



Smart Firefighting Technologies in Urban China

An Interactive Qualifying Project Proposal

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Abstract

As urbanization in China promotes rapid population growth, urban areas become increasingly densely populated. The distribution of citizens, the spatial organization of these cities, and the rate of development all present unique challenges to Chinese firefighters and disaster responders. In this report, Beijing, Wuhan, and Shanghai will be used as case studies to represent densely populated urban areas in China. The goal of our project is to develop recommendations for our sponsor, the WPI-Tsinghua University Center for Global Public Safety, that integrate new smart technologies to make firefighting safer and more efficient in densely populated urban areas within China. We achieved this goal through the research of current and emerging smart firefighting technologies globally and in China, identification of the current limitations of firefighting technology in urban China, and analysis of our findings to determine the best suited technology to help address the challenges.

Acknowledgements

Our project would not have been possible without the assistance and support of various individuals. We would like to thank our sponsor organization, the WPI-Tsinghua University Center for Global Public Safety and the students and professors from the Wuhan University of Technology for their continued support, guidance, and interest in our project. Furthermore, we would like to thank the Chinese Police Forces Academy, the Hubei Provincial firefighting equipment distributor in Wuhan, and engineers affiliated with the Shanghai fire station for taking the time to meet with our team and help with our primary data collection while in China.

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Executive Summary

Introduction:

On a global scale, firefighters are presented with similar challenges; they must perform physically demanding work in low oxygen and critically hot conditions, maneuver with heavy gear in unfamiliar layouts, and work quickly in unstable, deteriorating buildings. To address these challenges, it is vital that incident responses are as efficient and subsequently as safe as possible.

In this report, three major cities in China, Beijing, Wuhan, and Shanghai, will be used as case studies to represent densely populated urban areas in China. These cities are some of the most densely populated places on Earth, and their populations continue to grow rapidly due to the pace of urbanization in China. Therefore, the distribution of citizens, the spatial organization, and the rate of development of these cities all present unique challenges regarding firefighting within urban China. The goal of our project is to develop recommendations for our sponsor, the WPI-Tsinghua University Center for Global Public Safety, that integrate new smart technologies to make firefighting safer and more efficient in densely populated urban areas within China. We will achieve this goal through the research of current and emerging smart firefighting technologies globally and in China, identification of the current limitations of firefighting technology in urban China, and analysis of our findings to determine the best suited technology to help address the challenges.

Project Objectives:

In order to achieve our set goal, the team created four objectives:

1. Defined the challenges specific to firefighting and current technologies in urban China
2. Identified suitable recommendations to address the identified problems regarding firefighting technology
3. Developed a plan to implement suitable technologies in urban China fire departments
4. Presented report of recommendations and implementation plan to sponsors

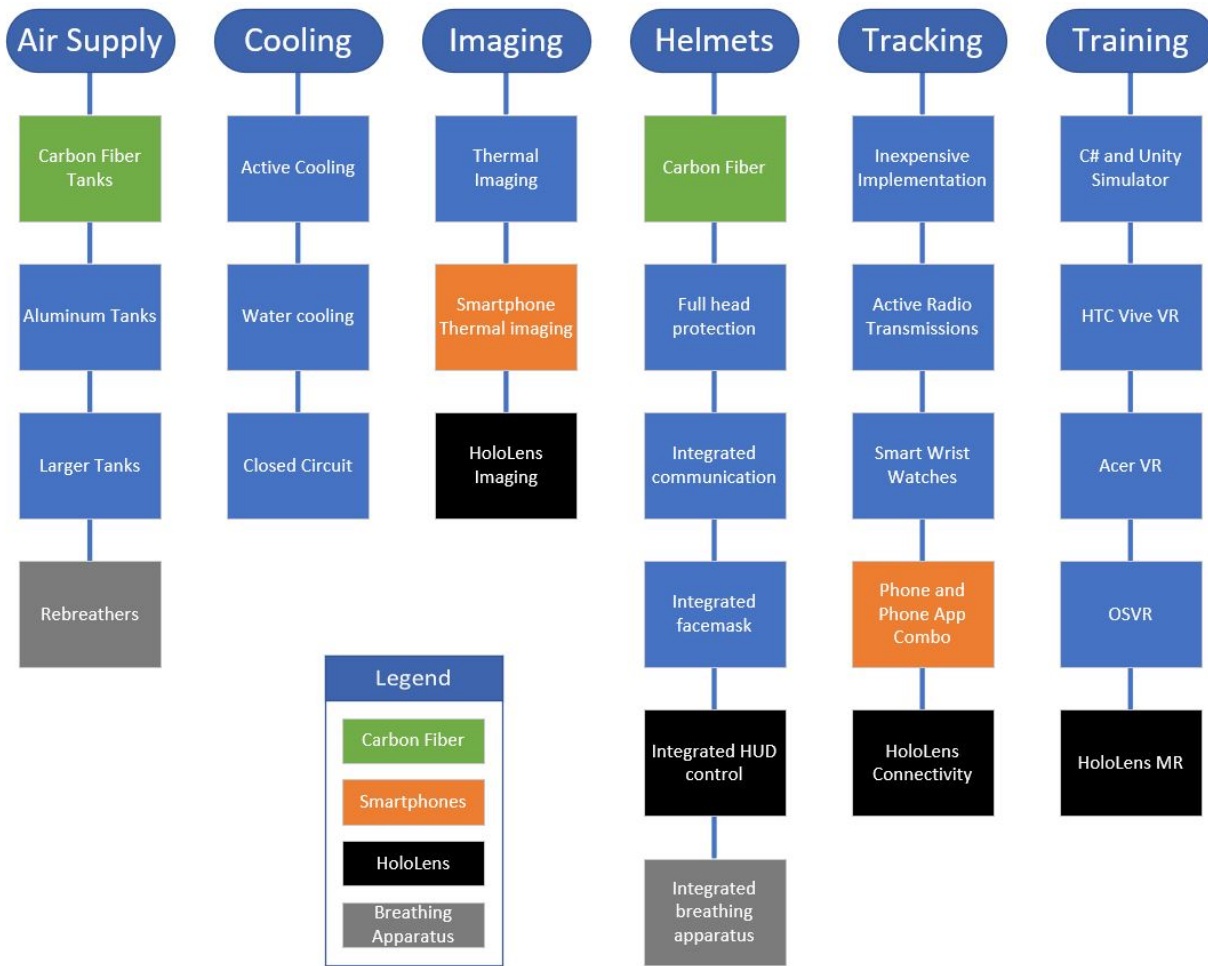
We achieved these objectives through research of current and emerging smart firefighting technologies globally and in China. We interviewed fire department staff and experts in the field of fire protection engineering in our research. The analysis of our findings was used to determine the best suited technologies to address firefighting challenges in urban China. The goal was to compile a report of recommendations and the determined implementation plan to our sponsor, the WPI-Tsinghua University Research Center for Global Public Safety.

Findings:

1. Communication is an essential component in safe and efficient firefighting and is restricted by outdated firefighting technology.
2. Situational awareness is low in fire disaster situations, making navigation difficult.
3. Fatigue and accidental injuries are a major safety risk for urban firefighters.
4. Updated smart firefighting technology could be applied to training to better prepare firefighters for actual incidents.

5. Improving actual equipment used to fight fires would increase the efficiency of firefighting and therefore the safety of firefighters within fires.

Recommendations:



This figure displays a comprehensive summary of our recommended solution. More information on each can be found in section 5.0.

Authorship

Section	Primary Author(s)	Primary Editor(s)
1.0 Introduction	AB	All
2.0 Background	AB	All
2.1 Challenges of Fighting Fires in Urban Areas	MP	All
2.1.1 Reaching The Fire	MP	All
2.1.2 D Maneuverability, Communication, and Fire Suppression Challenges	MP	All
2.2 Firefighting Within the Context of Beijing	AB	All
2.2.1 Fire Protection Technology Research and Development	AB	All
2.2.2 Chinese Fire Protection Codes and Standards	AB	YQ
2.3 Firefighting Technologies	AS	All
2.3.1 Current Technology	AS	All
2.3.2 Emerging Technologies	AS	All
2.4 Conclusion	AS, MP	All
3.0 Methodology	AB	MP, AS

3.1 Defining the Challenges Specific to Firefighting Procedure and Current Technology in Beijing	AB	MP, AS
3.1.1 Involve Focus Group of Beijing Firefighters	AB	MP
3.1.2 Assessing Current Firefighting Technologies	AB	MP
3.2 Identifying Suitable Recommendations to Address the Identified Problems Regarding Firefighting Technology	MP	AB
3.2.1 Analyzing Global Technology and Determine Its Applicability in Urban China	AS, MP	AB
3.2.2 Interviewing Professors at Tsinghua and Wuhan Universities in the Field of Fire Protection	AS, MP	AB
3.3 Developing a Plan to Implement Suitable Technologies in Beijing Fire Departments	YQ	AB
3.3.1 Creating an Instructional Report	AB	YQ, AS
3.4 Presenting a Report of Recommendations and Implementation Plan to Sponsors	YQ	AB
4.0 Results and Analysis	All	AB
5.0 Recommendations	AS, MP	AB
5.1 Air Supply	AS, MP	AB

5.2 Cooling	AS, MP	AB
5.3 Imaging	AS, MP	AB
5.4 Helmet	AS, MP	AB
5.5 Tracking	AS, MP	AB
5.6 Training	AS, MP	AB
5.7 HoloLens	AS, MP	AB
5.8 Creative Technologies	AS, MP	AB
6.0 Conclusion	AB	AS

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1.0 Introduction:

Fighting fires in densely populated urban areas presents a unique set of challenges compared with other geographic locations. First, to accommodate for larger populations, buildings are closer together allowing fires to spread more easily, increasing the risk of critical injury and loss (Himoto, Akimoto, Hokugo, and Tanaka, 2009.) Large populations also present traffic and crowd control challenges when responding to an incident. Limited land space in these urban areas calls for the need of high-rise buildings where fires are difficult to reach while the lack of open spaces poses challenges for safe evacuation.

Firefighters in different regions in general are presented with similar challenges; they must perform physically demanding work in low oxygen and critically hot conditions, maneuver with heavy gear in unfamiliar layouts, work quickly in unstable, deteriorating buildings (Sirpa, 2010), and account for congestion due to traffic, bystanders, and close proximity of buildings (Branlat, Fern, Voshell, and Trent, 2009.) To address these challenges, it is vital that incident responses are as efficient and subsequently as safe as possible. The unpredictability of uncontrolled fire and limited funding in general, causes fire protection to not be an immediate concern of citizens and policymakers.

In this report, three major cities in China, Beijing, Wuhan, and Shanghai, will be used as case studies to represent densely populated urban areas in China. According to the United Nations, in 2016, Beijing, China was listed as the sixth most populated city in the world. With a population of around 21.5 million, Beijing is one of the most densely populated urban areas on the planet. Beijing is an ancient city that was developed over 3000 years ago. Many buildings

were constructed before newer smart firefighting technologies were developed and are not up to current fire standards (Bloszies, 2012) as well as having faulty electrical systems as wires can deteriorate over time posing a risk for electrical fires. Another particular challenge unique to Beijing are the city's specific spatial patterns and infrastructure that must also be considered in developing firefighting technology for the city. High rise buildings are at risk of flashover fires where the fire moves from the lower floors upwards. If the lower levels of a high rise building combust first, people on the upper floors will be trapped (Chow, 1998). There is also a spatial mismatch between low-income and wealthy populations within Beijing. Low income areas far from the city's center have been hastily and cheaply built to accommodate for quickly rising populations seeking affordable housing (Qi, Fan, Sun, and Hu, 2017.) Regulations are overlooked in these areas making living spaces cramped. In these areas, regulations can be overlooked and living spaces cramped. One such example of a disastrous fire situation occurred in a low-income district of Beijing inhabited primarily by low-income migrant workers. An apartment complex caught fire, killing nearly all the residents of the building (Buckley, 2017.)

Engineers and scientists continually work to develop smart firefighting technologies to address some of the challenges described above. In Beijing, firefighters introduced the use of flame suppressant delivering rockets to put out fires in high rise buildings. In the case of a high rise fire the rocket can reach 80 floors off the ground (Lei, 2017.) A number of companies including Design Reality and Scott Safety have developed various respiratory masks that allow firefighters to breathe oxygen in burning buildings along with thermal imaging capabilities to view their surroundings in dense environments (Doran and Prisco 2017.) Researchers at the University of Edinburgh developed sensors that can be placed around a building to receive real-time thermal and pressure data. In the case of a building burning, data from the sensors will be

used in computer programs to predict how the fire is likely to spread, allowing firefighters to plan their course of action (University of Edinburgh 2010.) These developing technologies are examples of the recent movements towards the research and development of fire protection technology and standards.

Despite the existence of these new technologies and their potential to save lives, Beijing has been slow to implement them due to the city's rapid urbanization. Economic growth is faster than new research can be implemented. Many newer technologies require large budgets to purchase. New technologies also take time to learn and require development of methods to train firemen in their use and maintenance. If the technology is too complicated, it will not be efficient for firefighters. Due to these factors, Beijing's current firefighting technology is outdated (Y. M. Han et al. 2013). The technologies must be able to transition easily into China's current system, some of the biggest issues with implementing fire technology in Beijing are regulatory (Hu and Chow 2006).

The goal of our project is to develop recommendations for our sponsor, the WPI-Tsinghua University Center for Global Public Safety, that integrate new smart technologies to make firefighting safer and more efficient in densely populated urban areas within China. We will achieve this goal through the research of current and emerging smart firefighting technologies globally and in Beijing, identification of the current limitations of firefighting technology in Beijing, and analysis of our findings to determine the best suited technology to help address the challenges.

