Ordinary People and Effective Operation of Fire Extinguishers

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Abstract

There is much speculation about the average person's ability to use a fire extinguisher effectively. This speculation includes the ability of a novice user to adequately extinguish a fire with a fire extinguisher without harming oneself or others.

This study employed a random sampling of the population to gather data that described and quantified several aspects relating to use, technique, and safety. Participants were presented with an extinguisher and asked to extinguish a controlled propane fire. The BullEx Intelligent Training System was used in this study to simulate a Class A fire through a controlled propane system.

Participants were recruited from the campuses of Worcester Polytechnic Institute and Eastern Kentucky University. The sample pool consisted of 276 participants who participated in a two-trial process. The first trial observed the participant's ability to use a fire extinguisher without any training or guidance from the investigators. The second trial observed the participant's ability to use a fire extinguisher with a small amount of training provided immediately after the first trial. This enabled the investigators to determine the level of ability without training or guidance (Trial 1), and improvement demonstrated for each variable after a short training session (Trial 2).

Overall, the results demonstrate that the subjects of the study were able to operate a fire extinguisher without prior training. In addition, participants demonstrated increased confidence and performance in effective operation of the extinguisher when exposed to just basic levels of training.

Executive Summary

The ordinary person is able to use a fire extinguisher without hurting themselves or others. These same people's ability to use a fire extinguisher is improved by a measureable amount when they were exposed to a minimal amount of training.

This research investigated how effectively an untrained person would be able to extinguish a small or incipient fire. Specifically, the study posed two main questions that were answered by defining the four aspects that represent effective use of a fire extinguisher: usage, technique, safety, and extinguishment simulation. These aspects were represented by variables that can be measured.

The project team conducted a search of the literature on similar studies, i.e., a person's ability to use a fire extinguisher, but no archival published literature was found. Studies do exist related to incidents in which a fire extinguisher was used in an industrial setting, whether adults above age 60 are able to extinguish a small fire, and whether a fire extinguisher is useful to have in an academic setting. It should be noted that decisions are being made about placement, use, maintenance, and testing of portable fire extinguishers. No other studies were found, however, on the untrained individual's ability to use a fire extinguisher.

The study was carried out by Worcester Polytechnic Institute and Eastern Kentucky University. To assure repeatability and constituency throughout the tests, the project team employed the BullEx Intelligent Training System (ITS). The BullEx ITS is a training simulator that teaches participants how to use a fire extinguisher against Class A, B, or C fires. For this study, the BullEx ITS was used to replicate a repeatable Class A fire for participants to extinguish. Unlike a woodcrib, the BullEx ITS allowed for a fire to be simulated in the safest conditions possible with numerous fail safes. Specifically, the ITS has the ability to extinguish the simulated fire instantly through the controller.

For two years, the study collected data from a random sampling of the population on their ability to use a fire extinguisher. Specifically, the research answered the two main study questions.

1) What is ability of the study participants to use a fire extinguisher with respect to the four key aspects: usage, technique, safety, extinguishment simulation – without prior training?
2) How much would the participants' usage, technique, safety, and fire control and extinguishment simulation improve, if at all, with a minimal amount of training?

The project team addressed these questions by conducting two trials. Trial 1 observed a participant's performance on the 10 individual variables that make up the four aspects without any prior training. In the Trial 2, participants were given a small amount of training, similar to the instructions found on the side of a fire extinguisher, and observed for any improvement on the same variables.

The results were very consistent between the two investigating universities. Overall, participants are able to use a fire extinguisher with great effectiveness. However, the studies scope was limited to only the participants' ability. It is recommended, therefore, that this study should continue on a greater scale by focusing on:

- The flight-or-fight response when confronted with a fire.
- How the BullEx ITS compares to a real Class A fire.

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1.0 Introduction

In most public buildings and many other locations, fire and building codes require fire extinguishers. Extinguishers are typically bright red and highly visible to the occupants. Questions surround the placement of fire extinguishers in areas where the general, untrained population may use them. If a small or incipient fire were to break out, would the untrained individual be able to operate the extinguisher? That is a central question debated by the fire-protection community every time a protection designer considers the selection and placement of portable fire extinguishers.

Currently, some fire protection professionals hypothesize that an ordinary person ("amateur") untrained in the operation of a fire extinguisher will not use the device effectively. Furthermore, these same professionals often speculate that, even if an untrained person chose to operate the fire extinguisher, he or she would be unable to do so safely. Such questions result, in part, due to a lack of research on the many elements of the interaction between amateurs and fire extinguishers. An extensive search of the archival published literature failed to uncover any tests specifically aimed at people's ability to use a fire extinguisher.

The purpose of this study was to collect data from a random sampling of the general population on an ordinary person's ability to use a fire extinguisher safely and effectively. For the purposes of this study, an ordinary person is defined as an untrained, novice, or amateur user of a fire extinguisher. Specifically this study addresses the following questions and data points:

Question 1. What is an amateur's ability to use a fire extinguisher with respect to four aspects describing this ability: usage, technique, safety, and extinguishment simulation– without prior training?

Usage – Ability of a random sampling of the population to operate a fire extinguisher.

Data points collected:

- Percentage able discharge the agent on the fire?
- Average pre-discharge time?
- Percentage that reads the label before usage?

Technique – What percentage of the same random sampling of the population who use good techniques of extinguishment?

Data points collected:

- Aims at the base of the fire?
- Uses a back and forth sweeping motion?
- Continues spraying agent after the fire appeared to be extinguished?

Safety - What percentage of the population completes the task safely?

Data points:

- Stands a safe distance away from the fire?
- Doesn't turn his/her back on the fire?

Extinguishment Simulation – What percentage of the population is able to control and extinguish a fire?

Data Points:

- Percentage who are able to simulate extinguishment of the fire?
- Average time to extinguish a simulated Class A fire?

Question 2. With a minimal amount of training, how much would the participant improve his/her performance on the four aspects: usage, technique, safety, and extinguishment simulation?

During the 1980s a series of tests were conducted at the Underwriters Laboratories[1]. These tests were not designed to determine a person's ability to use a fire extinguisher, but to develop revisions to the UL test standard for portable fire extinguishers (1). During 1979, 1985, and 1996, the National Association of Fire Equipment Distributors (NAFED) collected data on incidents of use of portable fire extinguishers in industrial or building environments. The data from 1979 showed that 5,076 out of 5,400 fires (94%) reported were extinguished solely by one or more portable fire extinguishers. The data from 1985 showed that 1,049 out of 1,153 (91%) fires were extinguished solely by one or more portable fire extinguishers. The data from 1996 showed that 2,154 out of 2,267 fires (95%) were extinguished solely by one or more portable fire extinguishers. Of all the fires extinguished, it is unknown whether the person using the extinguisher had any formal training. The fires extinguished were a Class A, Class B, and a mixture of fire classes. The study concluded that portable fire extinguishers had an "extraordinary success rate" (2).

In 2010, D. Bruck and I. Thomas investigated "Interactions Between Human Behavior and Technology: Implications for Fire Safety Science." One part of the study examined the ability of adults above the age of 60 to use a fire extinguisher on a small fire. This study concluded that 18 out of 23 (78%) of the participants were able to extinguish a fire with a fire extinguisher in a moderate amount of time (3). The average time for extinguishment for the fire was 38 seconds with a standard deviation of 16.3 seconds (3). Of the five participants who were not able to extinguish a fire, three were able to extinguish the fire after failing the first part of the experiment's protocol. The study by Mr. Bruck and Mr. Thomas provides valuable insight on how older people use fire extinguisher equipment. As stated in their study, older adults have altered reflexes and cognition abilities that limit their reaction time.

Raymond Ranellone, a WPI graduate, conducted an investigation in 2010 called "Fire Extinguishers in Academic Settings." (4) His research involved tracking detailed news reports of incidents in which a fire extinguisher was used in an academic setting from 2001-2010 (4). Specifically, his project used Google Alerts to estimate the number of incidents in which "fire extinguishers were beneficial in providing life safety and property protection…" (4). The report documented that fire extinguishers do provide "life safety and property loss prevention." A close look at a fire incident reporting system showed that, when a fire extinguisher is used effectively, it goes largely unreported, as there is no need for further action by anyone.

