop out from the coil and function the mechanical switch, further functioning the blasting cap. Another method of the anti-tamper/boobytrap is if someone disconnects the battery that is energizing the relay coil. In that case it would function the relay switch and function the initiator.

As stated by a different participant,

> *Electromechanical relay collapsing circuits come with more hazards than most people realize. The magnetic element of the relay consumes power, so in addition to the typical collapsing circuit hazard, there is also time as the battery drains, and an anti-disturbance hazard exists as the battery powering the relay gets to critical levels (movement can cause the magnetic switch to momentarily fail if jostled if the switch is just barely hanging on).*

As another study participant notes, “The drain of the battery's voltage can be calculated. Not accurate but it can.” A *magnetic* hazard was also often attributed to electromechanical relays, but not as often as the other hazards noted. The question becomes, has battery drain actually been characterized in such a way as to define the hazards it may present to a bomb technician, if a relay is present in a circuit? It is one thing to note that a phenomenon exists, but quite another to universally assign hazards to that phenomena that would prevent a bomb technician from taking actions against a device, which is what appears to be the case here. This author recommends, that if such characterization has not already been conducted, that it be done, and the results published, preferably in a peer-reviewed journal.

Digital Timers

The next component, which should more appropriately be identified as a collection of components used to provide stimuli for activating an SCR or other semiconductor device such as a transistor, is the kitchen timer (i.e., digital timer). Of course, it would seem obvious to even the uninitiated, that a digital timer would carry a "time" hazard, but repeatedly in this study, circuits containing digital timers were also ascribed hazards such as "movement," "vibration," and "anti-tamper." One participant noted,

> *I would advise anyone handling the timer to be careful. My experience with those shows that if you hit the timer, some of them will output a voltage and trigger the electric switch. Of course, this is an unintended consequence of the circuit, but it can be a hazard. In this case, it presents an impact hazard.*

Another participant states,

> *Intended TBF is obviously time. However, there is the potential for the device to be triggered by vibration or shock. This is because the buzzer element in the timer is a piezoelectric device. When driven by a pulse stream it will change shape and produce noise. However, it can also work in reverse and provide a voltage exceeding the gate threshold voltage of the SCR.*

Another participant notes, "If the device is dropped or treated ruffly [sic] by the victim or bomb technician it could function. If the tool choice is an explosively driven tool it will function." Statements such as these drive this author to wonder again, about actual characterization of the hazards associated with digital timers. While acknowledging that most digital timers contain a piezo speaker element, this author recommends that if a full characterization of digital timers of different types and varieties has not already been conducted, that it be done, and the results published, preferably in a peer-reviewed journal.

Smartphones

Granted, we live in a marvelous age, and the smartphone has changed the way we do many things. What surprises this author however, are the miraculous powers the smartphone seems to have been ascribed by study participants. This author realizes and acknowledges that in addition to the traditional *Command* functions attributed to the smartphone, simply by being a phone, most smartphones are Bluetooth and Wi-Fi enabled, which could be used for other Command-type functions. This author also acknowledges that most smartphones have real-time-clocks (RTCs), that can serve as a timer or alarm clock, and as such, could have a *time* hazard, allowing a device, if smartphone enabled, to have a *Time* type-by-function. Beyond this, it becomes less clear to this author how some of the features and sensors participants claim could be used to initiate an IED, at least without a significant amount of additional electronics being incorporated, most of which would be easier to use independent of a smartphone. Regardless, comments like the following were provided by study participants:

> *Smartphone means that the hazards are limitless, I selected the primaries, but there is really no end to the possibilities here.*

And,

> *With the smartphone, almost any hazard is possible. The apps, sensors, and controls on a smartphone are nearly limitless, no hazard can safely be removed...*

This author recommends that the bomb disposal community be surveyed to determine what apps and sensors are of most concern to practitioners, and determine if in fact smartphone apps and sensors present the threat they are perceived to be. As suggested for other research topics, the results should be published, and preferably in a peer-reviewed journal.