2.0 Background

This chapter will establish challenges associated with urban firefighting and determine how emerging firefighting technologies will help address them. We will begin by establishing the challenges specific to fighting fires in urban areas and then focus on the unique challenges in Beijing, representative in this report of urban areas across China. We will then go into describing the limitations of current firefighting technologies currently used in Beijing and determine how emerging technologies will help address these limitations and firefighting challenges.

2.1 Challenges of Fighting Fires in Urban Areas

Challenges such as reaching the fires in a timely manner, maneuvering an unknown burning building, and adequately suppressing the fire hinder the safety and reduce the success rate of the firefighters. These challenges are amplified in urban areas, where high density of skyscrapers and close proximity of the buildings feed these challenges making it an unavoidable firefighting struggle in cities like Beijing.

2.1.1 Delays with Getting to The Fire-Sites and to the Fires Inside the Buildings

Responding to a fire in a timely manner is a major challenge associated with urban firefighting. On average, fire doubles every 30 to 60 seconds depending on the wind speed, meaning even the slightest delay can result in an induced spread of fire throughout the building and into the surrounding areas (Rothermel, R. C., & Anderson, H. E. 1966). This is a serious threat in large cities like Beijing where delays caused by traffic congestions, roadblocks, and firefighting in high rises are typical. Traffic congestion creates a delay by preventing the passage of emergency vehicles from reaching the fire site in a timely manner (Branlat, Fern, Voshell, &

Trent, 2009). Human activity and natural disasters, such as road work and earthquakes, create roadblocks which require emergency vehicles to be rerouted, ultimately causing a delay (Konishi, T., Kikugawa, H., Iwata, Y., Koseki, H., Sagae, K., Ito, A., & Kato, K., 2008). Fighting fires in high rises also causes a delay because firefighters have to manually climb multiple flights of stairs, while fighting the opposing flow of evacuees, to get to the fire (Kuligowski, E. 2003). On average, firefighters take 15 to 30 minutes to climb 60 stories, making firefighting a serious concern in urban areas (Baker, M. 2016).

2.1.2 Maneuverability, Communication, and Fire Suppression Challenges

When firefighters reach the fire site, they are faced with even more challenges which include maneuverability, communication, and fire suppression challenges that hinder the safety and reduce the success rate of the fire fighters. On average, 30,000 firefighters get injured onsite inside a burning building and 60 of them die yearly in United States alone (Haynes, H. J. G., & Molis, J. L. 2017). These deaths and injuries occur as a result of having insufficient knowledge of the building's layout and how it changes over time. As such, firefighters have to rely on ground support, which includes a chief who communicates with the firefighters and the tactical team who plans and updates safe routes for them to follow, to guide them safely throughout the building to conduct their firefighting missions. If ground support is unable to guide them, then firefighters have to instinctively and visually maneuver the building on their own (Fischer, C., & Gellersen, H., 2010). Thick smoke further adds to this challenge by impairing firefighters' vision to a point where they are walking around blind (Amon, F., Hamins, A., Bryner, N., & Rowe, J., 2008). Under these conditions, firefighting can become a serious safety hazard for the firefighters where slightest miscommunication or wrong judgment can entrap them within the

building, ultimately leading them to death or severely injuring them (Fischer, C., & Gellersen, H., 2010).

Suppressing the fire is also a challenge where inadequate suppression methods can increase the severity of the fire. With multiple types of fires, such as grease fires, chemical fires, electrical fires and general fires, each type must be suppressed in a certain way with adequate equipment and suppressants. Fighting a particular type of fire inadequately, such as fighting a grease fire with water, can result in an induced spread of the fire, causing it to go out of control (Nolan, D. P. 2014). This can ultimately result in injuries to the firefighters and an increased collateral damage.

2.2 Firefighting in Beijing

In 2016 Beijing was ranked by the United Nations as the sixth most populated city at 21.5 million people. As one of the most densely populated urban areas in the world, the city is highly vulnerable to fires. Narrow streets allow fires to spread quickly and the close proximity of buildings restricts fire engine access (Himoto, Akimoto, Hokugo, & Tanaka 2009.)

Beijing is an ancient city that has history dating back over 3000 years. The oldest continuously inhabited parts of the city date back to the Yuan Dynasty in the mid-13th century (National Commission of the People's Republic of China for UNESCO, 2013.) Buildings constructed before newer smart firefighting technologies were developed, lightweight, fire resistant materials or new technology such as sprinklers, pressurized fire stairs, smoke-ventilating vestibules, emergency power generators, or onsite water tanks (Bloszies, 2012), are not up to current standards. Additionally, they risk having faulty electrical systems as wires can deteriorate over time posing a risk for electrical fires (Hall 2013.)

Beijing has exactly 337 completed high rise buildings above 12 stories. High rise buildings are at risk to flashover fires, which means that if lower levels of a high rise building combust first, leaving people on the upper floors trapped (Chow, 1998). There is also a spatial mismatch between low-income and wealthy populations within Beijing. Low income areas far from the city's center have been hastily and cheaply built to accommodate for quickly rising populations seeking affordable housing (Qi, Fan, Sun, and Hu, 2018.) Regulations can be overlooked and living spaces cramped (Zheng, Long, Fan, & Gu 2013.) A disastrous fire to an apartment in the low-income southern Daxing district that killed 19 prompted safety checks in migrant neighborhoods. 25,395 sites with some sort of safety risk were identified (Rivers & Wang, 2017.)

2.2.1 Fire Protection Technology Research and Development

The number of instances of fires has increased in China with the development of industrialization and urbanization, this has encouraged an emphasize on fire protection research in China. China has since made a commitment to fire technology development and research. In the 1950's, when urbanization was relatively low (10.6%), the annual average property damage costs from fires was about 60 million Yuan. Since then the annual average has increased to 1.55 billion Yuan within the first five years of the 21st century (Guo & Fu, 2007.) Fires are occurring more frequently and are costly due to the damages they cause. Research in China focuses on developing fire detecting, alarming and suppression, fire resistance and prevention, fire modeling technologies, and performance-based fire safety design, urban fire protection, and fire protection standardization (Tienan, 2005.) Despite recent research, instances of property damage and casualties from fires remains very high. The pace of economic development is more rapid than

that of scientific research. Applying new technology and research in practice is slower than the rate of fire instances. As a result, the technology currently implemented in Chinese fire departments has not been modernized. These outdated technologies are inefficient and expensive. Heavy gear weighs down firefighters and water-based suppressants are ineffective at extinguishing industrial chemical fires (Guo & Fu, 2007.) Along with the concentrated efforts in fire protection technology research, development of standardized fire protection has been mobilized.

2.2.2 Chinese Fire Protection Codes and Standards

The Chinese government run Fire Service Department of the Ministry of Public Security has made efforts to boost research into fire science and its applications since the implementation of reform policies in 1978. Fire protection standardization has developed along with firefighting technology (Guo & Fu, 2007.) China has no performance based fire codes established yet and the existing fire codes are not suited to all buildings, especially those with unique architectural features. Performance based codes are regulations that vary depending on the specific requirements of a given building such as the energy efficiency of the building or seismic load as opposed to fire codes that are standardized for all buildings (Hu & Chow 2008.) Performance based fire codes differ from standardized codes as they can change depending on the demands of the building while generic standardized codes do not.

Firefighting, fire protection, and rescue have also moved to become standardized. Fire protection research has served as the basis of the creation of 289 fire codes and standards. A required capacity for urban water supply systems has been decided and a plan for allocation and

configuration has been proposed. Based on calculated fire risks, a method of allocating firefighting resources has been established (Tienan, 2005.)

2.3 Firefighting Technologies

Companies rise to the challenge in an attempt to solve challenges in firefighting. They develop technologies to assist and monitor firefighters in adverse environments in a wide range of fields from wearable technologies to firefighting drones to explosive fire extinguishers. Firefighting technologies fit into two categorical groups: interactive and connected technologies. Interactive technologies require hands-on interaction and focus on the task at hand to be successful. Equipment that requires extra lifting or training falls into this category. Connected technologies require no attention or monitoring by the firefighter to ensure proper function and operation. These technologies help people make decisions in real time and physically augment tasks that are normally assigned to people. Integrating connected technologies into fire brigades will allow firefighters to focus on more important tasks such as rescuing stranded people. Connected technologies can save buildings, but currently, people save people.

2.3.1 Current Technologies

Most current technologies are interactive. Firefighters must be prepared to fight fires or navigate a waste area where the contaminants in the air would incapacitate firefighters in a short amount of time. This challenge forced firefighters to carry large oxygen tanks on their backs during They must have the ability to maintain a clean source of oxygen while inside burning buildings, often having to stop moving and refer to gauges on their body while navigating burning buildings. This added weight amounts to less maneuverability and requires monitoring,

making oxygen tanks an interactive technology. Overall, this technology demands the interaction of firefighters and therefore holds firemen back from their maximum efficiency. While entering these extreme situations, firefighters require air reservoirs and facemasks in order to breathe the oxygen-low air. Firemen must be able to view their surroundings while in the vicinity of extreme heat or noxious gases. They must be able to work in adverse environments, so these safety measures are required for them to do their job (Neavling, 2015). The technology of facemasks is interactive because the firefighter has to monitor it to make sure that they are able to maintain a constant line of sight. If they are dislodged or dirty, they will compromise the effectiveness of the firefighters in situations where a facemask is the last line of defense.

All firefighters need the ability to traverse obstacles that cannot be maneuvered without the use of excessive force. In order to access locations that require eliminating obstacles, firefighters use tools like the Jaws of Life. The Jaws of Life cutting tool uses large cutting blades to chew up metal and force objects in motion. This gives firefighters the ability to remove formidable objects encountered in constricting areas. Firefighters also use them to cut open cars and metal structures without going through fire hazards (Bonsor, 2001). Interactive technologies require full attention to operate: technologies like the Jaws of Life require heavy interaction.

These technologies are essential to the jobs of firefighters, yet they strain the focus of firefighters away from self-preservation.

2.3.2 Emerging Technologies

Companies and experts in the field of fire protection engineering develop new technologies to address growing difficulties involved with firefighting. Developing technologies either re-implement existing technologies in innovative ways or consists of entirely new

research. One innovative implementation of mechanizing the normally arduous task of moving equipment and extinguishing fires includes the TAF20 firefighting robot. The TAF20 takes a regular skid-steer loader used in construction and mounts a water cannon on top, giving firefighters a mobile water truck for maneuvering tough situations. As shown in figure 1, the water cannon has the ability to shoot water out in a narrow and directed form or in a mist, as shown in Figure 2. The robot also has a plow on the front to push cars or rubble out of the way, giving firefighters protection from the fire as well as a safe path to the scene. The remote controlled robot makes it possible to forgo trained operators thereby reducing lives risked (EMI Controls). The capabilities of the robot tractors alleviate the need for firefighters to interact with the environment and maneuver obstacles allowing firefighters to focus on coordination and planning rather than losing focus on the objective of reaching people.



Figure 1. The TAF20 firefighting robot testing its water cannon. Notice the plow on the front of the tractor and the focused stream of water (Bharat, 2015).



Figure 2. The water cannon is spraying mist instead of a focused stream (Bharat, 2015).

Another implementation of currently existing technologies integrates e-textiles into firefighter suits. E-textiles include clothing or garments with electrical sensors and circuits wired into the clothing, removing the need for gear outside the suit. Some researchers implemented circuits inside a firefighter's suit to read information about the firefighter like temperature and motion. These sensors are all connected wirelessly to a central processing unit on the firefighter (Soukup et. al, 2014). This processing unit then transmits the information to firefighters on the ground, giving firefighter coordinators the ability to monitor the movements of firemen in real-time without the need for monitored firemen to have to stop their work and transmit information. This allows firefighters to alert ground control of their movement so as to assist in figuring out where to best move firefighters to contain the situation as well as rescue the firefighters in case they are in trouble. This constant connectivity prevents firefighters from being lost to fires as

well as remove the responsibility of localization from firefighters to computers, allowing firefighters to focus on finding stranded people.

This is an example of connecting technologies in that the firefighter communicates without interacting with equipment on their person. Not only do sensors actively monitor firefighters throughout burning buildings, the data the sensors collect gives computers the information they need to plan movements of firemen in disaster situations. Researchers created algorithms that continually monitor the motion of firefighters to build an accurate map of the surrounding terrain and topography. The computer algorithms not only have the ability to find firefighters but they are also able to analyze the movements of firemen and determine the best path to fight the blaze in real-time (Chammem et. al, 2012). Algorithms calculate risks involved in different decisions that firefighters could make and then decide which action the firefighters should take. This software control of motion planning alleviates the necessity for constant human monitoring and intervention. This freedom then allows more firefighters to focus on putting out the blaze rather than reporting back analysis in the scene. This algorithmic control is the forefront of connected devices: taking data and extrapolating information about the environment and automatically creating a response that can then be forwarded to relevant parties.

With wireless devices connecting firefighters and planners in real-time, the hardware that transmits the data must be powerful enough to provide the signals over long distances and through all sorts of obstacles. All of the connected technologies rely on hardware support, leading new technologies to create new platforms to support the high-bandwidth that connected devices rely on. Researchers developed an antenna with several advanced capabilities to solve high-bandwidth issues. In order to prevent gear from interrupting the signal, the helmet is mounted on the firefighter's head. The antenna, however, does not simply transmit and receive

data, it has its own computer controller that uses algorithms to control which portion of the antenna is receiving the best signal (Wang et. al, 1997). Figure three shows how the wireless signal distributes itself in the environment. Given the antenna disables portions of the antenna with weaker signals, firefighters maintain a constant and low-noise connection with firemen on the ground. Powering off the unused antennas also conserves battery power. This antenna technology is important because the quantity of sensors impacts communication performance, which, given the circumstances that firefighters may venture far away from safety, may lead to a life or death scenario. This automation of data transmission further alleviates any weakness in communication in burning buildings, allowing not only firefighters but also coordinators to focus on getting people out of dangerous situations.