A literature search was also performed that showed "to date, no study has addressed these concerns that are facing many fire protection professionals in their everyday design considerations, yet all major authors of fire, life safety, and building codes require them in many occupancies." (5) The National Fire

[1] Note: The 1984 edition of UL 711 was a revision; UL 711 was established long before then and is used to evaluate relative effectiveness of various extinguishers by using repeatable, live fire testing. The 1984 Edition of UL 299 made major changes to the design of the extinguishers, including new operating instructions and other changes based on live fire testing with novices.

Protection Association's Standard 10, Standard for Portable Fire Extinguishers, is one of the most commonly "incorporated by reference" source on the inspection, testing, and maintenance for these devices and addresses many topics on the matter. A search in the NFPA online code subscriptions using EKU's library search engine shows that this standard is referenced in at least 103 NFPA documents as of March 2, 2012 (5). The International Code Council's International Fire Code section 906 and International Building Code section 906 require the placement of fire extinguishers in many occupancies, save for few exceptions, and incorporate NFPA 10 for requirements of testing, inspection, and maintenance. The same applies to the Occupational Safety and Health Administration's Regulations in both general industry and construction as found in 1910.157, Fire Extinguishers, and many others, which also incorporates NFPA 10 by reference. As such, NFPA 10 is considered the authoritative document on the topic.

NFPA 10, 2010 edition Annex D addresses several areas related to this study, and although not mandatory, every annex to such a document must be carefully considered by the individual applying the code to the built environment. First, D.1.1.1 recognizes three types of users — those trained in extinguisher use, such as responders and employees, and two additional groups of novice users – untrained private owners and untrained members of the general public. It was the latter group, the general public novices, whom the authors of this study sought to observe.

Section D.1.2.1 in NFPA 10 recognizes five basic steps to the operation of a fire extinguisher:

1. Recognition of a device as a fire extinguisher
2. Selection and suitability of a fire extinguisher
3. Transport of a fire extinguisher to the fire
4. Actuation of the fire extinguisher
5. Application of the extinguishing agent to the fire

This study assessed the abilities of untrained individuals in all the listed areas, except number 2. This is in no way intended to minimize the importance of selecting a suitable extinguisher, but simply was not within the scope of the present study.

The United States Department of Labor and Occupational Safety and Health Administration (OSHA) has outlined a series of strict standards for the placement, use, maintenance, and testing of portable fire extinguishers provided for the use of employees. In its guidelines, "Should employees evacuate or be prepared to fight a small fire?" there is a table on options a business can take depending on its circumstances. The options range from "total evacuation with no fire extinguishers required" to "certain or all employees being able to use a fire extinguisher. (6)

The Fire Protection Engineering Department at Worcester Polytechnic Institute (WPI) and the Fire and Safety Engineering Technology Program at Eastern Kentucky University (EKU) jointly conducted a study of 276 participants. Participants between ages 18 and 76 were asked to extinguish a controlled propane fire using the BullEx Intelligent Training System (ITS) before and after some limited training. After the trials they were surveyed on their comfort level and knowledge of fire safety.

2.0 Background

The following background information provides *a Brief History on Fire Extinguishers* that will provide context on past fire extinguishers and many of the common chemical agents used today in fire extinguishers. The *Types of Fire* section details briefly the classifications of fire and classifications on the fire extinguishers used to extinguish them. Finally, the *BullEx I.T.S.* and *Smart Extinguishers* section provides details on the systems used by WPI and EKU for this research.

2.1 A Brief History of Fire Extinguishers

From hand pumps to bucket chains to portable fire extinguishers, fire extinguishing devices have been around for a long time. Can these devices be considered fire extinguishers? According to *Merriam-Webster*, a fire extinguisher is "a portable or wheeled apparatus for putting out small fires by ejecting extinguishing chemicals." (7) In 1723, German Chemist Ambrose Godfrey-Hanckwitz built the first fire extinguisher. (8; 9) His invention was a "cask of fire-extinguishing liquid containing a pewter chamber of gunpowder." (9) Notably his invention was used with great efficiency in stopping a fire in London, according to *Bradley's Weekly Messenger* on November 7, 1729. (9; 8)

However, it was not until 1818 that the modern fire extinguisher was invented by British Captain George William Manby. His invention, nicknamed "Extincteur," consisted of "a copper vessel of 3 gallons (13.6 litres) of pearl ash (potassium carbonate) solution contained within compressed air." (10; 9) The soda-acid extinguisher was invented in 1866 by Francois Carlier of France. His fire extinguisher mixed water and sodium bicarbonate with tartaric acid that produced a stream of carbon dioxide (CO_2) gases. Almon M. Granger also invented a soda-acid extinguisher in the U.S. in 1881. The soda-acid extinguisher used "the reaction between sodium bicarbonate solution and sulphuric acid to expel pressurized water onto a fire." (9; 11)

The Russian Aleksandr Loren invented the first chemical foam fire extinguisher in 1904. Similar to how the soda-acid fire extinguisher worked, the chemical reaction between water, foam of licorice root, and sodium bicarbonate would expel the CO_2-rich foam onto the fire. (9; 8; 11)

In 1910, the Pyrene Manufacturing Company of Delaware patented the use of carbon tetrachloride (CTC) on fires and in 1911 deployed this agent in their own fire extinguisher. This fire extinguisher utilized a "brass or chrome container with integrated hand pump, which was used to expel a jet of liquid towards the fire." (9) One unique aspect of this fire extinguisher was the ability to be refilled with CTC. However, CTC is toxic and converts into phosgene gas, which is most commonly found today in chemical weapons. (9) In essence, the hazards to occupants were just as great as that posed by the fire and by products of combustion.

Bell Telephone Company encouraged the invention of the next fire extinguisher. Bell needed an "electrically non-conductive chemical for extinguishing the previously difficult to extinguish fires in telephone switchboards." (9) In 1924, Walter Kidde Company invented the carbon dioxide fire extinguisher to meet Bell's need. The carbon dioxide fire extinguisher was a tall metal cylinder that held 7.5 lbs. of CO_2. (9)

In 1954, DuPont and the U.S. Army created Halon 1301, or bromotrifluoromethane. (9) This chemical agent "opened a new era in...industrial fire protection." (12) Though Halon 1301 is not a type of fire extinguisher, this chemical agent is an incredible extinguishment tool. This miracle chemical attacks fires

without harming sensitive electronics. Halon 1301 was used widely across Europe and the U.S. up to the 1980s, when speculation began that Halon 1301 caused ozone depletion. Now heavily restricted, Halon 1301 and its other iterations have phased out in favor of more environmentally friendly options. (12; 9)

Over the past century, fire extinguishers have naturally evolved from the common bucket to today's sophisticated portable fire extinguisher. This evolution implies that fire extinguishers have been a useful tool for trained or untrained individuals for close to 300 years.

2.2 Types of Fire and Extinguisher Classification

There are five different types of fire classifications, labeled A, B, C, D, and K. NFPA 10, Standard on Portable Fire Extinguishers, dictates the color, pictograph, and other components of these markings. A fire can be classified in more than one class. A campfire that uses lighter fluid to ignite can be classified as a Class A and B fire until the lighter fluid is completely burned away. (14) The following pictures used in the figures were taken from the New York City Fire Department's website [http://www.nyc.gov/html/fdny/html/home2.shtml], but are representative of those being used throughout the United States.

Figure 1: Class A Fire Symbol

Class A fires are those that are fueled by materials that, when burned, leave a residue in the form of ash. (15)
Examples: paper, wood, cloth, rubber, certain plastics

Figure 2: Class B Fire Symbol

Class B fires are those that involve flammable liquids or gasses. (15)
Examples: gasoline, paint thinner, kitchen grease, propane, acetylene

Figure 3: Class C Fire Symbol

Class C fires are those that are energized by electrical wiring or equipment. When the electricity to the equipment is cut, the classification changes to the other types of fire. (15)
Examples: motors, computers, circuit breakers

Figure 4: Class D Fire Symbol

Class D fires are those that involve “combustible metals.” (15)
Examples: magnesium, titanium, sodium

Figure 5: Class K Fire Symbol

Class K fires are those that involve cooking oils and fats used in cooking appliances. (15)
Examples: vegetable oils, animal oils, fats

For this study, a Class A fire is simulated for extinguishment using the BullEx Intelligent Training System. It should be noted that Class A fires are complex fires that involve many variables. A fairly detailed discussion of Class A fires can be found in NFPA 12A, Standard on Halon 1301 fire extinguishing systems, 2009 Edition, Annex I, Fire Extinguishment. Section I.2 reads in part:

> **I.2 Fires in Solid Materials**. Two types of fires can occur in solid fuels: one in which volatile gases resulting from heating or decomposition of the fuel surface are the source of combustion; and another in which oxidation occurs at the surface of, or within, the mass of fuel. The former is commonly referred to as “flaming” combustion, while the latter is often called “smoldering” or “glowing” combustion. The two types of fires frequently occur concurrently, although one type of burning can precede the other. For example, a wood fire can start as flaming combustion and become smoldering as burning progresses. Conversely, spontaneous ignition in a pile of oily rags can begin as a smoldering fire and break into flames at some later point.