Conclusion

Without attempting to be hypercritical, there is little wonder in the mind of this author as to why most bomb technicians, at least in the U.S., are less than willing to do manual procedures on a device, whether it be to conduct reconnaissance, perform diagnostics, or render safe a device. Data from this study suggests that bomb technicians almost universally perceive every device, from the most basic, to the most complex, to carry either a *time*, *movement*, or *collapsing circuit* hazard. As such, the perception is that it is only prudent and responsible for the bomb technician to conduct all operations remotely. However, how much of this is perceived threat, and how much is real? If, as the data suggests, bomb technicians are only able to correctly identify components 20% of the time on average; associated hazards 16% of the time; and circuit type-by-function 51% of the time, it is not unreasonable to suggest that some hazards are being misattributed, and that this misattribution is resulting in an overabundance of caution that can channel bomb technicians into conducting unnecessary procedures, expending unnecessary resources, and delay returning a scene to normalcy.

As this author used in his signature block for a long period, "Bomb technicians do a series of non-routine tasks that require mental and physical dexterity, complex critical thinking skills, and creative problem-solving....and that's the easy part of the job." No one is debating the difficulty of the job done by the brave men and women of bomb disposal, or that the job is often thankless. No one should question their actions while selflessly risking their lives in the performance of their duties either, but the results of this study suggest that we, as a community, can do better by these brave men and women, and give them better cognitive tools, in the form of education and training, which will allow them to better complete each mission successfully, and return home safely. Again, "The good news is, the problem can be fixed. The bad news is, you really have to want to fix it."

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APPENDICES

Appendix A: Initial Component List

555 Integrated Circuit	Micro Switch
Accelerometer	Microwave Sensor
Antenna	MOSFET
Arduino Microcontroller	Opto-Coupler
ATmega328P	Photodiode
Barometric Pressure Sensor	Phototransistor
Bipolar Junction Transistor (BJT)	Push-Button Switch
Buzzer	Pyroelectric Sensor
Capacitor	Raspberry Pi Microcontroller
Ceramic Capacitor	Reed Switch
Crystal	Resistor
Darlington Transistor	Resistor Array
Diode	RF Receiver
DIP Switch	RF Transmitter
DTMF Decoder	RF Transceiver
Electrolytic Capacitor	Saw Resonator
Espressif (ESP) Microcontroller	Schottky Diode
Film Capacitor	Silicone Controlled Rectifier (SCR)
Force Sensitive Resistor (FSR)	Slide Switch
Fuse	Solid State Relay
Inductor	Speaker
Integrated Circuit (IC)	Strain Gauge
Lamp	Thermistor
Laser Diode	Transformer
Light Dependent Resistor (LDR)	Transistor
Light-Emitting Diode (LED)	TRIAC
Logic Gate	Ultrasonic Sensor
Mechanical Relay	Variable Resistor
Mercury Switch	Vibratory Switch
Microcontroller	Zener Diode
Microphone	

Appendix B: Initial Associated Hazard List

Acceleration	Metal
Acoustic/Sound Level	Moisture
Anti-Penetration	Movement
Anti-Tamper	Object/Facial Recognition
Bluetooth	Piezo Electric
Boobytrap	Pressure
Camera/Video	Pressure Release
Capacitance	Proximity
Collapsing Circuit	Radiant Heat
Light/Dark Sensor	Radio Frequency (RF)
Electrostatic Discharge (ESD)	Smoke/Dust/Particulate Matter
Electromagnetic Radiation (EMR)	Tilt
Flame	Time
Flash	Vibration
Gas/Volatile Organic Compounds	Wi-Fi
Magnetic	X-Ray/Radiation