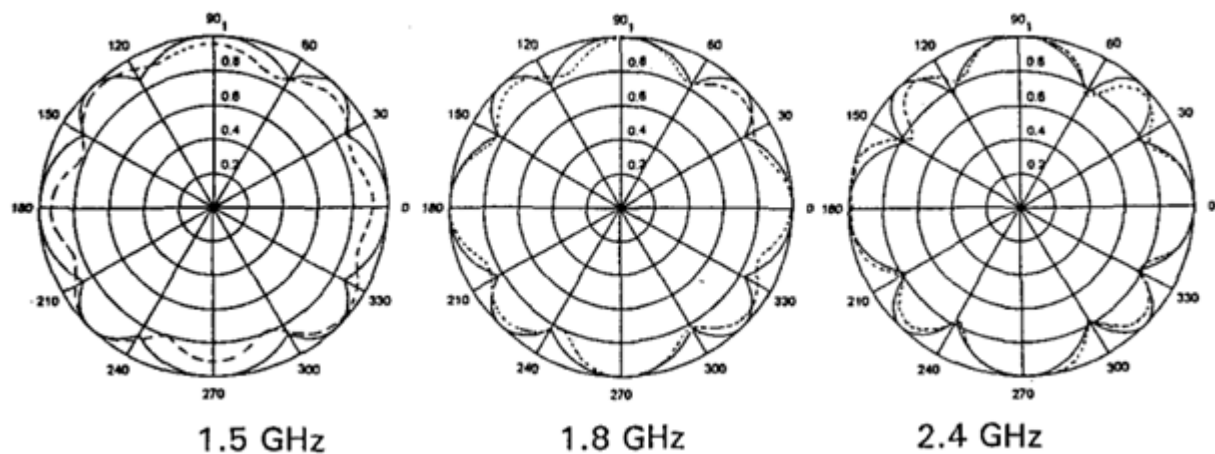


Figure 3. These diagrams show the spread of radio signals using the specialized antenna with dashed and solid lines (Wang et al., 1997).

Companies have also invented more creative technologies to extinguish fires, like fire extinguishing grenades. One recent implementation of a patent from 1979 describes a sphere

around the size of a soccer ball as an aqueous detonating fire extinguisher. The spherical orb contains an aqueous solution in a bladder that is surrounded in a tough shield. The orb can be detonated using either heat from flames or detonation upon impact with a surface. When the orb explodes it releases the aqueous solution into the air, spraying it around in all directions (Poland, 1979). This spreading creates a cloud of droplets around the orb, completely covering any surface within the direct vicinity of the orb. This cloud therefore covers any flames nearby, completely extinguishing the flames instantly. Although this patent has existed for decades, only recently have such devices been used to combat fires. This technology is interactive in application but also shares the automation capabilities that connected devices enumerate. This allows the technology to not only be used by firefighters but also by civilians trapped in buildings or spectating on the ground.

At George Mason University, a team of students developed an amplifier that puts out fires using low frequencies (30 to 60 hertz) to snuff out fires. To put out large fires, however, the students had to attach an amplifier to the audio generator so that the sound waves were powerful enough to put out the fire (Tegün, 2017). One popular example of sonic flame control is the Reuben's tube, which clearly demonstrates the effects sound has over flames. The students used this phenomenon and amplified a sound signal to control flames. The device only cost around \$600 to make, proving a viable and inexpensive option to put out fires. This invention uses interactive technologies but brings benefits through inexpensive components and high portability. This fire extinguisher also uses a commonly accessible fuel source that does not affect the weight firefighters carry, making this invention suitable for firefighting on a large scale. Such a technology has the ability to create an impact through cheap manufacturing and

ease of use which allows for greater adoption across Beijing fire agencies. These technologies have the potential to revolutionize firefighting in Beijing.

2.4 Conclusion

There are many challenges firefighters face, particularly in Beijing, as described in this chapter. The interactive, connected, and mixed technologies described here work to address the challenges firefighters face in increasingly connected environments. To overcome these challenges, this project will analyze the benefits of these new firefighting technologies and their costs and benefits in the context of firefighting in Beijing. This will allow us to best determine what solutions will operate well with firefighters and save the most lives in Beijing.

3.0 Methodology

The goal of our project was to develop recommendations that integrate new smart technologies to make firefighting safer and more efficient in urban China where Beijing, Wuhan and Shanghai were focused on as representatives of densely populated urban areas within China. To achieve this goal, we:

1. Defined the challenges specific to firefighting and current technologies in urban China
2. Identified suitable recommendations to address the identified problems regarding firefighting technology
3. Developed a plan to implement suitable technologies in urban Chinese fire departments
4. Presented report of recommendations and implementation plan to sponsors

We achieved these objectives through research of current and emerging smart firefighting technologies globally and in China. We interviewed fire department staff and experts in the field of fire protection engineering in our research. The analysis of our findings was used to determine the best suited technologies to address firefighting challenges in urban China. The goal was to compile a report of recommendations and the determined implementation plan to our sponsor, the WPI-Tsinghua University Research Center for Global Public Safety.

3.1 Defining the Challenges Specific to Firefighting Procedures and Current Technology in Urban China

Our first objective served to identify the specific challenges our project addressed based on cost, complexity of training, and efficiency of the technology. Through this objective, we allowed for the preparation of later objectives. We focused on assessing the technology used both by the Beijing Municipal Bureau of Public Security and throughout China. We made recommendations based on our analysis. The Beijing Municipal Bureau of Public Security is the component of Beijing's local government responsible for the public security of the municipality including fire protection, control, and brigades (Beijing International 2008.) The Beijing Municipal Bureau of Public Security is concerned with the general public specifically within Beijing. Commercial fire departments owned by private businesses were outside of the scope of this project.

3.1.1 Creation of a Focus Group of Firefighters

The first step was to organize a focus group of firefighters from the Beijing Municipal Bureau of Public Security. We worked closely with Tsinghua University during this project. This

university has close ties to Chinese police forces and disaster responders due to their maintenance of the GS911 CAD system. This system is used to predict future disasters, help firefighters make decisions, and communicate that guidance to firefighters in real time using data analysis. We utilized this connection to get in contact with firefighters affiliated with the Chinese Police Forces Academy. We created a focus group of five firefighters from Beijing and Wuhan in order to maintain a variety of data in multiple densely populated urban Chinese cities.

We first met with Beijing firefighters affiliated with the Chinese Police Forces Academy at Tsinghua University to conduct an interview. We spent no more than two hours moderating a conversation about the challenges of current firefighting process and technology as utilized by the Beijing fire department. We developed questions that allowed the firefighters to discuss the challenges and limitations of Beijing firefighting to either confirm our findings from our preliminary research or deepen them. Primarily, we wanted to determine what Beijing firefighters' primary concerns were regarding current firefighting technology in use by the Bureau and whether these challenges can be applied across China. We wanted to determine what is inefficient about current technologies and how improved technologies could reduce risk to firefighters, civilians, and property.

We also surveyed two groups of firefighters to collect both qualitative and quantitative data. We gave two separate surveys, one to eighteen firefighters in Beijing and another to eight firefighters in Wuhan. The firefighting experts consisted of people with a range of experiences, such as firefighters, students training to be firefighters, commanders and safety inspectors. Gathering a wide range of opinions allowed us to gain a deeper understanding of the challenges associated with Chinese firefighting. The two surveys were unique in the type of data they gathered. The data allowed us to gain an understanding of what improvements would be accepted

and helpful to firefighters. In addition, the data assisted us to determine the importance and urgency of the desired improvements. After the first set of surveys, we realized we wanted to focus more specifically on firefighting technology and not more general training methods and position requirements. Therefore, we edited the original survey questions, which we then gave out to Wuhan firefighters. These edits were created to improve the accuracy of our data collection, and also to refine the type of data we collected, to match the direction our project ended up heading.

We first surveyed a group of eighteen fire-fighters affiliated with Tsinghua University and the Chinese Police Forces Academy. The positions of these firefighters included duty squadrons members, lieutenants, students training to become firefighters, and commanders. The questions on the survey (translated into English) can be found in section 8.1 of the appendix. These survey questions were chosen to help us develop an understanding of what demands are put upon Chinese urban firefighters in their day to day jobs. The questions focused primarily on training. Training would reflect the demands of responding to genuine disaster incidents, however, the firefighters surveyed would likely have more experience in training than in actual incidents. We anticipated more data from a firefighter perspective regarding training than actual incident response which occur much less frequently.

After synthesizing data from both the survey results and interview responses with Beijing firefighters we decided to rework our survey before collecting data from Wuhan firefighters. This complete survey can be found in section 8.2 of the appendix. From the training focused survey given to Beijing firefighters, we had developed a sense of the daily demands of firefighting. Our project had since shifted direction and we were instead interested in gauging Chinese firefighter opinions on specific firefighting technology. This shift would better prepare

us to complete the final steps of our project in which we would generate educated recommendations on improving smart firefighting technology in China

Understanding the perspectives of firefighters in Beijing and Wuhan gave us direct feedback on the current firefighting system and technology in urban China to use as a basis for improvement moving forward.

3.1.2 Assessing Current Firefighting Technologies

We observed the current equipment used by Chinese firefighters in Wuhan in order to understand where exactly improvements would be advantageous. We applied our findings from 3.1.1 to define what technology is *outdated* or requiring improvements to improve their efficiency and safety as determined by the firefighters utilizing them.



First, we physically observed this identified technology to gain a clearer understanding of its flaws. We were helped with this project by students and professors at the Wuhan University of Technology. WUT arranged for an on-site visit of the Wuhan Fire Station. On-site visitation allowed us to shadow the fire department workers working and training when not responding to an incident. Shadowing firefighters responding to an actual incident was not be feasible as our presence may cause inefficiency and increased risk. On-site visitation at the fire department was the best option for collecting qualitative data. The fire department was able to show us what is limiting and outdated regarding their equipment and we asked additional questions as needed to support our understanding of what we saw.

We also analyzed the published data collected during standardized fire equipment inspections, testing, and maintenance. We received access to this data through our sponsor. This gave us hard, quantitative data useful for generalizing results and the development of a concise

problem statement. The original documentation was in Chinese, students from Wuhan University of Technology helped us translate the document into English for us to analyze.

Once we established a clear understanding of the challenges present, focusing on cost, complexity of training required, how well it addresses the problems firefighters experience in fire departments globally, and the availability of data, we presented our findings to our sponsor, and representatives from the WPI-Tsinghua University Research Center for Global Public Safety. This allowed our sponsor, including experts in the field of fire protection, to confirm that our findings are both reasonable and accurate.

3.2 Identifying Suitable Recommendations to Address the Identified Problems Regarding Firefighting Technology

Interactive (Current)	Connected (Emerging)
<p data-bbox="203 1083 654 1150">Walkie-Talkies, Land-Line Phones (Communication)</p> 	<p data-bbox="841 1083 1404 1188">Helmet HUD (Heads Up Display), Light-weight Batteries, Wearable sensors, Motion Tracking</p> 

Helmets, Tethered ropes, No internal cooling
(Safety)



Ultra-Durable, Smaller, Integrated High-Powered Antennas



Blueprints, exploration, professional guessing
(Visibility)

Visual and Thermal Cameras, Surveillance Drones, Disposable drones





<p>Heavy Equipment Hoses, Suits, Air tanks, (Mobility)</p> 	<p>Carbon Fiber materials, smaller electronics, Fire Tractors, smaller tanks, rebreathers</p> 
<p>Leadership, Little universal communication, Little decision assistance (Communication)</p>	<p>Real-Time Data Analysis and Decision Inferencing, Machine-Learning, Data mining</p>

Figure 4. This chart exhibits a variety of smart firefighting technology that could benefit urban firefighting in China

Our second objective was focused on identifying the benefits of emerging technologies around the world and in China to determine how those new technologies will overcome the challenges presented to the firefighters in urban China as described in our focus groups, onsite visitations, and the analysis of published data. To approach this objective, we split it into two subcategories where the first category will focus on analyzing and ranking firefighting challenges determined during focus groups and the second category will focus on gathering expert knowledge on specific technologies through interviews to determining if it will be feasible in urban China. We also outlined the benefits of each technology based on cost, complexity of training, and efficiency of the technology and explain how it will contribute to increasing safety of the firefighters and how it makes firefighting more efficient in urban China in this subcategory.

3.2.1 Analyzing Global Technology and Determine Its Applicability in Urban China

We related the preliminary background research to the challenges described by focus groups. The responses collected from focus groups, both interviews and surveys, were ranked according to which challenges majority of the focus groups found relevant to Chinese urban firefighting and also to understand what types of technologies will be accepted by firefighters in urban China. After we had determined the most relevant firefighting challenges in urban China, we addressed those challenges in the interview with the experts.

We also compared the preliminary research we collected on firefighting in the United States and globally to the challenges determined in urban China. Through this comparison, we gained an understanding of what technologies would benefit firefighters in urban China and how current technologies could be upgraded or optimized to overcome the challenges. After we analyzed our findings, we prepared to compile everything into a recommendation.

3.2.2 Interviewing Experts in the Field of Fire Protection

We interviewed experts in the field of fire protection engineering to gain an expert opinion on how to overcome the challenges presented by focus groups and technology assessments. Our goal for these interviews included: understanding which technologies could help address the challenges presented in the focus groups, understanding how the technology in question works, and determining the benefits of that technology and any specific implications it may have on firefighting in urban China. With guidance from our sponsor, we determined who we should interview to obtain the most relevant expertise. We interviewed four engineers at the Shanghai Fire Station to gain insight on currently implemented firefighting technology in China. This interview lasted between 1 to 2 hours and took place at the respective station.