This excerpt provides the background for discussion on the complexity of Class A fires and extinguishment with portable fire extinguishers. Portable fire extinguishers are installed in buildings to be used on small fires during their incipient stage. Typically, the incipient stage of a Class A fire includes flaming combustion at the surface of the fuel and will not include smoldering (deep seated) combustion because significant heat buildup is needed that can only occur over a prolonged period of time (not at the beginning stages of a fire).

The discussion in NFPA 12A continues:

> Flaming combustion, because it occurs in the vapor phase, is promptly extinguished with low levels of Halon 1301. In the absence of smoldering combustion, it will stay out.

Although the excerpt references the extinguishing agent Halon 1301, the concept can be used in a discussion of other extinguishing agents and portable fire extinguishers. A reasonable assumption is that the flaming combustion of an incipient fire can also be promptly extinguished with other more potent extinguishing agents applied with portable fire extinguishers. Once extinguished, these fires will stay out due to the absence of smoldering combustion.

2.3 BullEx Intelligent Training System

The BullEx Intelligent Training System (ITS) is a tool for training ordinary people how to properly and effectively use a fire extinguisher. The ITS uses sensor technology to determine if the trainee demonstrates the proper technique to extinguish a fire. The proper technique to extinguish a fire using the BullEx ITS is described later in the methods section.

On the front of the unit, there are four sensors that detect the sound of compressed air and water vapor being discharged from the Smart Extinguisher. These sensors are connected to a microprocessor that controls the flow of propane to the burner. (16) The system responds to different scenarios depending on how the user performs. For example, if the participant is aiming above or below the base of the flames, the system will dim the flames but not fully extinguish them. If the participant aims at one side of the flames only, it will extinguish on that side but increase in intensity on the other.

The Bull-Ex ITS consists of four parts: the unit, a propane fuel source, an electrical source, and a controller. The unit is 28 3/4" x 18" x 13", is made out of stainless steel, and has four 40 kHz ultrasonic sensors on the front. (16) Fueled by a conventional 20-lb. propane tank, the system produces 500,000 Btu/h. (16) The entire system is powered by a 12V DC battery pack that draws up to 6 amps. The final part of the unit, the controller, controls the fire. (16) The controller has settings for a Class A, B, or C fire. For each setting, the fire can be assigned a difficulty ranging from 1 to 4, with 1 being the easiest and 4 the hardest. (16)

Figure 6: BullEx ITS Activated

The system has five safety features that prevent accidental injury to the participant or trainer.

1. The controller has an emergency stop/deadman switch on the controller. The switch needs to be fully depressed and held for the system to run. If the switch is released or controller disconnected while testing, the system will immediately shut off. (16)
2. A bump/tilt sensor. If the system is no longer level, the unit will issue a loud beep and will need user input to reset the system. (16)
3. An auto-ignition pilot light that continuously sparks until there is ignition. (16)
4. An auto-off after 25 seconds of full-flame evolution. (16)
5. The system cannot be started unless a key-code entry is entered at start up. If an incorrect code is entered, the system will force the user to reassemble the unit before allowing the code to be input again. (16)

2.3 BullEx Smart Extinguishers

BullEx Smart Extinguishers are training extinguishers used to deploy agent on the controlled propane fire. The extinguisher comes in a variety of sizes to represent different types of fire extinguishers. The fire extinguishers are differentiated by how many discharges it has before refilling. This is marked either by 5X or 7X, standing for five or seven discharges before refilling respectively. (16) 5X extinguishers are filled with four liters of water. 7X extinguishers need six liters of water. All extinguishers are filled with 100 PSI of regular air. (16) This is marked by the Schrader valve on the extinguisher. The extinguishers

have approximately 15 seconds of discharge time of the agent before the pressure inside the extinguisher is too low. (15)

BullEx Smart Extinguishers mimic actual fire extinguishers in their size, shape, and weight. Most fire extinguishers can be described as metal cylinders filled with an agent to be deployed at high pressure on a fire. The agent is deployed from the extinguisher by the depression of the lever, allowing the pressurized air and water to escape (13).

Figure 7: BullEx Smart Extinguisher filled and ready for use.

3.0 Methods

This section details the study methodologies used for selecting participants, setting up the BullEx ITS, conducting the experiments, recording on each of the four aspects, and surveying the participants after the trials. The methods used during the study are discussed by topic. The *Participant Selection* section details information on the types of participants selected in the study. The *Set Up* section provides information concerning the materials used on how the BullEx system was set up in the WPI Fire Lab and EKU test site. *The Experiment* describes how the trials were carried out along with information defining the four aspects of fire extinguishers and their variables. Finally, the *Survey* details the final steps of experiment and how the survey was administered. A copy of the survey form given to participants can be found on page 18.

3.1 Participant Selection

The most effective way to test an amateur's ability to operate a fire extinguisher is to use a random sample of the population near the testing site. For WPI, the testing site is located in Higgins Laboratory in Worcester, MA WPI's random sampling of the population consisted of a diverse group of participants, including undergraduate and graduate students, faculty and staff at WPI. At EKU, the sample came from faculty and staff only employed at EKU's main campus in Richmond, KY, as well as the remote campuses in Corbin, Manchester, and Danville, KY.

3.2 Set Up

The BullEx ITS testing protocol set up was duplicated at both investigating locations, save for the type of location itself. At WPI, the location was in the WPI Fire Labs. The test areas for EKU's data collection mimicked the set up as described below, but occurred at several locations consisting of the main and several remote campuses. An outdoor location at the site of each EKU test was chosen to provide protection from wind gusts and vehicular traffic.

The complete system was assembled and disassembled following the BullEx guidelines. The BullEx ITS unit was placed in the middle of the identified test area free of any debris or unassociated items. To one side of the unit, a gas source and power source was located. There was a distance of at least four feet between the system and any object, wall or bench.

Two Bull-Ex Smart Extinguishers 7x were placed 10 feet away from the front of the propane training system. Each extinguisher was filled with six liters of water and pressurized to 100 PSI.

After the BullEx ITS base unit was placed in the center of the test areas, the quick-connect propane hose was connected to the rear of the ITS base unit. The other end of the hose was attached to the propane tank. The male end of the black controller cable was inserted into the ITS, and the female end inserted into the handheld controller. The yellow power cable was inserted into the rear of the ITS base unit. The other end of the power cable was inserted into the 12 V battery pack. The battery pack had an industrial-grade extension cable inserted into the battery pack and wall circuit. The ITS unit was leveled by adjusting the position and adjustable feet. The unit was then filled with water until it overflowed the overflow cut-outs. The sensor guard was then removed and placed eight feet away in front of the unit. The propane valve was opened and soapy water solution was added on all connections on the propane hose and unit to check for leaks.

The head assemblies of the BullEx Smart Extinguishers were removed and placed gently on the table to prevent damage. Six liters of water were measured out and slowly added into the fire extinguisher. The head assemblies were then placed back inside the fire extinguisher and screwed on hand-tight. They were carried to the air pressure valve and filled with 100 PSI or until no sound of filling was heard. This was marked by the sound of no rushing bubbles inside the fire extinguisher. The single metal pin was inserted into the tank so that the loop was beside the valve. The pin was perpendicular to the floor when the BullEx plastic break-away tamper tab was inserted around the top part of the handle and tightened so the pin could not move freely. The extinguisher was placed off to the side one foot away from where the participant was asked to stand.