Appendix C: 50 Circuits from Difficulty Rating List

SCR Kitchen Timer	Nokia 3310 Op-Amp
Collapsing Circuit	Microcontroller-Based Ultrasonic
Indonesian Light SCR	DIY CWC 7 Receiver RC Timer SCR
Balanced SCR	Microcontroller-Based PIR
Adjustable Light Sensor	Urdu Touch Switch
Transistor Trap Det Dual	Reed Pro Micro
Urdu Watch Timer	ATmega328P DTMF
Casio Anti-Lift	AtTiny Mail Device
Dual SCR	Esp8266 RCIED
Battery Removal	Active IR Pro Micro
Command Wire	Urdu Water Level Fill Switch
Single Wire Command Det	Iraq Timer CEXC
Decade Counter	Iraq Timer Pic16
Monostable 555 Variable Timer	LDR Logic Gate
Casio Pressure	NRF24L01 RCIED
Capacitor-Based Collapsing Circuit	RC Armed Dual MOSFET
Cellphone Optocoupler	Active IR Counter
FRS LDR Light Anti-Lift	Lora 328p
Microcontroller LDR	Wire Disconnect Boobytrap
NRF24L01 PIR	ATmega328P NO/NC
TIP122 Radio Squelch	Astable 4020
Casio Breakwire	Accelerometer 328p With LDR
FRS Breakwire	Odessa Device
Radio Squelch	Wi-Fi Mac Device
MOSFET RC Timer	Squelch Counter

Appendix D: List of Final Study Circuits

Active IR Counter
Adjustable Light Sensor
ATmega328p DTMF
Battery Removal
Cellphone Optocoupler
Collapsing Circuit
Capacitor-Based Collapsing Circuit
DIY CWC-7 Receiver Dual SCR
Iraq Timer CEXC
Microcontroller Enabled Mercury Tilt Switch
Microwave Sensor Nano 33 BLE Sense Circuit
Monostable 555 Variable Timer
NRF24L01 RCIED
Microcontroller-Based PIR
Radio Squelch
SCR Kitchen Timer
Microcontroller-Based Ultrasonic
Wire Disconnect Boobytrap

Appendix E: Circuits in Study

Practice Scenario Circuit. Microcontroller Enabled Mercury Tilt Switch

This circuit uses a PIC12 microcontroller to identify the Normally Open/Normally Closed (NO/NC) state of two mercury switches at opposing angles. After identifying the NO/NC state of the two switches, which occurs during a 15 second delay after power is applied to the circuit, any change in the NO/NC state of either mercury switch will fire the device. The 15 second delay used to identify circuit condition can also acts as a safe-separation period for the individual placing the device into operation. The following is a generic component list for the Microcontroller Enabled Mercury Tilt Switch :

- Battery
- Ceramic Capacitor
- Fixed Resistor
- Initiator
- Light Emitting Diode (LED)
- Mercury Switch
- Microcontroller
- Silicon Controlled Rectifier (SCR)
- Transistor

Circuit 1. Adjustable Light Sensor

This circuit uses a Metal–Oxide–Semiconductor Field-Effect Transistor (MOSFET) and a Light Dependent Resistor (LDR) to control voltage flowing from the devices power source to the initiator. A safe-to-arm switch is incorporated into the design, allowing the bomber to adjust the amount of light required to initiate the device. The following is a generic component list for the Adjustable Light Sensor:

- Battery
- Fixed Resistor
- Initiator
- Light Dependent Resistor (LDR)
- Light Emitting Diode (LED)
- MOSFET
- Safe/Arm Switch
- Variable Resistor

Circuit 2. SCR Kitchen Timer

This circuit uses a modified digital kitchen timer to supply current to a Silicone-Controlled Rectifier (SCR) when the time set by the bomber has expired.

The following is a generic component list for the SCR Kitchen Timer:

- Battery
- Digital Kitchen Timer
- Fixed Resistors
- Initiator
- Light Emitting Diode (LED)
- Safe/Arm Switch
- Silicon Controlled Rectifier (SCR)

Circuit 3. Two Battery Collapsing Circuit

This circuit uses a single mechanical relay and two power sources to form a normally closed switch, and a separate firing circuit. The circuit fires when the battery on the coil control circuit (i.e., the normally closed switch) is disconnected. The following is a generic component list for the Two Battery Collapsing Circuit:

- Batteries
- Fixed Resistor
- Initiator
- Light Emitting Diode (LED)
- Mechanical Relay
- Safe/Arm Switch

Circuit 4. Battery Removal Circuit

A charged capacitor and Metal–Oxide–Semiconductor Field-Effect Transistor (MOSFET) are used use to create a circuit where, when power is removed from the gate of the MOSFET by battery removal, the charged capacitor will initiate the device. The following is a generic component list for the Batter Removal Circuit:

- Battery
- Diode
- Electrolytic Capacitor
- Fixed Resistors
- Initiator
- Light Emitting Diode (LED)
- MOSFET
- Safe/Arm Switch