If the interviewee did not speak English, we set up two group members as the interviewers, one member as a translator and one member as the note taker. If they spoke English, we had one note taker and the rest asking questions in a predetermined order. The interviewer asked questions from a list of prewritten and pre-approved questions that were then relayed to the translator who then relayed the question to the interviewee. Our questions were directed towards emerging firefighting technologies, but the interviewee was encouraged to add background context to the question where necessary.

After we analyzed these findings through comparison, we prepared to compile our analysis into a recommendation.

3.3 Develop a Plan to Implement Suitable Technologies in Urban Chinese Fire

Departments

At this point, we had established the challenges specific to firefighting in the representative cities and identified suitable recommendations that address firefighting challenges in these cities and within major Chinese cities. The next objective was to construct a feasible plan to facilitate how these new smart firefighting technologies would be implemented. This objective was necessary to analyze our data collected and to organize it into a deliverable for our sponsor.

3.3.1 Create an Instructional Report

Our report takes the form of a report and database that analyzes recommendations brainstormed to address the specific firefighting technology limitations and challenges within urban China in a practical context, providing each step necessary to transition to updated

technologies. Furthermore, our plan accounts for factors that affect fire departments. These factors include cost, complexity of training required, and how well it addresses the problems firefighters experience in fire departments globally. We also analyze testing results of the technology if it is still in development. This narrative clearly delineates the feasibility of the adoption of our recommended practices and compares and contrasts the benefits of each potential technology.

Once we established an implementation plan of the technologies we recommend to address the challenges present, we presented our findings to our sponsor, a representative from the WPI-Tsinghua University Research Center for Global Public Safety.

3.4 Presenting a Report of Recommendations and Implementation Plan to Sponsors

The final step was to prepare our deliverable taking the form of a compiled report of our findings. We presented this report detailing the recommendations determined and the plan to facilitate implementation of these recommendations to our sponsor.

4.0 Results and Analysis

Communication is an essential component in safe and efficient firefighting and is restricted by outdated firefighting technology.

A major point stressed during all sessions of contact with Chinese firefighters was the importance of communication between combatant squadrons, teams, and command outside of the fire. Communication is necessary to articulate decisions and vital safety information between command and combatant firefighters.

The survey conducted in Beijing (section 8.1 of the appendix) heavily focused on the

topics of training such as challenges during simulated and live training processes. With limited previous understanding of firefighting training, we believed it was essential to begin our investigation starting with understanding the basics of training. We believed that by uncovering the motivation behind the various training simulations, we would understand the hardships faced by firefighters in the field as training should be reflective of actual incident response. Firefighters train very often while actual incidents are less frequent so we anticipated firefighters would offer more accurate feedback from training experience than actual disaster response experience. We prompted surveyed firefighters on common methods used for training.

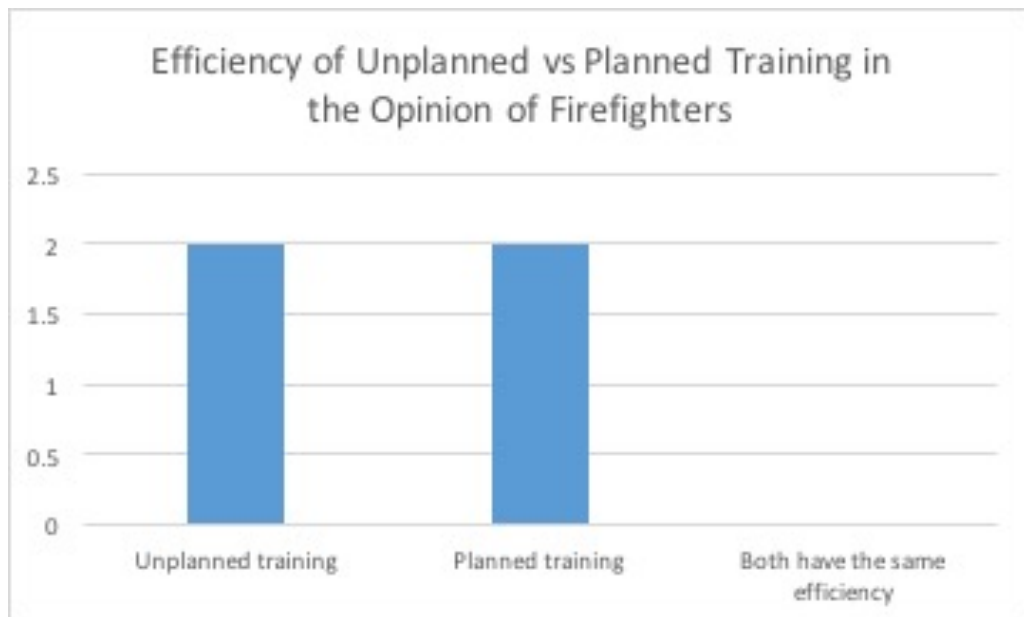


Figure 5. Efficiency of unplanned compared with planned training by number of firefighter responses Survey 1: Beijing (section 8.1)

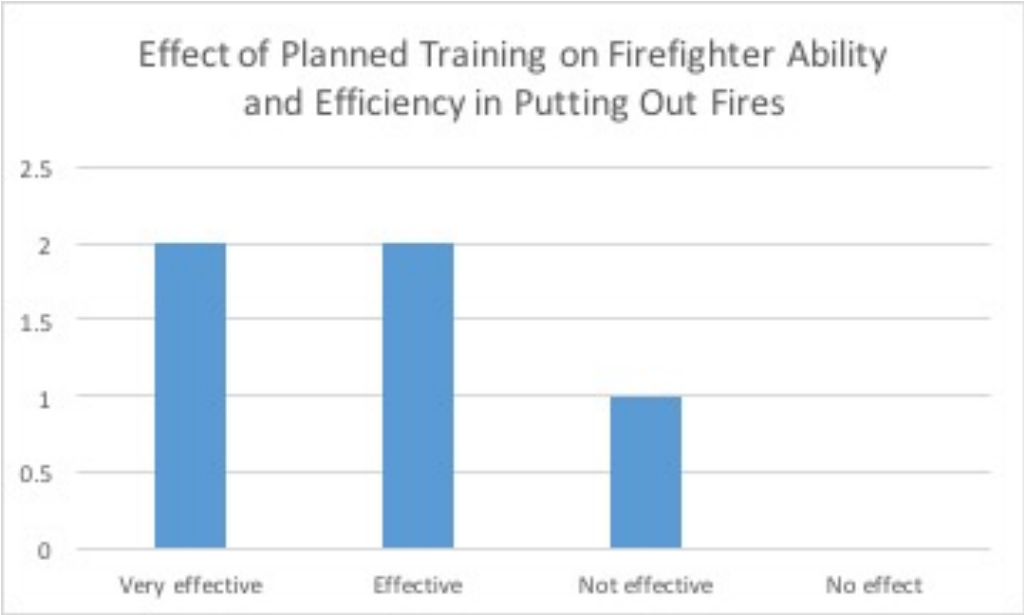


Figure 6. Effect of planned training on firefighter ability and efficiency by number of firefighter responses Survey 1: Beijing (section 8.1)

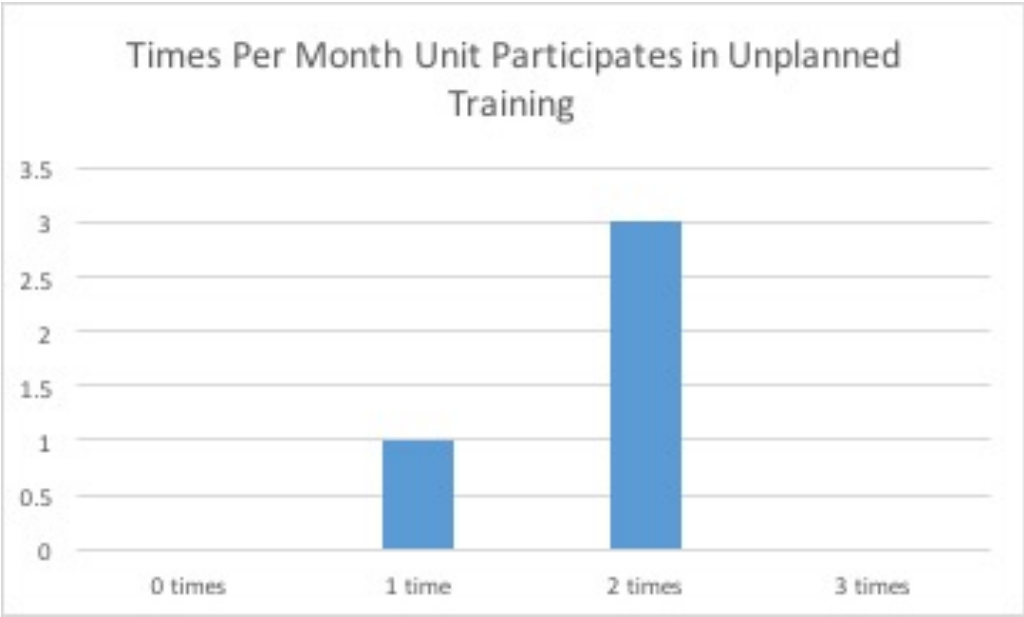


Figure 7. Times per month unit participates in unplanned training by number of firefighter responses Survey 1: Beijing (section 8.1)

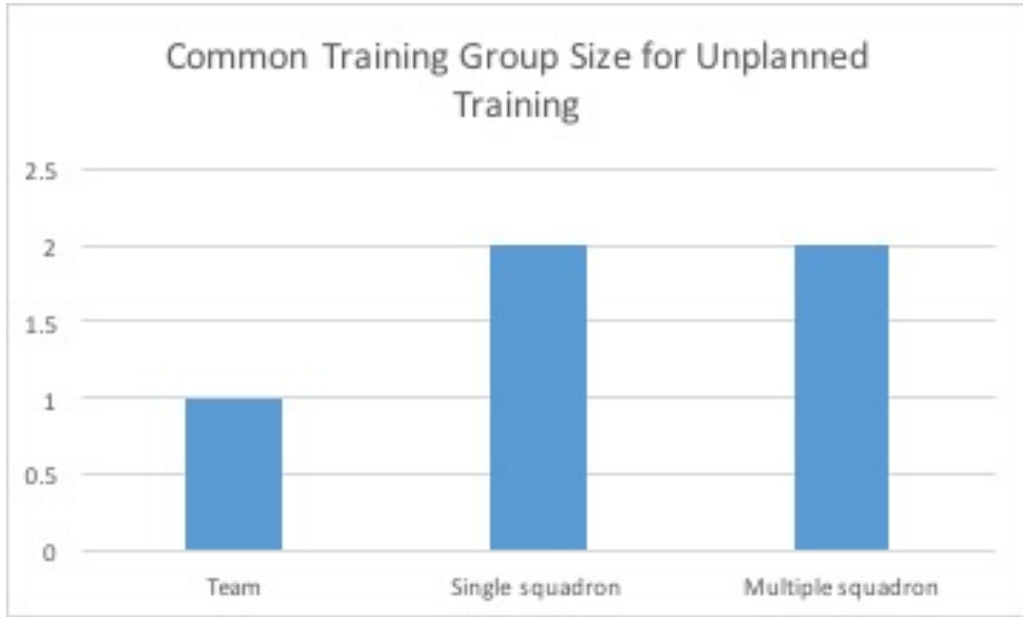


Figure 8. Common training group size for unplanned training by number of firefighter responses Survey 1: Beijing (section 8.1)



Figure 9. Unplanned training by number of firefighter responses Survey 1: Beijing (section 8.1)

Chinese combatant firefighters participate in both planned and unplanned training.

Planned training involves a predetermined plan of how to put out the fire by the commander or

squadron leader. Each team member has a predetermined role in how they will put out the fire. Less communication is needed in this type of training, as each unit has an idea of what they will do during the response. In unplanned training, firefighters go into the training without a plan and must improvise how to put out the fire during the time of the training. Communication between the team is absolutely necessary in this type of training in order to improvise effective strategies and communicate roles to all units. Unplanned training helps build communication and improvisation skills while planned training simply practices known strategies when entering a familiar situation to improve efficiency. According to our survey, each type of training is equally significant in preparing for actual disasters (fig. 5). This shows that in unfamiliar situations, communication is vital. It is worth valuable training time, training time having been indicated on the survey as the biggest restriction to training (fig. 9), to practice these unfamiliar situations and communicative skills regularly, 1-2 times per month (fig. 7). Additionally, the training group sizes for unplanned training vary between large teams, multiple squadrons, and smaller groups of a single squadron (fig. 8). Again, this reinforces the unpredictability of real disaster situations. Firefighters must have experience communicating improvised information in a variety of groups.

It was also determined from our Beijing survey that firefighters from all departments and positions should be well trained in a variety of aspects of firefighting, including those that don't directly involve the individual's position. Fighting fires efficiently depends on the communication between departments, therefore all individuals must have an understanding of all aspects of firefighting.