The startup sequence was entered into the controller and the ITS was started up to make sure all systems were working on a setting of Class A Level 2. The system ran for 15 seconds before the switch was let go and testing could begin.

3.3 The Experiment

WPI and EKU employed the same experimental procedure and data-recording procedure. This was achieved by common test protocol and data-collection spreadsheet. Each participant was provided a date and a location for the test. When participants arrived, they were directed to read through the Institutional Review Board Approved Informed Consent Agreement for Participation. After they reported that they fully understood the form and signed it, they were given a safety briefing. Only one participant was permitted in the testing area at a time. For Trial 1, the participant stood 10 feet away from the system and was read a short introduction to the study and what to do:

> Hello, today you are participating in our study on fire extinguishers. There is a fire extinguisher to your left (POINT TO BULLEX EXTINGUISHER). We will be remotely lighting the fire. When you see the flames from the BullEx ITS (POINT TO BULLEX ITS), we will ask you to grab the extinguisher and use it to extinguish the fire we have created. Please stay behind the safety line at all times (Point at safety line). There is a label on the extinguisher to answer any questions. We are now ready to start the study. The BullEx System takes a few seconds to warm up so I will give you a verbal “Go” when you may look at the fire extinguisher and use it to extinguish the fire to the best of your abilities.

The area was checked once more to ensure the safest possible testing environment. After pressing down the BullEx ITS ignition key, the fire lit and the investigator gave a verbal “Go” when the fire reached full intensity. Two stopwatches were used to record the pre-discharge time and the total time it took to

discharge agent. At any time, the test was stopped when the subject stopped discharging agent, the fire extinguisher ran out of compressed air, or there was a safety violation.

In this experiment, the BullEx ITS worked as a constant test source, as it was able to reproduce the same intensity fire for every simulation. When the BullEx ITS had reached full flame evolution or intensity, the system emitted a beep and began recording time until extinguishment. When the beep was heard by the investigator, he/she gave the verbal "Go." The ITS continued to simulate a Class A fire until the participant was able to extinguish the simulated fire. For a participant to extinguish the fire, the water spray from the Smart Extinguisher would be recognized as an acoustic signature by the BullEx ITS. Depending on the signature made by the water spray, the system would be able to understand the trajectory of the agent and vary the heights of the flames by metering the flow of propane. The fire was considered extinguished when the controller displayed an extinguishment time.

The participants were observed and measured on the two main questions posed at the start of this paper. The two main questions can be broken down into four aspects, each with a set of variables.

3.3.1 Usage

Percent Discharged: The percentage of subjects who were able to expel the agent onto the simulated fire.

Pre-Discharge Time: The time from when the subject was told to start until the time when the agent was discharged from the fire extinguisher, measured in seconds. This time involves the subject picking up the fire extinguisher, reading the label if he/she choose to do so, breaking the seal, removing the pin, and applying pressure to the level to expel the agent.

Read the Label: The percentage of subjects who read the label of the fire extinguisher before or during the individual trial.

3.3.2 Technique

Percent Aimed at Base of the Fire: The percentage of subjects who consistently aimed at the base of the fire as they discharged agent.

Swept Back and Forth: The percentage of subjects that used a proper sweeping motion when applying agent to the fire. The proper sweeping motion is detailed as a moderate sweep of the agent across the entire fire from both left to right or right to left and back again.

Continued to Apply Agent: The percentage of subjects that continued to apply agent after the fire was no longer visible and the BullEx ITS indicated extinguishment.

3.3.3 Safety

Stood a Safe Distance Away from the Fire: The percentage of subjects that did not cross the eight-feet safety line.

Back to Fire: The percentage of subjects who physically turned their backs to the fire. This is measured by observing the subject and noting whether their shoulders were parallel with the sides of the BullEx ITS.

3.3.4 Extinguishment Simulation

Able to Simulate Extinguishment: The percentage of the subjects who were able to simulate extinguishment and an extinguishment time was displayed on the BullEx controller.

Average Time to Extinguish a Simulated Class A Fire: Time from when the BullEx ITS activated its internal stopwatch until the BullEx system determined that the simulated Class A fire was extinguished, subtracted from the amount of time the participant took to deploy agent onto the fire.

For Trial 2 of the experiment, the participant was directed back to the 10-foot mark for the test to begin. The investigators briefed the participant on the proper way to safely and effectively use a fire extinguisher via a training sheet. The sheet was modeled after the "P.A.S.S" technique (Pull, Aim, Squeeze, and Sweep). The first tip on the sheet was "Twist pin to break seal." The investigator showed the physical action in the air of inserting fingers into the imaginary pin and twisting left or right.

The next tip is to "Pull pin put". The investigator demonstrated this with a quick tug of the imaginary pin in the air. The investigator also verbally mentioned that the plastic seal can be broken by pulling it apart with their fingers instead of using the pin to break the seal.

After "Pull pin out," the sheet recommends to "Stand back 6-8 feet" from the fire. The investigator reiterated the point of that this is general fire safety information and for lab safety. If the participant crosses a safety line that is eight feet away from the fire, the investigator stops the test.

The sheet then briefed the participant on the proper way to deploy the agent stored in the fire extinguisher: "Aim and squeeze the lever. Aim at the base of flame. Use a slow sweeping motion. Continue to spray until you are sure fire will not rekindle." The investigator gestured and mimicked aiming at the base while using a slow sweeping motion toward the BullEx ITS.

When the participant indicated an understanding of the proper technique, he/she was briefed for the next trial:

> You have now been briefed on the proper way to extinguish a fire. We ask you now to use the training we have just issued you while you repeat our experiment. We ask you again to be sure to not step over the tape line for your safety. The extinguisher is full and ready for use. We are now ready to begin the second trial of our experiment; we will again be giving you a verbal "Go" for when to begin.

The participant was then timed and observed again on fire extinguisher usage and general fire safety knowledge. When the second trial was over, the participant was directed out of the lab area to a place where he/she could fill out the survey. Any questions or concerns of the participant were addressed at this point. At this time, one of the investigators reset the experiment area by clearing away the floor from the plastic break-away tamper tabs and refilling the extinguisher. The extinguishers were refilled with compressed air after every test and with water after every two to three tests.

3.4 Survey

A post-trial survey was used to gauge the participant's general knowledge of fire safety, his/her experiences with fire, and overall comfort level with the experiment. The survey was given directly after completion of Trial 2. The investigator briefed participants to fill out the survey to the best of their abilities and said to feel free to ask questions about the survey if any arose. The investigator then left

the room to help his/her partner in setting up the experiment for the next participant or briefing new participants on what they were about to test for.

Fire Protection Lab (Survey Form)

Fire extinguishment assessment

Please put an "X" in the column that best shows your answer:

How often does this happen?	Never/None	A little	Some	A lot	Strongly agree/Always	Yes	No
Have you ever used a fire extinguisher before?							
What is your knowledge level of fire extinguishers?							
Have you ever witnessed a real fire?							
Can you remember your last fire training course?							
Can you remember your last fire drill?							
Comfort level in extinguishing a Fire before the experiment?							
Comfort level in extinguishing a fire after the experiment?							

- What was your age during your most recent fire drill or fire safety training?
- Have you had a real life situation with a fire? If so please explain what actions you took.
- Briefly state any Do's and Don'ts in extinguishing fires:
- What is your first form of action when a fire is present? Ex. Run, call authorities, or look for a fire extinguisher
- Did you find the training sheet is an effective way to teach an individual how to properly use a fire extinguisher or do you find that the instructions on the fire extinguisher are sufficient?

4.0 Results

The quantitative data collected on each of the four aspects of ordinary people and the effective operation of fire extinguishers is presented here. This data answers the two main study questions[2]:

1. What is an amateur's ability to use a fire extinguisher with respect to the four aspects (usage, technique, safety, extinguishment simulation) without prior training?
2. How much, if at all, would the participants improve their usage, technique, safety, and fire control and extinguishment simulation with a minimal amount of training?

Presentation of the results is organized by the four individual aspects of fire extinguishers: usage, technique, safety, and extinguishment simulation. For each aspect, multiple data points were collected.