Circuit 5. 555 Timer Circuit

This circuit uses a 555 integrated circuit as a timer. When power is applied, the circuit is activated, and upon completion of the time delay, the 555 uses a P-channel MOSFET to fire the detonator. A single LED acts as a Safe/Arm indicator, in that if the detonator is attached when the LED is lit, it will fire. The following is a generic component list for the 555 Timer Circuit:

- 555 Integrated Circuit
- Battery
- Electrolytic Capacitors
- Fixed Resistors
- Initiator
- Light Emitting Diode (LED)
- MOSFET

Circuit 6. Cell Phone Optocoupler Circuit

A signal from the speaker of the cell phone is used to activate the optocoupler, which then triggers a relay, providing power to the detonator, thereby firing the device. A single LED acts as a Safe/Arm indicator, in that if the detonator is attached when the LED is lit, it will fire. If the LED is unlit, the bomber may safely attach the detonator, throwing the safe/arm switch, arming the device. The following is a generic component list for the Cell Phone Optocoupler Circuit:

- Battery
- Diode
- Fixed Resistors
- Generic Cell Phone
- Initiator
- Light Emitting Diode (LED)
- Mechanical Relay
- Opto-Isolator IC
- Safe/Arm Switch
- Silicone Controlled Rectifier (SCR)

Circuit 7. Capacitor-Based Collapsing Circuit

This circuit functions along the same lines as a typical collapsing circuit, but uses a capacitor and diode to replace one of the batteries. Battery removal will fire the charged capacitor, initiating the device. The following is a generic component list for the Capacitor-Based Collapsing Circuit:

- Battery
- Diode
- Electrolytic Capacitor
- Fixed Resistors
- Initiator
- Light Emitting Diode (LED)
- Mechanical Relay
- Safe/Arm Switch

Circuit 8. Radio Squelch SCR Circuit

This circuit uses an SCR and the output from a modified handheld radio to fire a detonator. A single LED acts as a Safe/Arm indicator, in that if the detonator is attached when the LED is lit, the detonator will be initiated. The following is a generic component list for the Radio Squelch SCR Circuit:

- Battery
- Fixed Resistors
- Generic Radio
- Initiator
- Light Emitting Diode (LED)
- Safe/Arm Switch
- Silicon Controlled Rectifier (SCR)

Circuit 9. Microcontroller-Based PIR Circuit

This circuit uses an Arduino Pro Micro and a Passive Infrared (PIR) sensor to trip a relay, which then allows power to flow to a detonator, causing initiation of the device. The circuit incorporates a programmable sensor delay in the Pro Micro code, acting as a safe separation mechanism. The following is a generic component list for the Microcontroller-Based PIR Circuit:

- Arduino Pro Micro
- Batteries
- Diode
- Fixed Resistors
- Initiator
- Light Emitting Diodes (LEDs)
- Mechanical Relay
- PIR Sensor

Circuit 10. Microcontroller-Based Ultrasonic Circuit

This circuit uses an Arduino Pro Micro and an ultrasonic sensor module to trip a relay, which then allows power to flow to a detonator, causing initiation of the device. The ultrasonic sensor module has a built-in 30 second delay, acting as a safe separation mechanism. After arming the sensor takes an initial distance reading to the nearest object, and if that benchmark distance changes, the device will fire. The following is a generic component list for the Microcontroller-Based Ultrasonic Circuit:

- Arduino Pro Micro
- Batteries
- Diode
- Fixed Resistors
- Initiator
- Light Emitting Diodes (LEDs)
- Mechanical Relay
- Ultrasonic Sensor Module

Circuit 11. RF Receiver with SCR

This RCIED circuit uses a 433 MHz radio receiver and a PT-2272 Radio Frequency Decoder Integrated Circuit. One pin of the PT-2272 is used for arming, and one for firing. The following is a generic component list for the RF Receiver with SCR:

- 433 MHz Radio Receiver
- Battery
- Electrolytic Capacitor
- Fixed Resistors
- Initiator
- Light Emitting Diodes (LEDs)
- RF Decoder IC
- Safe/Arm Switch
- Silicon Controlled Rectifiers (SCR)
- Voltage Regulator