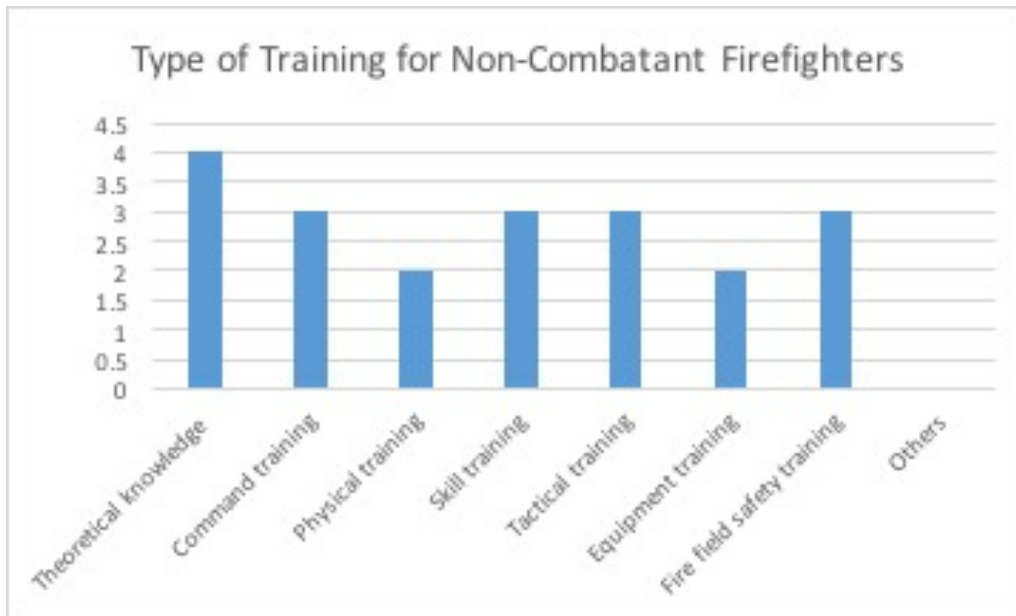


Figure 10. Number of survey responses associated with each answer to the type of training relevant to non-combatant firefighters Survey 1: Beijing (section 8.1)



Figure 11. Number of survey responses associated with each answer to the type of training relevant to commanders Survey 1: Beijing (section 8.1)



Figure 12. Number of survey responses associated with each answer to the type of training relevant to commanders Survey 1: Beijing (section 8.1)

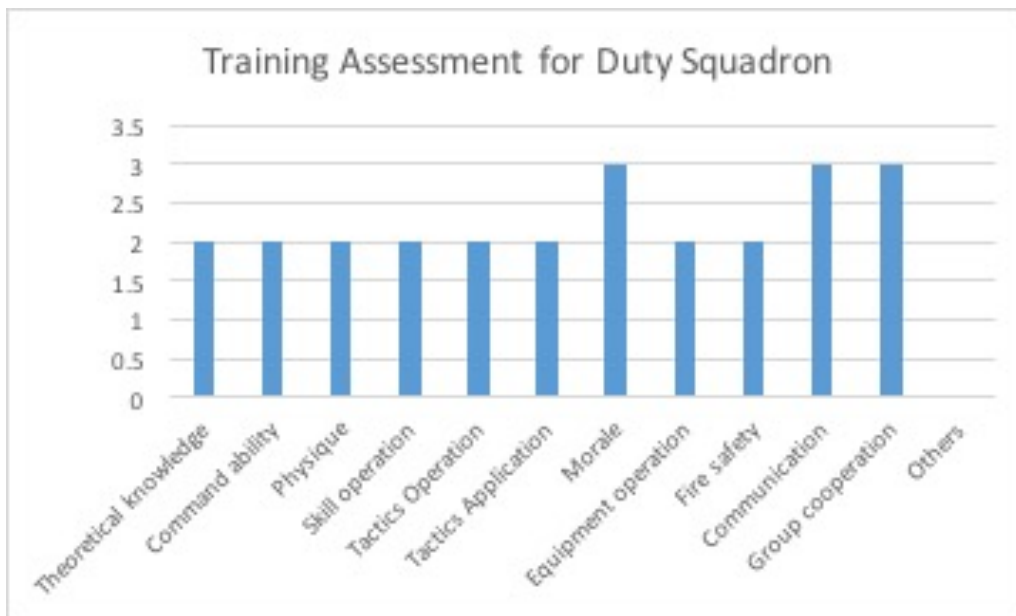


Figure 13. Number of survey responses associated with each answer to the type of training relevant to duty squadrons Survey 1: Beijing (section 8.1)

In all firefighting departments, combatant squadrons, non-combatant firefighters, and

commanders, it is important all firefighters have a comprehensive understanding of firefighting even outside of their discipline. Non-combatant firefighters never actually enter fires but must make plans for and command combatant firefighters. They therefore must have a comprehensive knowledge of many subjects and abilities surrounding firefighting and disaster response, however they tend to need less physical training than combatant firefighters. During disaster response, all departments are in communication and must have a common understanding of the roles of the entire team. The survey of Beijing firefighters supports the significant role that communication plays in firefighting.

With assistance from Tsinghua University, we were able to speak directly with firefighters affiliated with the Chinese Police Forces Academy. The goal of our discussion with these firefighters was to both confirm and fill in the gaps of our preliminary research as discussed in 2.0. The interview with these firefighters indicated that the current communication technologies being used in China are outdated and may compromise efficiency. Based on the interviews, we concluded that communication between firefighters is a challenge in Beijing as the equipment used is unreliable. Low frequency walkie-talkies cannot easily transmit signals from within buildings and the heat of the fire interferes with the signal as well. We then wanted to know if there were available communication alternatives to walkie-talkies. We learned that internal landlines (fig. 14) are common within buildings that firefighters can plug mobile phones into. However, each firefighter does not carry one of these phones with them as firefighters already carry a lot of equipment and adding more is a burden. Communication challenges in firefighting can also be simply owed to the chaos of the disaster. Heavily user-interactive communication equipment such as handheld devices are a burden to use in dangerous, chaotic situations. Communication between firefighters does not flow easily in high-stress situations.



Figure 14. Internal landlines are common within buildings that firefighters can plug mobile phones into

Furthermore, we wanted our interview to help gauge the Beijing firefighters' views on the future of communicative firefighting technology. Smart cities are a broad concept introduced to us at Tsinghua University. Tsinghua's GS911 CAD system builds on this idea, creating a system used to predict future disasters, help firefighters make decisions, and communicate that guidance to firefighters in real time. This system has the potential to help decrease a lot of the identified challenges but is not currently feasible as the data necessary to analyze is not currently being accessed. Accessing data from building layouts, building maintenance and fire safety features, and the current environment costs funding. Internet connection is required to communicate this information to firefighters. China's police forces, including firefighters, operate on a closed internet server, separate from the public server. This closed government server is a lot slower than the public one, making data communication unreliable. These two limiting factors, funding and data access, need to be considered as we move forward in the identification of solutions. Additionally, many of the communication challenges explained above

would still apply to this system. These challenges would still need to be addressed to take full advantage of this system.

Finally, we performed inspections of firefighting equipment at the Chinese Police Forces Academy in Beijing and the Hubei Provincial firefighting equipment distributor in Wuhan. We were shown the facemasks that firemen might use in the fire. They have many examples of the standard oxygen mask and chemical masks, but the integrated communication masks are scarcer at the distributor. They do have facemasks with integrated antenna, microphone, and amplifier, but those are far less common. The technologies we observed showed an interest in modern technologies, but there is room for improvement in choice and implementation of technologies for firefighting.

Situational awareness is low in fire disaster situations, making navigation difficult.

In firefighting, situational awareness affects not only firefighters' visibility through smoke and darkness, but their ability to navigate unknown, large buildings and the ability to locate firefighters and victims within burning buildings.

The second survey conducted in Wuhan mainly focused on challenges firefighters faced while on duty, what technological upgrades would assist in overcoming those challenges, and what technologies would be acceptable by the firefighters in China. This survey was our second set, revised and adapted after analyzing the data gathered from the first set of surveys and interviews in Beijing. The goal in this survey session was to determine which challenges were most apparent in firefighting, among the challenges described by the data from Beijing. We asked surveyed firefighters to rank a series of firefighting challenges, current equipment and new smart firefighting technology based on previously collected data in order of importance. We

applied weighted scores based on the resulting order ranking. In this survey, we asked firefighters to rank which technologies could be improved to best improve the safety and efficiency of firefighting. Firefighting tracking sensors and visibility equipment were ranked by Wuhan firefighters as one of the top technologies to be implemented (fig.15).

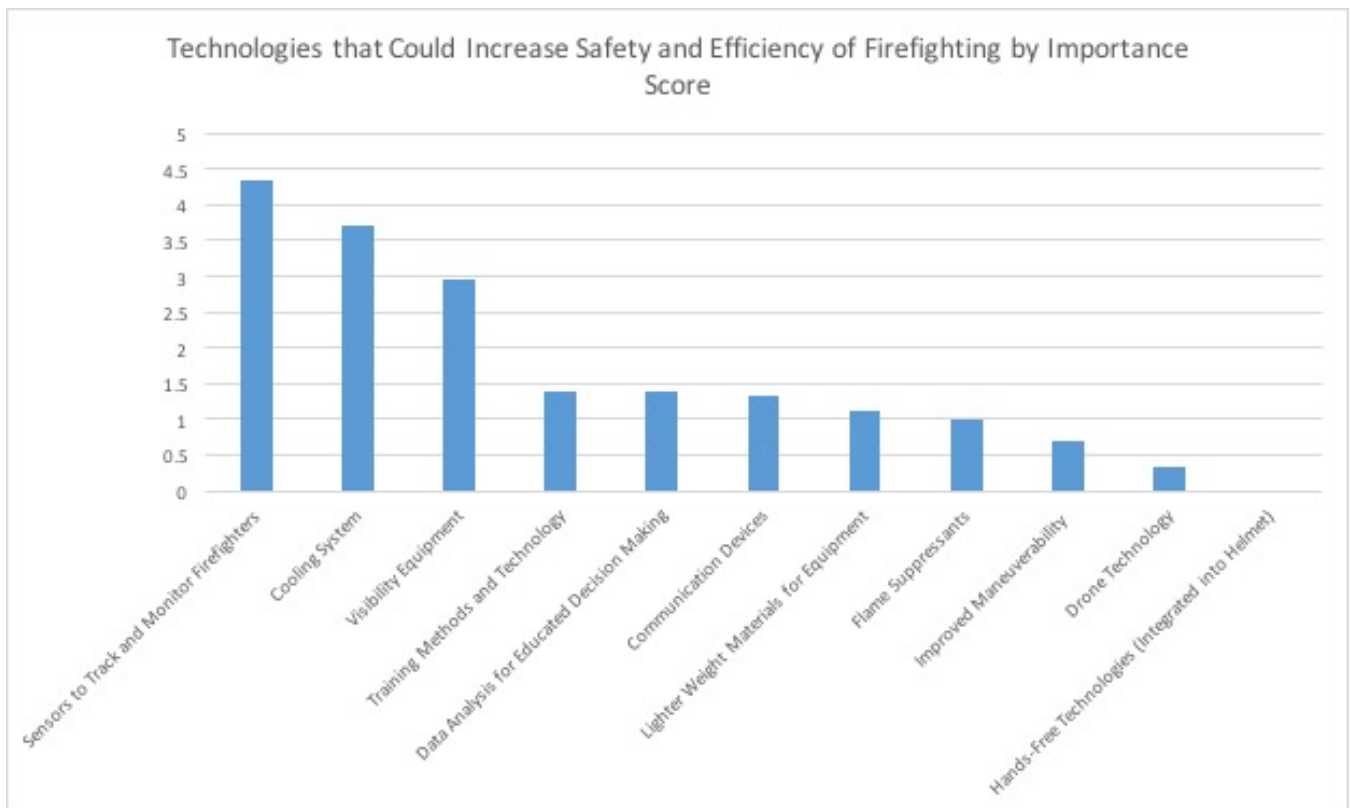


Figure 15. Technologies that could increase the safety and efficiency of firefighting by importance scores associated with the average ranking order of surveyed firefighters on Survey 2: Wuhan (section 8.2).

During our interview with Beijing firefighters affiliated with the Chinese Police Forces Academy at Tsinghua University, it was indicated that the current situational awareness technologies being used in China need to be updated and implemented. High-rise buildings limit

the situational awareness firefighters have within the buildings. High-rise buildings are typically large and their layout unknown to firefighters. Firefighters do not know the fastest routes in these buildings and time is wasted trying to reach the fire. On top of the unknown building layout, irregular building inspections make many fire safety features within buildings unreliable. Fire elevators are often turned off as they run on a different electrical system than the main source of building electricity. Without fire elevators, firefighters may have to climb many stories within high-rise buildings in order to reach fires. Oxygen is limited and they only have about 40 minutes' or less due to exertion and fatigue worth of breathable oxygen. Waterlines are another example of unreliable safety features. National standards require waterlines for firefighting within large and high-rise buildings, however these regulations are overlooked in older buildings. Safety features within buildings effect firefighters' situational awareness as they do not know what to expect upon arriving at a scene and time is wasted due to the unreliability of these features. Another issue that the Beijing firefighters shared with us was the limited visibility within buildings. The firefighters explained to us that the smoke and darkness within burning buildings makes it incredibly difficult to see. We discussed the prospect of improved equipment used commonly in the United States, such as virtual reality maps in helmets and thermal cameras, however foreign equipment is very expensive.

Again, with assistance from our sponsors at Tsinghua University, we were able to speak directly with engineers at the Shanghai Fire Station. These engineers are responsible for the creation and improvement of firefighting technology in Shanghai. We were able to speak to these engineers to gain a greater perspective on the challenges of firefighting technology. These engineers confirmed that low visibility due to smoke and darkness within burning buildings is a predominant issue in Chinese firefighting and they are currently working to address it. Another

point the Shanghai engineers brought to light was the proposed method in which they can calculate the position of the firefighters within buildings using relative position. Absolute position is an unreliable method for tracking firefighters as it depends on the constant monitoring of a signal that can be lost within buildings. The engineers are working on developing a portable relay system using data analysis that calculate the relative position of firefighters to help keep track of firefighters within buildings. One of the biggest risks to firefighter safety is getting lost within large fires. If a firefighter becomes lost in a fire due to an unreliable signal, they may become trapped and die. A reliable firefighter tracking system could greatly improve firefighter safety.