[2] The Results section of this report details the results collected from WPI 2011, WPI 2012, and EKU 2011-2012. WPI 2011 and WPI 2012 are not combined, as there were different primary investigators collecting the research. For WPI 2011, Scott Brady and Chrystian Dennis were the primary investigators. Along with Professor William Hicks and Professor Kathy Notarianni, they created the procedure, handout, and survey to give to students. For WPI 2012, Brandon Poole was the primary investigator. Working with Professor Notarianni, they updated the procedure and survey for clarification. As previously mentioned, all investigators at WPI and EKU followed the same guidelines and procedures to collect the data.

Each section of the results focuses one of these aspects and the specific data points collected that define the aspect both for Trial 1 – with no prior training, and Trial 2 – with minimal amount of training. The last section contains data concerning the survey administered to participants from EKU and WPI 2012.

Between January 20 to February 22, 2012, 85 participants were tested using the BullEx ITS on key aspects of fire extinguisher usage for WPI 2012 testing. During the previous academic year (2011-2012), WPI and EKU also collected data, bringing the grand total of number of participants that chose to contribute to the study to a staggering 276. WPI 2010-2011 data contributed 64 participants. EKU 2010-2012 data contributed 127 participants. WPI 2011-2012 data contributed 85 participants.

For WPI 2011, 80% of those were male and 20% were female. The average age of participants was 20 years. For WPI 2012, 74% of those were male and 26% were female. This ratio, while skewed in favor of the male population, was expected as the ratio of male to female students at WPI is 3:1. (17) The average age of the participants was 21 years. The range of ages for WPI 2011-2012 was 18 to 56 years. For EKU 2010-2012, 61% of participants were males and 39% were female. The average age of the participants was 36 years. The range of ages for EKU was 20 to 76 years.

4.1 Key Milestones of Usage Results

During the experiment, participants demonstrated their ability to use a fire extinguisher as they deployed agent. Specifically, the investigators observed whether or not the participants read the label on the extinguisher, if they were able to discharge agent from the extinguisher, and the amount of time it took them to deploy the agent.

Observations from both locations included:

- Throughout the experiment, it was observed that many participants had difficulty pulling the pin out from the extinguisher.
- There were occurrences in which participants did not use enough strength to pull the pin, which led them to read or reread the label.
- For Trial 1, one participant was not able to understand how to pull the pin out of the extinguisher, and the machine timed out after the fire had burned for one minute and 30 seconds.
-

Table 1: Trial 1 Collected Data for Key Milestones of Usage

Trial 1 Collected Data for Key Milestones of Usage*				
	# of tests conducted	% able to discharge agent	Ave. Pre-discharge time (sec)	Read Label
WPI '11	64	100%	15.2	47%
WPI '12	85	99%	14.6	49%
EKU '11-'12	127	97%	11.6	16%
TOTAL/AVERAGE	276	98%	13.4	33%

*BullEx ITS and Smart Extinguishers were used to measure these variables

Table 1, Trial 1 Collected Data for Key Milestones of Usage, shows all the collected data throughout the entire experiment for key milestones of usage for Trial 1. Specifically this table looks at the number of participants in Trial 1 and the averages for the trial. For WPI ’11, all 64 participants were able to discharge agent onto the fire; 47% chose to read the label with an average discharge time of 15.2 seconds. EKU ’11-’12 had 127 participants, of which 97% were able to discharge the agent; 16% read the label; and the average discharge time was 11.6 seconds. WPI ’12 had 85 participants; 99% of those were able to discharge the agent with 49% reading the label and an average discharge time of 14.6 seconds. The total number of tests conducted for Trial 1 was 276, with 98% of those who participated being able to discharge agent, 33% chose to read the label, and an average discharge time of 13.4 seconds overall.

Table 2: Trial 2 Collected Data for Key Milestones of Usage

Trial 2 Collected Data for Key Milestones of Usage*				
	# of tests conducted	% able to discharge agent	Ave. Pre-discharge time (sec)	Read Label
WPI ‘11	64	100%	6.5	2%
WPI ‘12	85	100%	6.7	7%
EKU ’11-‘12	127	100%	7.9	22%
TOTAL/AVERAGE	276	100%	7.2	13%

* BullEx ITS and Smart Extinguishers were used to measure these variables

Table 2, Trial 2 Collected Data for Key Milestones of Usage, shows all collected data throughout the entire experiment for key milestone of usage for Trial 2. Specifically this table looks at the numbers of participants in Trial 2 and the averages for the trial. For all participants, they were able to discharge the agent. For WPI ’11, 2% chose to read the label, EKU ’11-’12, 22% chose to read the label and WPI ’12 7% chose to read the label. Of the 276 particpants, 13% chose to read the label. WPI ’11 discharge times average for 64 participants was 6.5 seconds. EKU ’11-’12 average discharge times average for 127 was 7.9 seconds. WPI ’12 average discharge time for 85 participants was 6.7 seconds. The average time for the 276 participants was 7.2 seconds.

Table 3: Percent Improvement with Training for Key Milestones of Usage

Percent Improvement with Training for Key Milestones of Usage*				
	# of tests conducted	% able to discharge	Pre-discharge time (sec)	Read Label
WPI '11	64	All Subjects Discharged Agent	Decreased by 57%	Decreased by 45%
WPI '12	85	All Subjects Discharged Agent	Decreased by 54%	Decreased by 42%
EKU '11-'12	127	All Subjects Discharged Agent	Decreased by 31%	Decreased by 6%
TOTAL/AVERAGE	276	All Subjects Discharged Agent	Decreased by 44%	Decreased by 26%

* BullEx ITS and Smart Extinguishers were used to measure these variables

Table 3, Percent Improvement with Training for Key Milestones of Usage, shows the percentage improvement from Trial 1 to Trial 2 for key milestones of usage. Overall, all 276 participants were able to discharge agent. There was a 46% decrease in discharge agent time. And there was a 20% decrease in reading the label.

Figure 8: Participant viewing the label on the BullEx Smart Extinguisher while BullEx ITS was active

Figure 8 shows a participant squatting down to read the label on the fire extinguisher. The participant was not permitted to read the label on the fire extinguisher before the BullEx system reached full intensity. A verbal "Go" was given when the system started recording the time until stopping the discharge and this was the first action of the participant. At all times the participant had the fire and BullEx ITS in his field of vision.

4.2 Technique in Handling a Fire Extinguisher Results

Participants were then observed on their technique as they handled the fire extinguisher. Did they aim at the base of the fire, use a slow back and forth sweeping motion, and continue to spray after the fire was not visible?

Observations from both locations included:

- In one occurrence a participant did not grab the hose from the holder on the fire extinguisher and used the base of the fire extinguisher to aim at the fire.
- Another participant misread the instructions and pulsed on the handle of the fire extinguisher to deploy the agent instead of allowing for a continuous stream.

Table 4: Trial 1 Technique in Handling a Fire Extinguisher

Trial 1 Technique in Handling a Fire Extinguisher*				
	# of tests conducted	Aimed at base of fire	Back/forth sweeping motion	Continued to spray after fire not visible
WPI '11	64	64%	81%	50%
WPI '12	85	54%	45%	32%
EKU '11-'12	127	88%	89%	57%
TOTAL/AVERAGE	276	72%	74%	48%

* BullEx ITS and Smart Extinguishers were used to measure these variables

Table 4, Trial 1 Technique in Handling a Fire Extinguisher, shows all the collected data for Trial 1. For WPI '11, 64% aimed at the base of the fire, 81% used a back-and-forth sweeping motion, and 50% continued to spray after the fire was not visible. For EKU '11-'12, 88% aimed at base of fire, 89% used a back-and-forth sweeping motion, and 57% continued to spray after the fire was not visible. For WPI '12, 54% aimed at the base of the fire, 45% used a back-and-forth sweeping motion, and 32% continued to spray after fire was not visible. For all 276 participants, 72% aimed at the base of the fire, 74% used a back-and-forth sweeping motion, and 48% continued to spray after fire was not visible.