Circuit 12. ATmega328P DTMF Circuit

This circuit uses a cellphone to generate a specific Dual Tone Multi-Frequency (DTMF) signal to initiate the device. The bomber presses one number on the generators keypad to arm the device, and three numbers to fire the device. The required arming and firing numbers are coded into the ATmega328P microcontroller, and can be easily changed in the code if required. The following is a generic component list for the ATmega328P DTMF Circuit:

- 3.579545MHz Crystal
- ATmega328P Microcontroller
- Batteries
- Cellphone or FRS Radio
- Diode
- DTMF Decoder
- Electrolytic Capacitors
- Fixed Resistors
- Headphone Jack, Female
- Initiator
- Light Emitting Diodes (LEDs)
- Mechanical Relay
- Voltage Regulator

Circuit 13. PIC16 Microcontroller Timer Circuit

In this circuit, a PIC16 microcontroller is used to send a signal, coded to a delay of the bomber's choosing, to a transistor, which then closes a normally-open (NO) relay, firing the device. The following is a generic component list for the PIC16 Microcontroller Timer Circuit:

- Batteries
- Diode
- Electrolytic Capacitors
- Fixed Resistors
- Initiator
- Light Emitting Diodes (LEDs)
- Male Header, 6 Pin
- Mechanical Relay
- Microcontroller, PIC 16
- Transistor
- Voltage Regulator

Circuit 14. NRF24L01 RCIED Circuit

This circuit uses an NRF24L01 wireless transceiver module, paired with an Arduino Pro Micro, to make an RCIED. The following is a generic component list for the NRF24L01 RCIED Circuit

- Arduino Pro Micro
- Batteries
- Diode
- Electrolytic Capacitors
- Fixed Resistors
- Initiator
- Light Emitting Diodes (LEDs)
- Mechanical Relay
- NRF24L01 Wireless Transceiver Module
- Transistor
- Voltage Regulator

Circuit 15. Active-Infrared Sensor Violation Counter

This circuit uses a 4017 Counter Integrated Circuit and active-IR sensor module combination. After a programmed safe separation time has expired, the circuit counts sensor violations, and fires after a chosen number of violations has occurred. The following is a generic component list for the Active-Infrared Sensor Violation Counter:

- Arming Switch
- Battery
- Decade Counter
- Electrolytic Capacitor
- Fixed Resistors
- Initiator
- IR Obstacle Avoidance Sensor
- Light Emitting Diodes (LEDs)
- MOSFET
- Silicon Controlled Rectifier (SCR)
- Transistor
- Voltage Regulator

Circuit 16. Wire Disconnect Circuit

This circuit uses a Quad NOR Gate Integrated Circuit to compare the voltages across two inputs, in this case, a break-wire. If the wire is broken, a disparity in voltage levels is detected, and the device initiates. The following is a generic component list for the Wire Disconnect Circuit:

- Battery
- Break-Wire
- Detonator
- Electrolytic Capacitor
- Fixed Resistors
- Initiator
- Light Emitting Diodes (LEDs)
- Quad NOR Gate Integrated Circuit
- Silicon Controlled Rectifier (SCR)
- Variable Resistor

Circuit 17. Nano 33 BLE Sense Microwave Sensor Circuit

This circuit uses an Arduino Nano 33 BLE Sense microcontroller and a microwave sensor module to trigger a solid-state relay, which then allows power to flow to a detonator, causing initiation of the device. The Light Dependent Resistor attached to the microwave sensor module allows the module to operate in low power mode, so the sensor will only activate in the dark, and built-in microcontroller LEDs provide safe/arm feedback conditions. The circuit incorporates a programmable delay in the microcontroller code, preventing a firing signal from reaching the solid-state relay for the delay period, acting as a safe separation mechanism. This circuit also uses the microcontrollers built-in LSM9DS1 inertial sensor chip to create a programmable vibration, motion, and tilt alarm firing mechanism.