In our background research, we collected a lot of data on the use of firefighting drones to collect data about the fire, search for victims, and perhaps deliver flame suppressants. We asked the Shanghai firefighting equipment engineers if they had considered implementing drone technology. They explained that although drone technology would be helpful fighting fires, many challenges need to be addressed before this technology can be implemented. Controlling the drone through the disturbance of airflow caused by the heat of the fire, and actually building the drones with an affordable, temperature resistant material are major challenges that would need to be addressed before use of this technology would be efficient.

Finally, we performed inspections of firefighting equipment at the Chinese Police Forces Academy in Beijing and the Hubei Provincial firefighting equipment distributor in Wuhan. One of the technologies that we researched included thermal cameras. The Hubei distributor only had one handset at the facility. The only other thermal camera handset in the province is in the Hankou district of Wuhan. The camera cost ¥200,000, which is around \$30,000 USD. This cost a fortune for the firefighting teams, so Chinese fire departments need an alternative to thermal

hand-held cameras. When the firefighters first started a demo of the camera, the battery died, so they had to replace the battery. This process took about 2 minutes to complete, from pulling the battery out to having the device operational again. Battery operated devices can be inefficient, especially if they are not used very often. This camera does not come in a helmet mounted variant, so the we researched methods to replace this technology as presented in our recommendations. This camera is considered an interactive technology given the amount of user interaction required to operate. Highly interactive technologies can be a burden to firefighters as they need their full concentration to navigating the high risk environment within burning buildings.

This distributor employs many methods for firefighter tracking. The more conventional method for keeping firefighters together involves the use of ropes similar to a belaying system. This has its drawbacks: if one firefighter gets stuck, the whole team gets stuck. The more modern technologies use trackers mounted on the shoulder of the suits. The alarm is designed so that if the firefighter does not move for 4 seconds, the alarm will sound. The firefighters can also activate the alarm manually. This alarm does not communicate real-time data over radio signals to the fire chief. This fire station also employs more modern tracking technologies for use in more broad applications. The fire chief can control a software application on an iPad that interfaces with a set of GPS tracking devices inside of firefighter's boot soles so that he can monitor how long firemen have been in a fire and where they are in the fire. This iPad control software is a cheap and readily available alternative to more expensive technologies, but still suffers from several deficiencies. The application reads out oxygen levels, fatigue readings, and the location of firefighters, but the application creates its oxygen level and fatigue level estimates from dead-reckoning, not from real-time analysis of the firefighter's fatigue and oxygen levels.

The radios have an open-air maximum range of 2 kilometers, suggesting that these radios emit powerful enough signals to support communicating through concrete and fires in skyscrapers.

The GPS estimations can't guarantee accuracy in determining the elevation because the trackers lack the hardware and software support for proper fusion of sensor readings to determine a precise location. This also contributes to the lack of knowledge of the fatigue levels of firefighters: the fire chief doesn't know when to call the firefighter in.

Fatigue and accidental injuries are a major safety risk for urban firefighters.

We asked firefighters during the interview at Tsinghua University to identify the main challenges of firefighting within Beijing. They responded with injuries and fatigue, in short, risks to firefighter safety are a major challenge in their day to day lives. We had the firefighters expand on this response by asking what the major sources of injury are in firefighting. As previously established, high-rise buildings are common in densely populated urban areas within China. Due to the unpredictable situational awareness of large buildings, time and energy is wasted reaching fires when firefighters do not know the fastest routes through the burning buildings. Fire elevators are unreliable and when fighting fires in high-rise buildings, there is a chance that firefighters will have to climb many stories in order to reach fires. Oxygen is limited and they only have about 40 minutes' or less, due to exertion and fatigue, worth of breathable oxygen. Combatant firefighters also must carry heavy equipment into fires which adds further to their exertion levels. In these situations, fatigue becomes a risk to firefighter safety, as they may be unable to escape buildings or put out the fire quickly enough.

Interviewed Beijing firefighters described the risks of accidental injury to us as well. Explosions are a common cause of injury and death for firefighters. Explosions may be caused

by compressed air containers exploding within buildings due to heat, or the reaction of chemicals with heat. These explosions may cause falling debris that can hit firefighters or block exits trapping them inside. The fires may also release unknown toxic chemicals into the air. Firefighters again must have preliminary knowledge of these hazards and be able to sample the air for toxic chemicals. Finally, the heat from the fire may cause burns and firefighters do not have a cooling system.

Engineers at the Shanghai fire station further asserted the gravity of firefighter fatigue when fighting fires. We asked the engineers how technology and methods are commonly used to address challenges of fatigue used when putting out fires in high-rise buildings. They are working to develop even lighter materials for firefighting equipment as firefighters must currently carry between 30-40 pounds of equipment into fires. This equipment includes breathing apparatuses, helmets, cameras, and walkie-talkies. Climbing stairs with so much added weight is inefficient and may cause fatigue. Buildings above 50m are required to have fire elevators within but as previously indicated, these elevators are unreliable.

Surveyed firefighters from the Wuhan fire station ranked high-rise buildings as the greatest challenge in urban firefighting, followed by fatigue from heavy equipment (fig. 16). They ranked technology intended to help alleviate fatigue such as breathing apparatus (air supply) and cooling systems highly as technology in need of improvement and technologies that increase the safety and efficiency of firefighting (fig. 17 and 18).

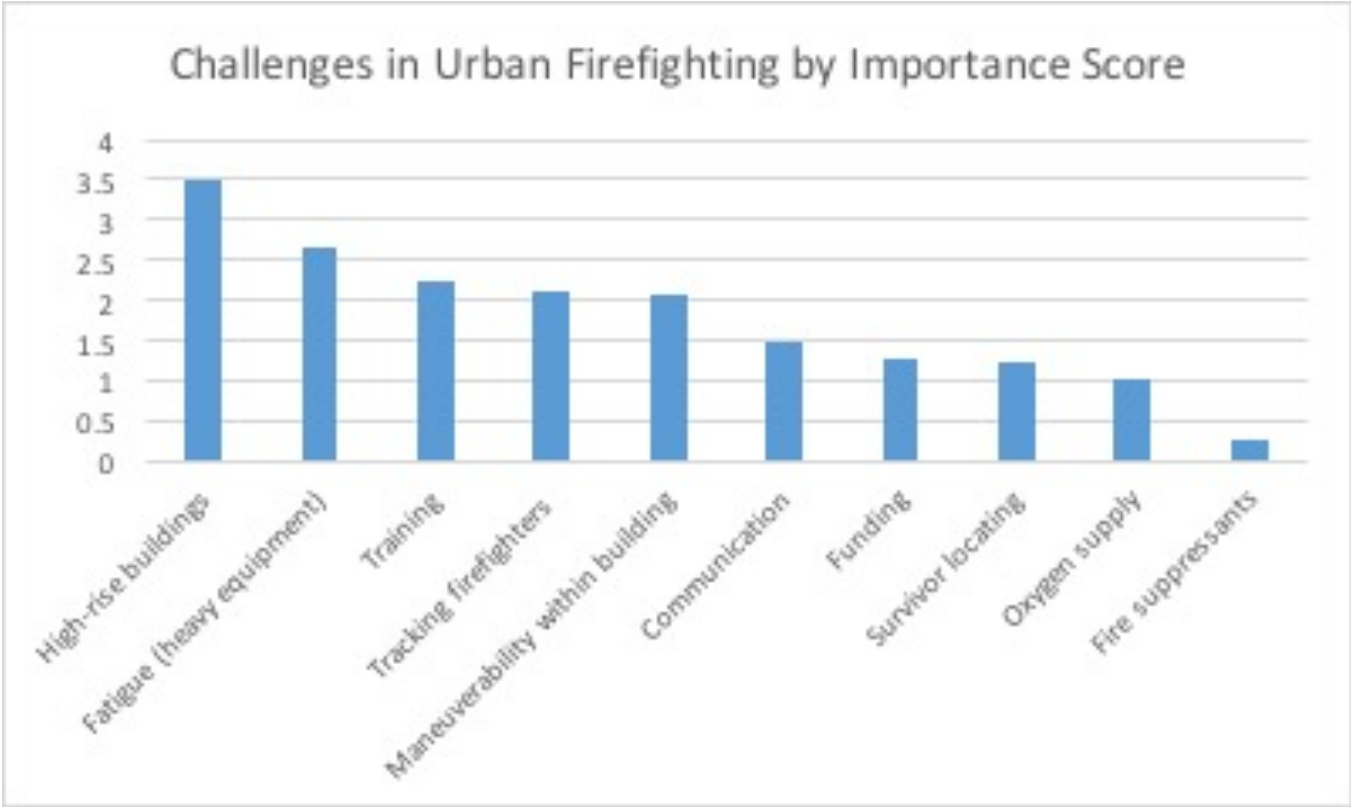


Figure 16. Importance scores associated with the average ranking order of surveyed firefighters for most significant challenges in urban firefighting on Survey 2: Wuhan (section 8.2).

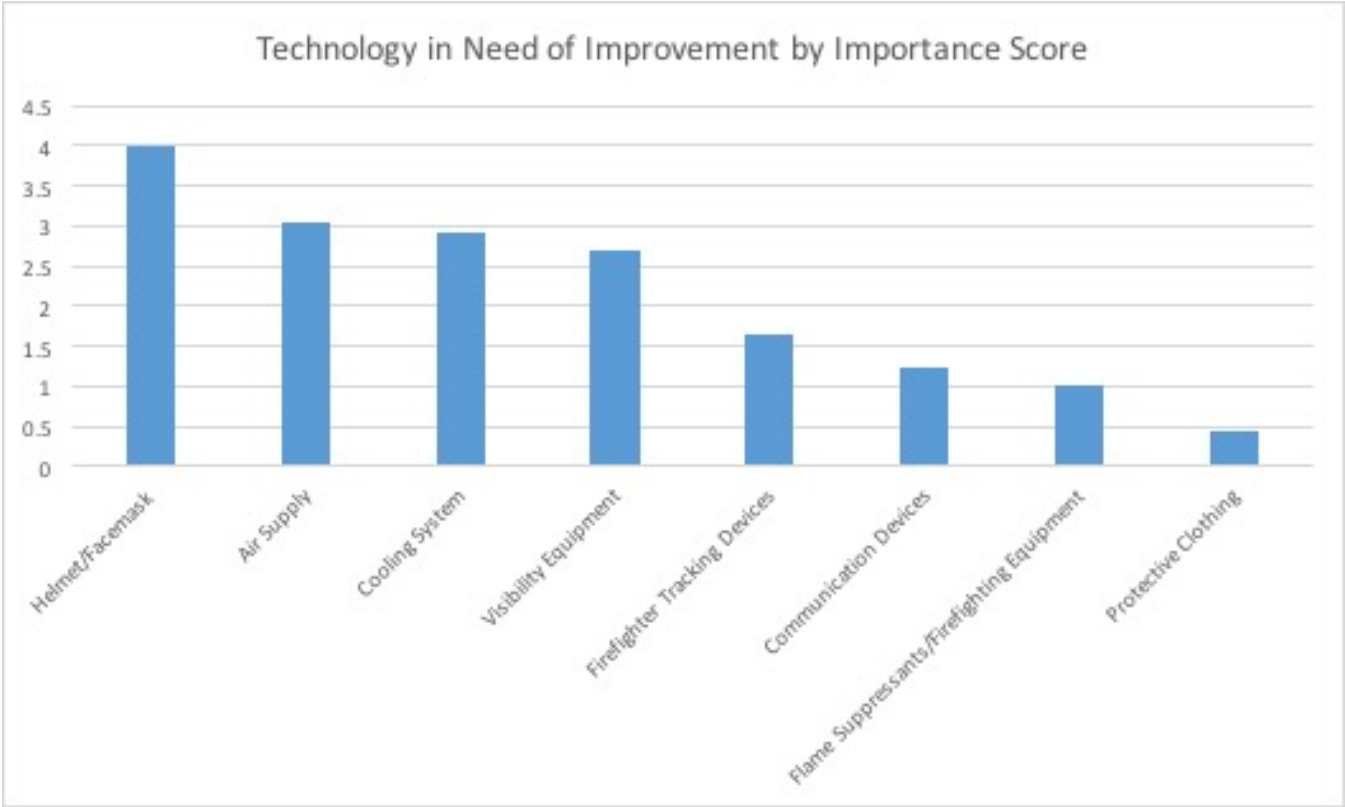


Figure 17. Importance scores associated with the average ranking order of surveyed firefighters for technology in need of improvement on Survey 2: Wuhan (section 8.2).