Table 5: Trial 2 Technique in Handling a Fire Extinguisher

Trial 2 Technique in Handling a Fire Extinguisher*				
	# of tests conducted	Aimed at base of fire	Back/forth sweeping motion	Continued to spray after fire not visible
WPI '11	64	98%	100%	80%
WPI '12	85	86%	94%	86%
EKU '11-'12	127	96%	95%	82%
TOTAL/AVERAGE	276	93%	96%	83%

* BullEx ITS and Smart Extinguishers were used to measure these variables

Table 5, Trial 2 Technique in Handling a Fire Extinguisher, shows all the collected data for Trial 2. For WPI '11, 98% aimed at the base of the fire, 100% used a back-and-forth sweeping motion, and 80% continued to spray after the fire was not visible. For EKU '11-'12, 96% aimed at base of fire, 95% used a back-and-forth sweeping motion, and 82% continued to spray after the fire was not visible. For WPI '12, 86% aimed at the base of the fire, 94% used a back-and-forth sweeping motion, and 86% continued to spray after fire was not visible. For all 276 participants, 93% aimed at the base of the fire, 96% used a back-and-forth sweeping motion, and 83% continued to spray after fire was not visible.

Table 6: Percent Improvement of Technique in Handling a Fire Extinguisher

Percent Improvement of Technique in Handling a Fire Extinguisher*				
	# of tests conducted	Aimed at base of fire	Back/forth sweeping motion	Continued to spray after fire not visible
WPI '11	64	Increased by 34%	Increased by 19%	Increased by 30%
WPI '12	85	Increased by 32%	Increased by 49%	Increased by 52%
EKU '11-'12	127	Increased by 8%	Increased by 6%	Increased by 25%
TOTAL/AVERAGE	276	Increased by 21%	Increased by 22%	Increased by 34%

*BullEx ITS and Smart Extinguishers were used to measure these variables

Table 6, Percent Improvement of Technique in Handling a Fire Extinguisher, shows the percentage improvement from Trial 1 to Trial 2. Overall, 276 participants improved their ability to aim at the base of the fire by 21%, so 93% aimed at the base. Participants improved their ability to use the proper sweep technique by 22%, so 96% used the sweeping back-and-forth motion. Finally, 83% of participants continued to spray after the fire was not visible, a 35% increase.

Figure 9: Participant aiming above the base of the BullEx ITS

Figure 9 shows the participant incorrectly aiming at the top of the flames. The compressed air and water mixture was depolyed to the top of the flames and sprayed the door instead of the base of the flames. A black line was added to indicate where the base of the flames are.

Figure 10: Participant aiming at the base of the BullEx ITS

Figure 10 shows a participant correctly aiming at the base of the BullEx ITS unit. The participant also used a slow sweeping motion as she aimed at the base of the flames to deploy agent.

Figure 11: Participant using a sweeping motion to deploy agent on BullEx ITS

Figure 11 shows a participant aiming at the base of the flames and using a slow sweeping motion across the BullEx ITS system. The two arrows represent the path that should be followed as the extinguisher is swept slowly from side to side. The BullEx ITS system reacts to the correct sweeping motion and aiming at the base, as signified by dimming of the flames on the right side of the unit.

Figure 12 and 13: Participant is not continuously deploying agent

Figures 12 and 13 shows a particpant extinguishing the fire but but not continuing to deploy agent. The fire re-ignites in Figure 13 as the participant begins to turn away from the fire.

Figure 14: Participant continuously deploys agent on propane fire, thereby preventing re-ignition

Figure 14 shows a participant continuously deploying agent onto the fire by using the proper technique. The participant continued to spray the unit until she was told that the trial was over.

4.3 Key Knowledge in Fire Safety Results

During the test, participants were observed for key knowledge in fire safety. Did the participant turn his/her back to the fire once it was started, and did the participant cross the recommended safety distance of eight feet from the fire?

Table 7: Key Knowledge in Fire Safety for Trial 1

Key Knowledge in Fire Safety for Trial 1*			
	# of tests conducted	Stood a safe distance away	Turned back to fire
WPI '11	64	100%	2%
WPI '12	85	100%	4%
EKU '11-'12	127	99%	6%
TOTAL/AVERAGE	276	100%	4%

*BullEx ITS and Smart Extinguishers were used to measure these variables

Table 7, Key Knowledge in Fire Safety for Trial 1, shows data for Trial 1. For WPI '11, all participants stood a safe distance away from the fire, and 2% turned their backs to the fire. For EKU '11-'12, 99% of participants stood a safe distance away from the fire, and 6% turned their backs to it. For WPI '12, all participants stood a safe distance away, and 4% turned their backs to the fire. Overall, on average all participants stood a safe distance away, and 4% turned their backs to the fire.

Table 8: Key Knowledge in Fire Safety for Trial 2

Key Knowledge in Fire Safety for Trial 2*			
	# of tests conducted	Stood a safe distance away	Turned back to fire
WPI '11	64	100%	0%
WPI '12	85	100%	4%
EKU '11-'12	127	100%	2%
TOTAL/AVERAGE	276	100%	2%

*BullEx ITS and Smart Extinguishers were used to measure these variables

Table 8, Key Knowledge in Fire Safety for Trial 2, shows data, for Trial 2. For WPI '11, all participants stood a safe distance away from the fire and no one turned their backs to the fire. For EKU '11-'12, all participants stood a safe distance away from the fire, and 2% turned their backs to it. For WPI '12, all participants stood a safe distance away, and 4% turned their backs to the fire. Overall, on average all participants stood a safe distance away, and 2% turned their backs to the fire.

Table 9: Percent Improvement of Key Knowledge in Fire Safety

Percent Improvement of Key Knowledge in Fire Safety*			
	# of tests conducted	Stood a safe distance away	Turned back to fire
WPI '11	64	All participants stood a safe distance back	Decreased by 2%
WPI '12	85	All participant stood a safe distance back	Decreased by 0%
EKU '11-'12	127	All participants stood a safe distance back	Decreased by 4%
TOTAL/AVERAGE	276	All participants stood a safe distance back	Decreased by 2%

*BullEx ITS and Smart Extinguishers were used to measure these variables

Table 9, Percent Improvement of Key Knowledge in Fire Safety shows the percent improvement of key knowledge in fire safety from Trial 1 to Trial 2. Overall, all participants stood a safe distance away. The percentage of participants who turned their backs to the fire was decreased by 2%

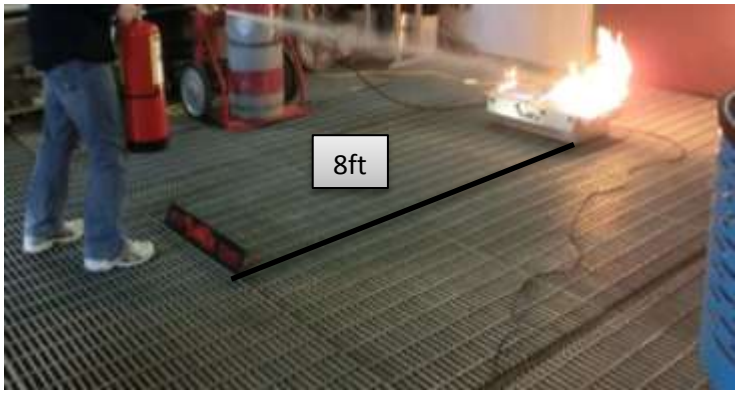

Figure 16: Participant standing just over 8ft away from the BullEx ITS

Figure 16 shows a participant standing more than eight feet away from the BullEx ITS system. Due to safety regulations, if a participant were to cross the BullEx black sensor guard, the investigator would immediately end the test due to safety concerns.

Figure 17: Participant turning back to the fire while attempting to free the pin from the BullEx Smart Extinguisher

Figure 17 shows a participant turning her back to the fire. The participant immediately turned her back to the fire to read the label and then attempted to free the pin from the fire extinguisher.

4.4 Participants Effectiveness in Extinguishing a Simulated Fire Results

During the tests, participants were observed on how effective they use the BullEx device to simulate extinguishment. For this study, we used a setting that simulates a Class A fire. Although the device provides an extinguishment time when the proper technique is used and simulated extinguishment occurs, the results are not intended to be used as a direct correlation with actual Class A fires due to the many variables that are associated with a Class A fire.

Further testing is needed to determine if the extinguishment times achieved using a BullEx training tool correlate with the extinguishment times achieved using a fire extinguisher on a real fire. The following information lists the percentages of participants able to cause extinguishment simulation via the BullEx ITS and the average amount of time it took to simulate extinguishment for all the trials.