It should be noted that the Nano 33 BLE Sense is a sophisticated microcontroller, with the following micro-sensors built directly onto the surface of the microcontroller:

- 9-Axis Inertial Sensor
- Omnidirectional Microphone
- Absolute Pressure Digital Barometer
- Digital Proximity Sensor
- Ambient Light Sensor
- RGB Color Sensor
- Gesture Sensor
- Humidity Sensor
- Digital Temperature Sensor

It should also be noted that the BLE Sense is Bluetooth enabled, as well as having the ability to run Edge Computing (Artificial Intelligence) applications. As such, this microcontroller is capable of performing image and video object recognition if a camera module is incorporated into the circuit, or sound or color object recognition using built-in sensors. A device incorporating this microcontroller is also capable of be remotely armed or fired via built-in Bluetooth. The following is a generic component list for the Microwave Sensor Nano 33 BLE Sense Circuit:

- Arduino Nano 33 BLE Sense
- Batteries
- Initiator
- Microwave Sensor with Light Dependent Resistor (LDR) attached
- Solid-State Relay

Appendix F: Biographies of Expert Panelists

Chief Superintendent (Retired) Michael Cardash

Michael is the former deputy head of the Israeli National Police Bomb Disposal Division where he served 27 years as a senior bomb disposal officer, He has participated in numerous missions defeating IEDs while commanding bomb disposal units within the Israeli police and border guards.

Michael currently researches global IED incidents, tactics and trends, and is a senior instructor at the EU CBRNe training center in Budapest Hungary. He is an advisor for IABTI (International Association of Bomb Technicians and Investigators) and IBDCWG (International Bomb Data Center Work Group), and is the Senior C-IED analyst at Terrogence Global, and author of the Möbius C-IED reports analyzing and assessing global IED-related technical and tactical intelligence.

Lieutenant Colonel (Retired) Adam Modd - GM, DSD (George Medal, Distinguished Service Decoration)

Adam served in the Armed Forces conducting EOD / IEDD /CBRN operations for over 34 years, recently retiring as a Lieutenant Colonel. Starting in the British Army EOD he operated in Germany, Northern Ireland, Iraq, Hong Kong, Bosnia, Kosovo, Rwanda, Nepal, and Afghanistan. Subsequently, in 2007 he was requested to be part of a project to develop Domestic, Expeditionary, and Special Forces EOD capabilities for the New Zealand Defence Force.

Adam commanded E-Squadron, 1st New Zealand Special Air Service (SAS) Regt for five over years, during his 13 year career in the New Zealand Defence Force he represented New Zealand on FVEY and NATO steering groups, technical working groups and International forums. Adam also deployed overseas to Columbia and Cambodia supporting the FBI and Interpol, as well as on Special Forces combat operations to Afghanistan. Adam took a two year sabbatical in 2009 / 2010 to work in support of the United States DoD Special Forces programs.

During the span of his military career, Adam undertook a range of roles including Leadership, Command, Operational, Scientific Research & Development, and Capability

Development, and Capability Delivery roles. Adam has experience a on a wide range of operational deployments that include: Humanitarian Aid & Disaster Relief (HADR), De-mining, Biological Chemical Radiological Nuclear (BCMD), Trans-National Crime, Counter-Terrorism, Counter-Proliferation, and Intelligence.

Adam was awarded the George Medal (GM) by Queen Elizabeth II in 2002 for his gallantry Bomb Disposal operations, and most recently he was recognized with the award of the Distinguished Service Decoration (DSD) on the 2021 Queens Birthday Honors. Adam has also recognized for his counter terrorist work globally with a U.S. Bronze Star, U.S. Army Commendation Medal (ACOM) and three FBI Commendations.

Jared French

Jared is a U.S. DoD bomb technician actively serving on a tactical operations response unit. Jared is a recognized IED subject matter expert, and has trained extensively with US and international partners.

Rick Haworth, BENG, CENG, MIET, Int P.E. (UK), PMP

Rick is an electronics engineer with over 35 years of post-graduate experience working with a wide variety of firing systems. He started his career in 1983, with the UK Ministry of Defence at the Atomic Weapons Establishment as a sponsored student. Over the next 20 years he designed firing, safety and security systems, as well as leading the design of novel detonator and explosive systems. He joined the offsite response team in the mid-1990s which led to teaching firing system electronics and high voltage firing system concepts to specialist EOD personnel. His experience in security and firing systems led to technical assessments of foreign weapon systems and to becoming a technical adviser to a specialist Counter-WMD SOF team, for whom he developed several tools and training materials, and helped to shape some of the basic concepts of manual Render Safe Procedures.