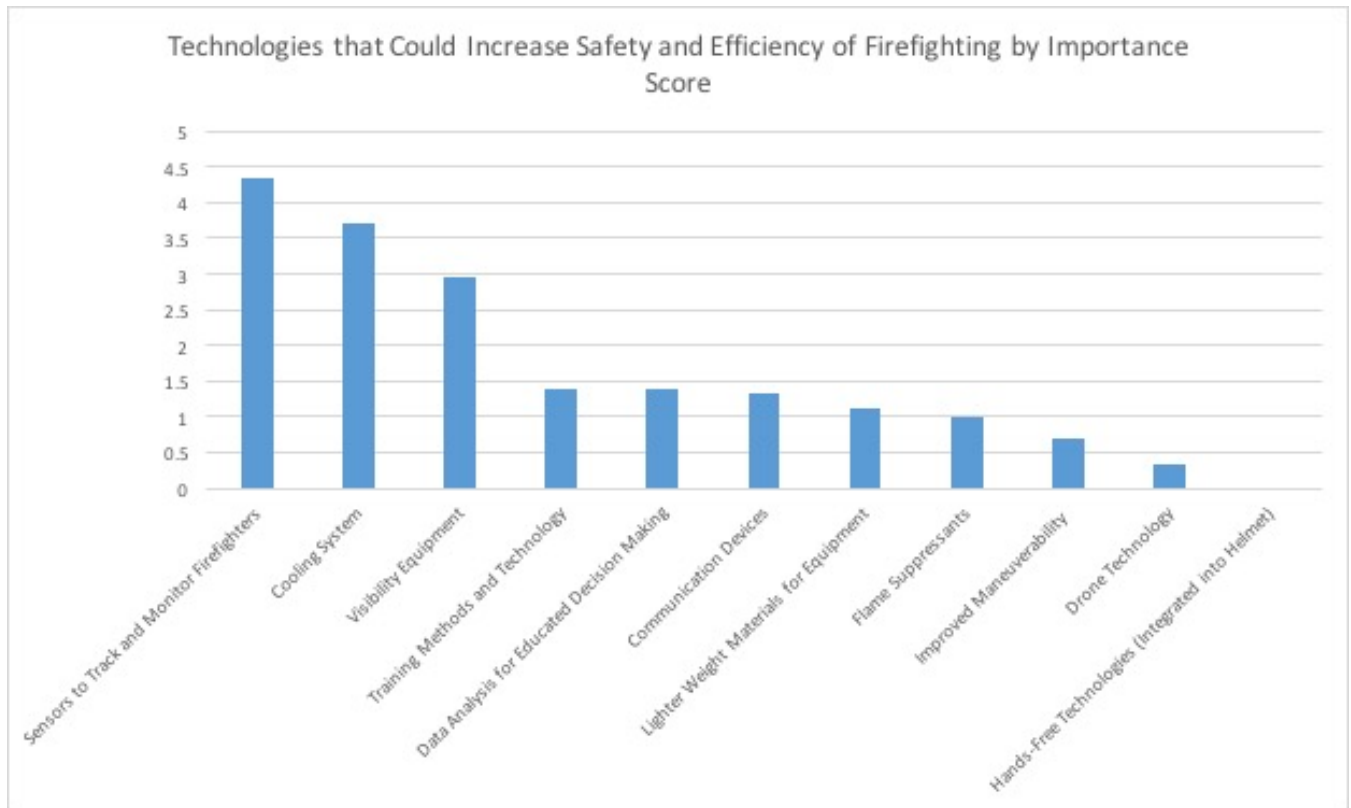


Figure 18. Importance scores associated with the average ranking order of surveyed firefighters for technology that could increase the safety and efficiency of firefighting on Survey 2: Wuhan (section 8.2).

During the inspections of firefighting equipment at the Chinese Police Forces Academy in Beijing and the Hubei Provincial firefighting equipment distributor in Wuhan, we examined firefighting suits. The team learned that the suits weigh 30 kilograms, not including the air tank. The air tank has 30 minutes of air supply, which is around the same estimate that the team researched. The suits don't have any form of active cooling for the firemen, for example, water tubes carrying cold water along the body, or fans sucking in air to draw out the hotter, encapsulated air: all cooling is passive. The suit merely insulates the firemen from the heat: it does not protect them from catching on fire.

Updated smart firefighting technology could be applied to training to better prepare firefighters for actual incidents.

Surveyed firefighters from the Wuhan fire station ranked training as one of the most challenging aspects in urban firefighting (fig. 19). Firefighters rated training as a greater issue than even many challenges in actual incident response including firefighter tracking and communication.

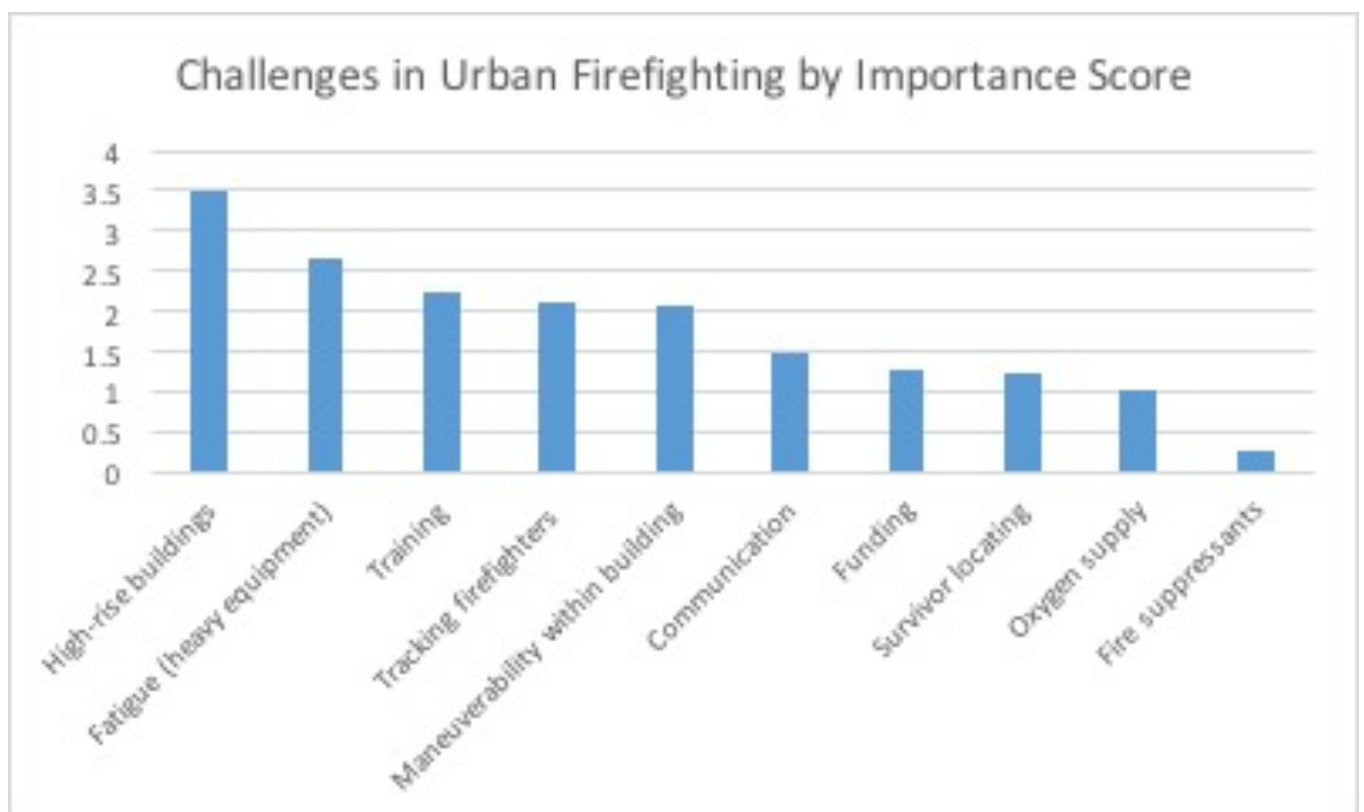


Figure 19. Most challenging aspects of firefighting by importance scores associated with the average ranking order of surveyed firefighters on Survey 2: Wuhan (section 8.2).

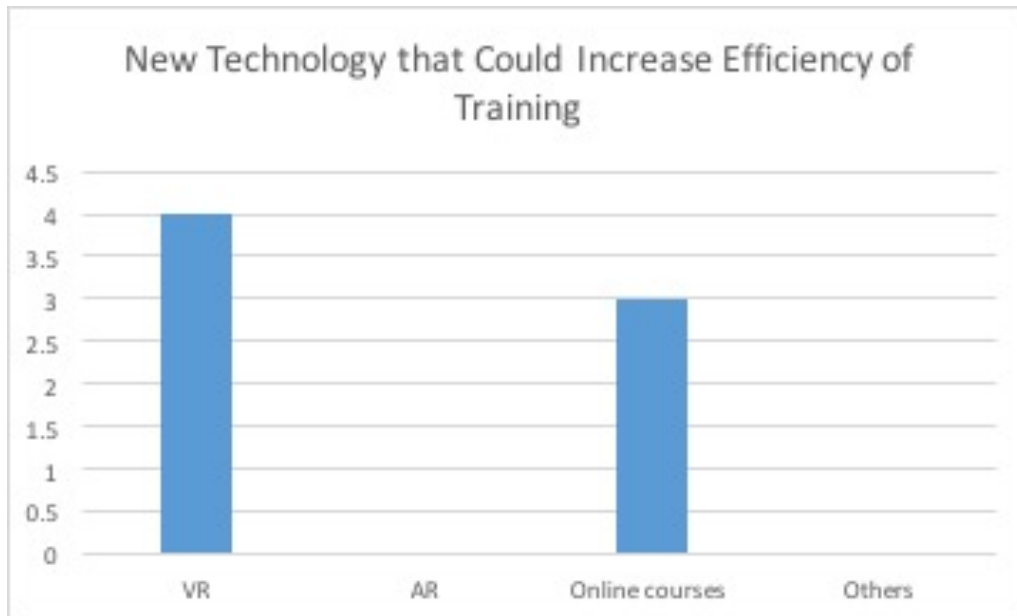


Figure 20. New technology that could increase the effectiveness of firefighter training by number of survey responses Survey 1: Beijing (section 8.1).

In Beijing, we asked surveyed firefighters what technology could be implemented to increase the efficiency of training (fig. 20). The data suggests that firefighters expressed interest in improving training with modern technology including virtual reality and online training courses.

Improving actual equipment used to fight fires would increase the efficiency of firefighting and therefore the safety of firefighters within fires.

Aside from improving technologies designed simply to protect firefighters, we also looked into technologies that could actually make suppressing fires more efficient. If the fire is put out faster, there is less opportunity for firefighters to get injured, fatigued, or lost in the burning building.

The Wuhan fire station we visited tests and distributes fire equipment and newer technologies for other fire stations throughout the province. and distributes fire equipment and newer technologies for other fire stations throughout the province. This fire station also handles abnormal operations like chemical fires, extreme elevation fires in skyscrapers, and disaster-relief efforts. This station equips firefighters with equally non-conventional firefighting substances like chemical sprays and foam mixtures to fight fires where water-based solutions don't suffice.

One of the more modern technologies we observed included a firefighting robot tank. This tank has a water deluge gun mounted on top plus accessory adapters below. This tank, however, did not have a plow on the front of it like the water tractor we researched for our background. This tank has a simple radio transmitter on top and 2 cameras so that the operator could drive it around and have an idea of its surroundings. This tank had a very bulky controller setup that is not intuitive for hand-held use.

The station also employs the jaws-of-life cutters for entering cars and metal structures in the way of firefighters. They also have heartbeat sensors for disaster relief. Their heartbeat sensors cannot work in firefighting environments because the flames interrupt heartbeat signals.

Finally, we spent time summarizing data listing the standardized inventory of equipment in Chinese fire stations. We received access to this data through our sponsors at Tsinghua University. This information gave us hard, quantitative data useful for generalizing results and the development of a concise problem statement. This information also gives us an idea of what fire stations already have available which is important to consider when developing recommendations. The complete data can be found summarized in section 8.3 of the appendix.

5.0 Recommendations

The data gathered during the course of this project suggests that the most significant challenges firefighters face amount to firefighting in high-rises, fatigue, and tracking firefighters inside burning buildings. Technologies that hinder progress in these situations include operation with outdated helmets, limited supply of oxygen, and the lack of cooling system. Firefighters we met specifically highlighted that the use of newer, more effective technologies like active cooling systems, imaging sensors, image analysis, and tracking equipment would greatly improve their firefighting capabilities in these challenging situations. We further concluded, through our survey results, that improved training equipment, more training time, and simulated training environments would also greatly improve the capabilities of firefighters in their daily duties. Considering all of the challenges proposed above, we have created recommendations for implementing more advanced technologies found in use around the world to better the situations of firefighting in China.