In Trial 1, 65% of the 276 participants (both WPI and EKU) were able to extinguish the fire using the BullEx ITS. The average amount of time it took to extinguish the simulated fire was 11.2 seconds. In Trial 2, 90% of the participants were able to cause extinguishment simulation via the BullEx ITS. The average amount of time it took to extinguish the simulated fire was 7.3 seconds. In this portion of the study, there was a 25% increase in the number of test subjects able to cause a simulated extinguishment in the second trial. In addition to this increase, the time to achieve a simulated extinguishment was reduced by an average of 34%.

4.5 Survey Results

The same survey was given out to all study participants. The survey's purpose was to understand the participant's knowledge about fire safety, experiences with fire, and overall comfort level with the experiment. Participants were surveyed on 15 questions in a table or free response.

Only one question from the table section generated useful information: Have you ever witnessed a real fire? The remaining questions in the table had a wide variety of responses to the seven possible choices.

In the free response section, eight questions gave adequate responses. Of the five questions on the original survey sheet, four more were asked verbally and added at the end of the survey. The verbal questions were:

1. Have you ever used a fire extinguisher before? Yes/no.
2. On a scale of 1-10 with 1 being the most uncomfortable and 10 being the most comfortable, what was your comfort level of using an extinguisher before this experiment?
3. On the same scale of 1-10, what is your comfort level with using an extinguisher after this experiment?
4. Did you find the training sheet an effective way to teach an individual how to properly use a fire extinguisher, or do you find that the instructions on the fire extinguisher are sufficient?

Table 10: Survey Responses

	Witnessed Fire	Age of Last Fire Drill	Used a Fire Extinguisher	Comfort Level Before Using the BullEx ITS	After using the BullEx ITS	Instructions after Trial 1 were more helpful
WPI	49%	19	11%	6	9	31%

	Witnessed Fire	Age of Last Fire Drill	Used a Fire Extinguisher	Comfort Level Before Using the BullEx ITS	After using the BullEx ITS	Instructions after Trial 1 were more helpful
EKU	54%	32	17%	5	9	45%

Table 10, Survey Responses, show the percentage of participants from both test locations who have witnessed a fire, the average age of participants' last fire drill, the percentage of participants who have used a fire extinguisher before, the average comfort level of the use of a fire extinguisher before and after an experiment, and the percentage of participants who clearly stated that the instructions were more helpful.

Of the 127 participants tested by EKU, 54% had witnessed a fire emergency. The average age of the participants' last fire drill was 32 years. Seventeen percent of participants had used a fire extinguisher before this experiment. On a scale of 1-10 with 1 being the most uncomfortable and 10 being the most comfortable, the average participant had a comfort level of 5 before picking up a fire extinguisher. After the experiment, the average participant had a comfort level of 9. Of the 127 participants, 45% said that the instructions were more helpful than what was written on the fire extinguisher.

Of the 85 participants tested by WPI '12, 49% had witnessed a fire emergency. The average age of the participants' last fire drill was 19 years. Eleven percent of participants had used a fire extinguisher before this experiment. On a scale of 1-10 with 1 being the most uncomfortable and 10 being the most comfortable, the average participant had a comfort level of 6 before picking up a fire extinguisher. After the experiment, the average participant had a comfort level of 9. Of the 85 participants, 31% said that the instructions were more helpful than what was written on the fire extinguisher. This does not mean that 69% did not find the instructions more helpful, but chose not to respond to the final question.

Both studies collected similar results for the query *Briefly state any Do's and Don'ts in extinguishing a fire.* Most participants chose to respond by reiterating the instructions on the fire extinguisher and what was verbally told to them. Some participants added this *Do*: Keep calm during a fire and not to panic. A few participants added specific information on how to extinguish specific fires, such as not using water on grease fires.

5.0 Discussion

The purpose of this study was to examine the current questions of the fire protection industry concerning the ability of amateurs to operate a portable fire extinguisher. The study was conducted in two stages to answer the two separate questions:

- What are the capabilities of the novice population to operate a fire extinguisher effectively?
- How well can the above performance improve with a small amount of training?

WPI and EKU studied this problem and conducted experiments involving 276 participants. Study participants discharged a fire extinguisher on a simulated fire using the BullEx ITS. They were observed on the four aspects of fire extinguishers, which were quantitatively measured by 10 variables.

5.1 Key Milestones of Usage

In the data point titled Key Milestones of Usage, participants were observed for their ability to discharge agent onto the fire, their average pre-discharge time, and whether or not they read the label. As shown in Table 3, Percent Improvement with Training for Key Milestones of Usage, participants were able to increase their ability to discharge the agent as well as being able to decrease the time it took to discharge the agent. Overall, participants were more confident in their second trial in not needing to read the label for instructions.

For both WPI '11 and WPI '12, the average age of the participants was the early 20s. The *read the label* variable for WPI '11-'12 decreased from Trial 1 to Trial 2. Overall, 33% of participants read the label for Trial 1, and 13% of participants read the label for Trial 2. This suggests that most participants do not need to read the label to use a fire extinguisher. This decrease in reading the label was expected as approximately half of the participants viewed the label in the first trial.

For EKU '11-'12, the average age of the participants was the late 30s. There was an increase of 6% in reading the label. EKU '11-'12 also had the least amount of improvement for time to discharge agent by 31%. For WPI '11 and '12 pre-discharge time, they decreased by 57% and 54%, respectively, for Trial 1 to Trial 2. This suggests that the younger generation has a faster reaction time.

5.2 Technique in Handling a Fire Extinguisher

In technique in handling a fire extinguisher, participants were observed for if they were able to aim at the base, used a slow back and forth sweeping motion, and continued to spray agent on the fire even after the fire was no longer visible. As shown in Table 6, Percent Improvement of Technique in Handling a Fire Extinguisher, all milestones showed improvement from Trial 1 to Trial 2. EKU '11-'12 had the smallest overall amount of improvement with WPI '11 following and WPI '12 with the greatest amount of improvement. EKU '11-'12 had the highest starting numbers for their key milestone data for Trial 1. The data suggests that most participants are able to use the proper technique to deploy agent onto the

fire and with verbal instructions of how to use a fire extinguisher, the participants' ability to use a fire extinguisher improved.

5.3 Key Knowledge in Fire Safety

For the key knowledge in fire safety, participants were observed on if they turned their backs to the fire and if they kept a safe distance from the fire. Of all the aspects, this one resulted in the smallest improvement. Overall, only 4% of the participants turned their backs to the fire in Trial 1. Two percent of EKU '11-'12 still turned their backs to the fire in Trial 2. WPI '11 had the greatest improvement, with no participants turning their backs to the fire in Trial 2. WPI '12 had no improvement in the number of participants who turned their backs to the fire.

The data suggests that most participants know not to turn their backs to the fire. All participants respected the eight-foot mark after being briefed not to go beyond it at the start of the experiment, per Institutional Review Board general guidelines and BullEx safety instructions. There were some instances at EKU in which a participant did cross the line but by a marginal amount. For WPI '11-'12, many participants stood at a distance greater than eight feet away. This finding suggests that participants will approach the fire at a distance they are comfortable with.

5.4 Participants Effectiveness in Extinguishing a Simulated Fire

Investigators observed participants on their effectiveness in extinguishing a simulated fire. Two key factors from the data collected are considered in this measure: the percentage of participants able to simulate extinguishment of the fire, and the amount of time it took to extinguisher a simulated Class A fire. According to the data collected, nearly all participants were proficient in their ability to discharge agent onto the fire (98% in Trial 1, 100% in Trial 2). The majority of participants were able to simulate complete extinguishment in the Trial 1 (65%), and almost all were able to do so in Trial 2 (90%). Participants that were able to complete extinguishment in Trial 1 accomplished this task in 11.2 seconds and 7.3 seconds in Trial 2.

The question remains: Can this data validate the current ability of an ordinary operate a fire extinguisher successfully? Before this is answered, what does the study need to accomplish to answer this question? In order to compare extinguishment of Class A fires, they need to be created in repeatable configurations and materials, provided with a reliable/repeatable ignition source, and allowed a known pre-burn time. For example, UL 711, Standard for Safety for Rating and Testing of Fire Extinguishers, goes into great detail to specify exact lengths and sizes of lumber used in their wood crib fire tests, prescribing the percentage of moisture content as determined by ASTM D2016-74, Test for Moisture Content of Wood; the exact configuration of the crib; the flammable liquid ignition source in a specific pan; and a precise pre-burn time in order to establish a standardized repeatable test.