In 2004, he moved to the U.S. as a "person of extra-ordinary ability," and worked as an instructor with US Special Operations Forces, as well as being one of the initial Subject Matter Experts on the Department of Homeland Security (DHS) TripWire project. For 14 years he worked for A-T Solutions as Chief Engineer, and split his time between teaching electronics and HME, and designing tools and techniques for specialist EOD and Bomb Technician operations.

In early 2018 he left the contracting world and joined the FBI as an Electronics Engineer – Forensic Examiner for the Technical Exploitation Unit at Terrorist Explosive Device Analytical Center (TEDAC), where he is currently the Technical Lead.

Robert "Bob" Epps

Bob Epps is a US Marine who retired from the Riverside County Sheriff Department as a Sergeant after a 24-year career. He spent over 16 of those years on the department's bomb squad, with 11 years as the Bomb Squad Commander. He has responded to thousands of explosives and IED related calls during his career. He led a team of bomb techs that successfully developed an RSP technique for a propane bomb from the Inspire magazine. He has completed countless bomb and explosives related courses in the US and abroad, and he is an ATF Certified Explosives Specialist. Bob is a Past International Director for the International Association of Bomb Technicians and Investigators (IABTI) and he currently serves on their board as the Region 1 Director. After retiring from the bomb squad, he joined a team of blasters who use explosives to topple structures in the USA and Canada.

Robert "Rob" vonLoewenfeldt

Robert vonLoewenfeldt, a recently retired Special Agent Bomb Technician, from the South Carolina Law Enforcement Division, spent over 30 years in both military and civilian law enforcement. In 2006 he became the Savannah-Chatham Metropolitan Police Bomb Squad Commander, and shortly after became the Combating Terrorism Technical Support Group Southern Technician representative to the National Bomb Squad Commanders Advisory Board (NBSCAB). During his tenure as a NBSCAB Tech Rep, his duties took him to Israel, Australia, the United Kingdom, and Sweden, where he training with, and advised international national bomb squads, and help develop tools, tactics, and techniques for the United Stated bomb squad community.

During his career, Rob worked in every aspect of police work, from homicide detective to working as an explosive detection K-9 handler, from a SWAT operator to the commander of the Police Dive Team. In addition to teaching at the Georgia and South Carolina Police Academies, he was an instructor in both the FBI's Intermediate and

Advance IED Electronics Course, was a primary author and instructor for the FBI’s Maritime Bomb Technician program.

Rob also served as a member of the DHS's First Responder Response Group, a member of the Combating Terrorism Technical Support Office's IDD/EOD-LIC subgroup, and a member of the National Institute of Standards and Technology's ASTM Robotics group. He has published several FBI Special Technician bulletins and, helped the National Institute of Standards and Technology develop and publish the national testing standards for underwater robots.

VITA

Edwin A. Bundy

Candidate for the Degree of

Doctor of Philosophy

Thesis: DIAGNOSTIC REASONING APPROACHES AND SUCCESS RATES IN BOMB DISPOSAL

Major Field: Forensic Sciences

Biographical:

Education:
Completed the requirements for the Doctor of Philosophy in Forensic Sciences at Oklahoma State University, Stillwater, Oklahoma in May 2023.

Completed the requirements for the Doctor of Philosophy in Education at Capella University, Minneapolis, Minnesota in May 2006.

Completed the requirements for the Master of Science in Educational Change/Innovation at Walden University, Minneapolis, Minnesota in May 1999.

Completed the requirements for the Bachelor of Science in Political Science at Oklahoma State University, Stillwater, Oklahoma in May 1984.

Experience:
Government program manager for advanced technology development. Forty years of experience in explosives disciplines related to combating criminal and terrorist use of explosives. Former US Army Explosive Ordnance Disposal (EOD) Technician. Certified International Post-Blast Investigator, and Licensed Private Investigator.

Professional Memberships:
International Association of Bomb Technicians and Investigators
International Society of Explosive Engineers
National Fire Investigator Association
U.S. Bomb Technician Association