However, the Bull Ex system, like any good simulator, is capable of presenting very challenging and similar conditions. This makes it highly likely that in real world incipient fires, the extinguishment success rate would be higher. Therefore the data reported in this report may or may not correlate with an amateur person's ability to extinguish a Class A fire or any other type of fire. The data does show the ability of participants to extinguish the Class A fire simulated by the BullEx ITS.

5.5 Survey

The post-test survey provided valuable insight on how knowledgeable and comfortable the "current" generation is with fire safety. Of the 276 participants surveyed, more than half had witnessed a fire emergency. Therefore is can be speculated that, when the population is in their early 20's, about 50% will have witnessed a fire emergency. For WPI '12, the average age of their last fire drill was 19 years; at EKU the average age of their last fire drill was 32 years. Only 11% of the 85 participants surveyed from WPI '12 and 17% of the 127 participants at EKU have used a fire extinguisher before participating in this study. Yet judging from the experiments results, this did not affect the participant's ability to use a fire extinguisher.

For both EKU and WPI '12, the comfort level before using a fire extinguisher was 5-6 on a scale of 1-10. After using the BullEx ITS, their comfort level rose to a 9. Due to the safe environment created by the experiment, it is unknown what the ordinary person's comfort level would be while using a fire extinguisher during a true emergency. The data does show that, with one trial and a brief instruction on how to effectively use a fire extinguisher, a participant's comfort level rose significantly. The verbal instructions given to participants were received well by 45% of EKU's 127 participants and 31% of WPI's '12 85 participants. This suggests that verbal directions about how to effectively use a fire extinguisher improved the participant's performance.

5.6 Conclusion, Limitations, and Further Study

As shown throughout the Results section, the data collected strongly suggests that the ordinary person can operate a fire extinguisher and utilize proper technique to effectively extinguish a fire. Overall, 98% of the 276 participants were able to discharge extinguishing agent onto a fire on their first trial; 100% of the participants were successful on their second trial. Second, with a minimal amount of training, there was a measureable improvement in all variables measured for in this experiment from Trial 1 to Trial 2.

During testing, many ideas surfaced on how to improve the experiment and possible areas of further study. This section addresses these ideas.

As previously mentioned, the BullEx Smart Extinguisher can deploy agent for approximately 15 seconds before the effectiveness of the extinguisher decreases. Specifically, the sound signature produced by the extinguisher begins to weaken. This time limit affected the participants' ability to extinguish the simulated fire through proper use of the fire extinguisher. Many participants went past the 15-second mark of extinguishment and were unable to extinguish the fire at this point, as there was no longer any pressure inside to expel the agent. When it was obvious to the investigators that the extinguisher ran out of pressurized air to expel agent, the test was stopped and marked as not extinguished. It is reported that real fire extinguishers have up to 30 seconds of agent to deploy. Given this extra 15 seconds to extinguish the fire, it is expected that many participants would have been able to extinguish the fire on their first trial. This hypothesis is support by the results of Trial 2 extinguishment, in which 90% of the 276 participants were able to extinguish the simulated fire.

According to the BullEx recommendations, the Smart Extinguishers would need to be refilled with water after 3-4 trials of use. This recommendation was followed in the experiment, enabling some participants to use a fire extinguisher weighing slightly less to extinguish the fire. There were no instances where a participant ran out of water to extinguish the fire, only out of pressurized air. There was only one

instance in which a participant struggled to lift the fire extinguisher and had to drag it on its base toward the safety line to deploy agent.

Due to the enclosed area, which included a ventilation system for added safety, the BullEx ITS tended to operate at a somewhat higher difficulty setting. This caused a small increase in extinguishment time for WPI compared to normal outdoor usage, such as at the EKU the setting.

The experiments conducted by EKU occurred on the main campus as well as several remote campuses. These locations were out-of-doors in areas sheltered from wind gusts. No negative factors were observed in these locations that affected data collection.

The participants gathered at WPI and EKU were limited to participants that visit or work on a college campus. This includes students, faculty, staff, friends, and family. Thus the data collected represents only a small portion of the general amateur population.

The experiment conducted by WPI and EKU brought participants into an environment that controlled as many variables as possible, with a focus on participant safety. Participants had the knowledge of where the fire extinguisher and simulated fire were located and were allowed to ask any questions that could be answered without influencing the study. This alleviated anxiety that could exist when confronted with a real fire. Participants did have a choice to stop the experiment at any time if they felt they were unsafe, even though they were also surrounded by numerous safety precautions that they had been briefed on.

An area meriting further study is to examine the percentage of participants that would pick up a fire extinguisher in a real fire emergency along with the other factors studied for in the present experiment. The participant would need to be deceived and walk into a normal room where a controlled fire is lit remotely. The participant would be provided access to a fire alarm, fire extinguisher, and several exits.

To further study an ordinary person's ability to use a fire extinguisher effectively, a study needs to be conducted investigating an ordinary person's ability to extinguish different types of fire classifications or whether a fire extinguisher should be used at all.

As noted in the Results section, participants had difficultly removing the pin. During data collection at both EKU and WPI '12, it was noted that most participants during either Trial 1 or Trial 2 had difficultly removing the pin. This can be seen in the number of participants whose pre-discharge time was more than 15 seconds. While this can be attributed to the participant being flustered in a stressful situation, the use of a fire extinguisher can be a very stressful activity. An investigation should be conducted to see if there is a more user-friendly design for the pin or more appropriate way to prevent accidental discharge.

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7.0 Appendix

7.1 Procedure

Protocol for Test Day

1. Set up the BullEx system
    a. See BullEx Quick Reference Manual
2. Fill the BullEx extinguishers for the test subjects with 6 liters of water
    a. This is the 7x Smart Extinguisher (This lasts 3 trials at most)
3. Pressurize the extinguishers to green line
4. Set Hood on the "Low" setting to ventilate area.
5. Mark safety line 8 feet away

   Hello, today you are participating in our study on fire extinguishers. There is a fire extinguisher to your left (POINT TO BULLEX EXTINGUISHER). We will be remotely lighting the fire. When you see the flames from the BullEx ITS (POINT TO BULLEX ITS), we will ask you to grab the extinguisher and use it to extinguish fire we have created. Please stay behind the safety line at all times (Point at safety line). There is a label on the extinguisher to answer any questions. We are now ready to start the study. The BullEx System takes a few seconds to warm up so I will give you a verbal "Go" when you make look at the fire extinguisher and use it to extinguish the fire to the best of your abilities.
6. Double check the test area for safety
7. Fill out date and age for the subject
8. Clear the test area for the test subject to begin
9. Ignite fire and start the timer (for the stop watch)
10. Record time up to water being sprayed
11. Monitor to see if subject puts back to fire
12. Monitor to see if subject reads the label
13. Record how far back from fire the subject stays
14. Monitor to see if the subject aimed at base
15. Monitor to see if subject used a sweeping motion
16. Record if the continued to spray
17. Record total extinguishment time (from BullEx ITS)
18. Turn Hood on the 'Medium' setting after 1st test. If trial lasted for more than 45 seconds, turn Hood on 'High' setting and open door to ventilate area.
19. Investigator briefs the test subject on the correct use of a extinguisher
    (See Training Sheet)
20. Investigator returns the lab to its original state prior to the first extinguishment
21. Fill the used extinguisher for second trial
22. Turn Hood back to 'Low' as not to interfere with acoustics of system.
23. Test subject is returned to the FPE lab to perform the experiment again

    You have now been briefed on the proper way to extinguish a fire. We ask you now to use the training we have just issued you while you repeat our experiment. We ask you again to be sure to not step over the tape line for your safety. The extinguisher is full and ready for use. We are now ready to begin the second trial of our experiment; we will again be giving you a verbal "Go" for when to begin.

24. Return to STEP 7, repeat all steps until STEP 17
25. Test subject exits, Return to Step 1 to begin the next session

7.2 Hand Out

Training Script for Proper Extinguishment

- TWIST PIN to break seal
- PULL PIN OUT
- Stand back 6 to 8 feet
- AIM and SQUEEZE the lever
    - Aim at base of flame
    - Use a slow sweeping motion