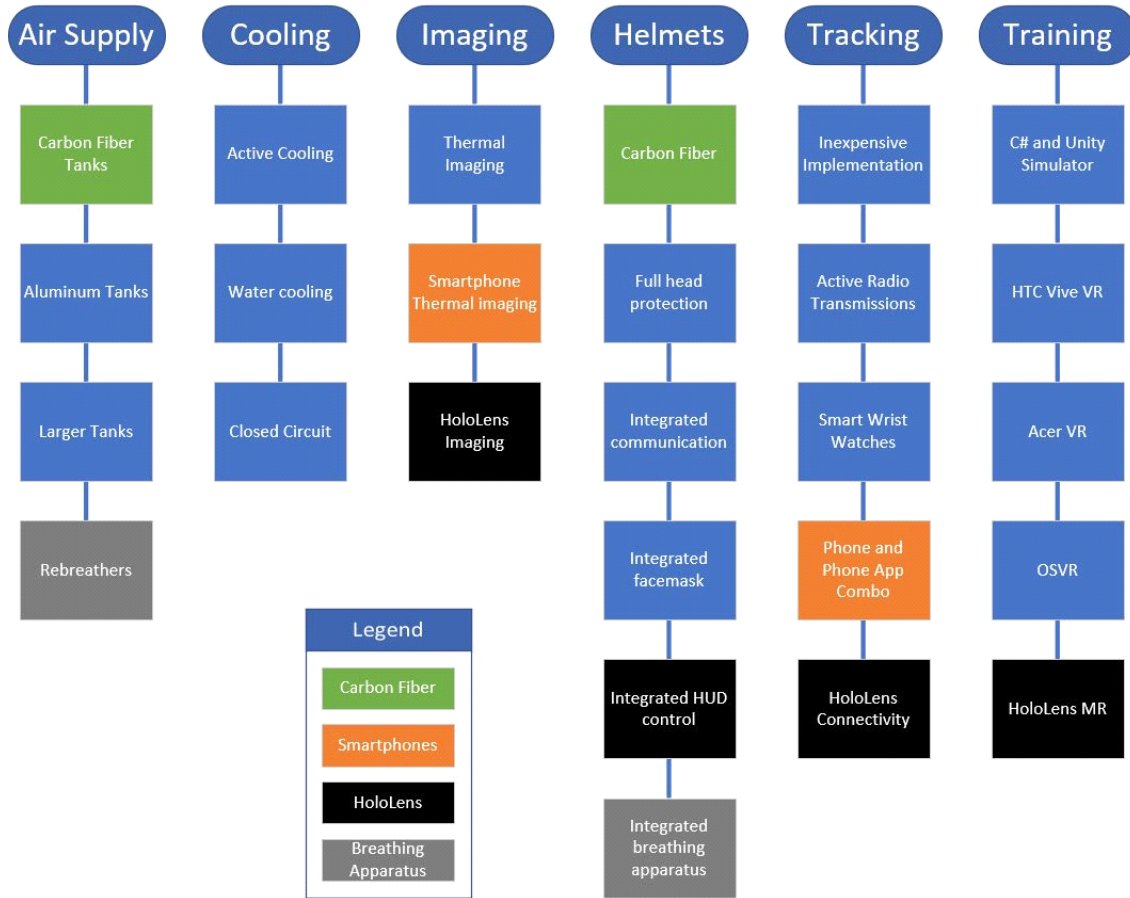


Figure 21. A comprehensive graphic of recommended technologies

5.1 Air supply

One of the critical challenges firefighters face while on duty is having a sufficient supply of oxygen. Oxygen supply is affected by fatigue levels. Navigating high risk environment with heavy equipment requires strenuous activity and oxygen is used up rapidly by firefighters.

To provide recommendations on how to improve oxygen supply and storage technology for firefighters, we first inspected the equipment used by firefighters in Wuhan. During our inspection, it was concluded that their oxygen supply and storage equipment were indeed outdated and underdeveloped. Informed observation revealed that their oxygen storage tanks were composed of thick steel and their respiratory masks only had the ability to deliver oxygen.

This equipment heavily limits the supply of oxygen these firefighters are able to carry at a time, only providing a maximum of 30 minutes towards effective performance.

We have two recommendations that will increase firefighters' active duty time through the management of oxygen supply. We first recommend upgrading the steel oxygen tanks currently in use with either aluminum or carbon fiber tanks. By doing this, the tank's overall weight will greatly decrease. Compared to their steel counterpart, aluminum tanks are one third the weight of steel while carbon fiber tanks are one fifth the weight of steel for the same size tanks. With this diminished weight, tanks can then be engineered larger to hold greater volumes of oxygen at higher pressures while maintaining weight similar to a steel tank. Doing this will ultimately increase the amount of oxygen firefighters can carry at a given time without adding to the overall load on active respondents.

We place emphasis on the implementation of carbon fiber material as opposed to aluminum when solely considering optimal performance. Material properties of carbon fiber such as tensile strength, stiffness and coefficient of expansion are either similar or superior to steel. Those same material properties of aluminum, however, are much worse in comparison. As such, aluminum tanks must be engineered thicker to compensate for those losses in quality, reducing the overall benefit as opposed to a carbon fiber tank. Where aluminum lacks in material quality, it makes up for in its reduced cost and rate of production. Although effective in theory, widespread use of carbon fiber would precipitate an exponential cost. This disparity helps aluminum retain some consideration for practical implementation.

Our second recommendation to increase firefighters' active duty time is to equip their respiratory masks with rebreathers. A rebreather is a technology that allows for the reuse of exhaled air. It does this by stripping carbon dioxide from exhaled air and reintroducing it with

oxygen that is being provided by the equipped oxygen reserves. This technology is extremely beneficial for firefighters because it reduces the depletion rate of breathable air by recycling latent oxygen expelled by the human body.

In conclusion, both recommendations should be implemented in conjunction for optimal benefit. These solutions of aluminum oxygen tanks and rebreathers are already well developed and in use by firefighters around the world, adding to their viability through proven field testing. However, in the case of cost saving advances developing in the material production of carbon fiber, utilization of this material in tanks should then take preference over aluminum in the near future.

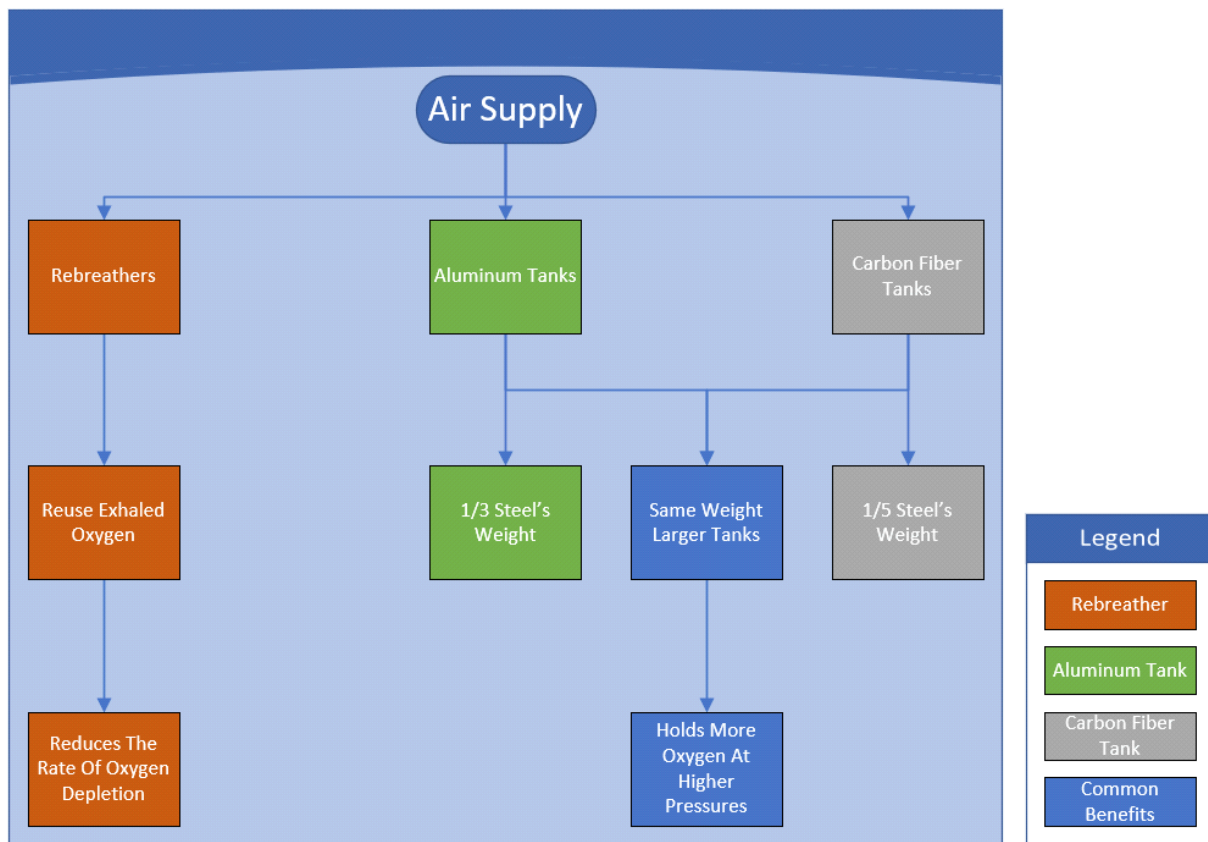


Figure 22. A comprehensive graphic of recommended air supply technologies

5.2 Cooling

Another critical challenge firefighters face on duty is having sufficient body cooling. Our investigation of the equipment used by Chinese firefighters revealed that their suits lacked the ability to cool the firefighters. Furthermore, the suits themselves act as an insulator, trapping the firefighters' body heat with thick layers of fabric that help protect against burns. This, as a result, causes discomfort to the firefighters which in turn reduces their concentration and increases their fatigue in dire situations.

Our recommendation to resolve this challenge involves implementation of actively cooled inner wear. We particularly recommend the “Veskimo Personal Cooling System” or VPCS. This system consists of a liquid cooled body vest with an ice reservoir backpack. The vest itself can be worn by the firefighters underneath their suits without any required modifications. The current backpack, however, must be re-engineered to be worn alongside the oxygen tank. The backpack houses a water pump, a battery pack and holds up to seven pounds of ice. This ice has the capability to retain cooling potential for up to 90 minutes under nominal conditions, yet this time would be significantly lessened under more intense situations like firefighting.

The system cools by first extracting the heat produced by the body and dissipating it into the water circulating throughout the vest. The water is then pumped into the backpack where it is chilled by the ice before being recirculated into the vest again. This cooling process continues until the ice is completely depleted.

One large drawback of this technology is the cost. The current cost of the system lies around one thousand dollars. This amount is extremely impractical when considering large scale implementation in China. However, continued research into this technology could produce more cost-effective variants of the apparatus for future consideration.

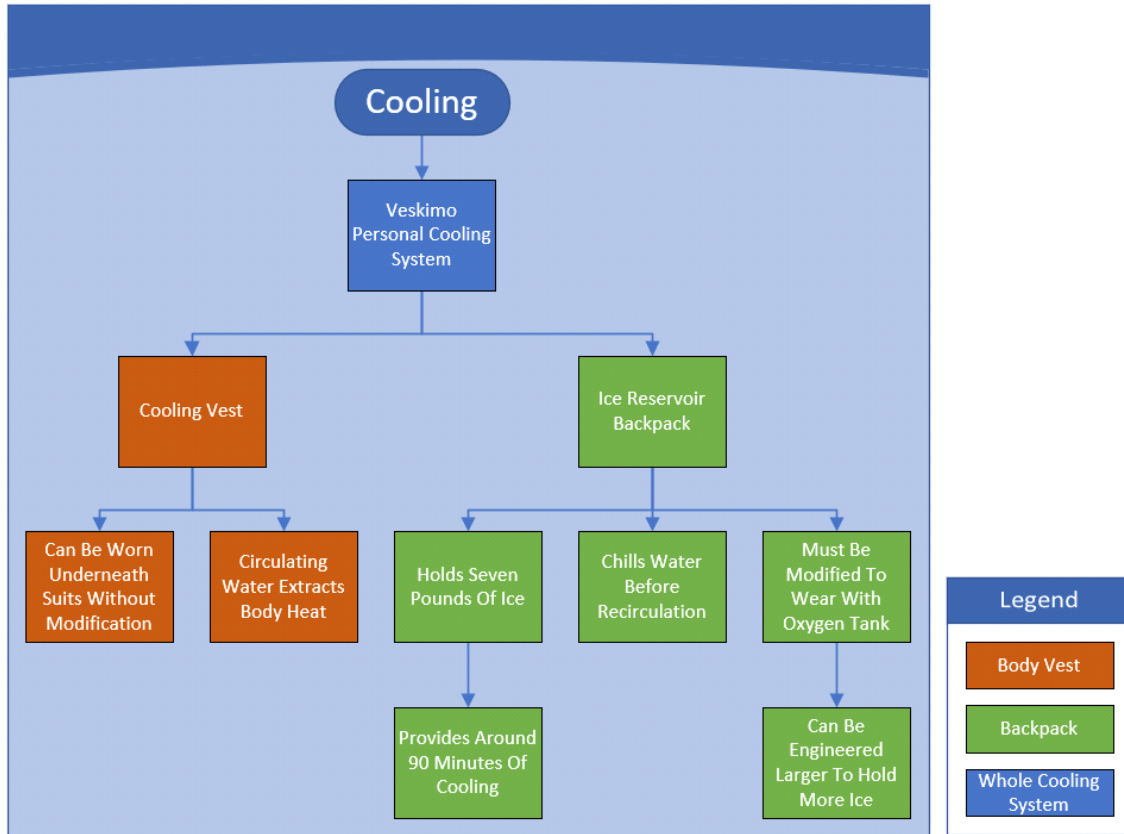


Figure 23. A comprehensive graphic of recommended cooling system technologies

5.3 Imaging

Firefighters run into burning buildings billowing with smoke in an expectation of saving lives and putting out fires. These tasks demand advanced imaging technology to complete by allowing firefighters to navigate the burning buildings safely. Modern thermal cameras are the de-facto standard for navigating visually-impairing environments. The thermal camera we observed at the fire station in Wuhan had a high-resolution video stream which clearly identified the obstacles in smoky environments. The camera also gave temperature gradients of the environment in real time.

The device observed is powerful enough for use in firefighting, however, there are many drawbacks with it. A few of the drawbacks include long boot times and lengthy battery

replacements. This can pose a serious threat to firefighting by forcing the firefighters to wait idly during these processes. The device also requires both hands for operation, making it impossible for continued use during firefighting. The last major drawback and the most important one is the thermal camera's cost. A fire station would have to spend ¥200,000 for each firefighting approved thermal camera, which translates to around \$30,000. This cost does not include maintenance and repairs. As a result of the high cost of these devices, only a single member on a team would have access to it. Rest of the team members would be forced to rely on that single man for navigating the building, meaning they would be maneuvering the building blind if separated. Despite how advanced the observed thermal camera is for firefighting, the cost is still too high for wide spread implementation in China. We believe that there are more affordable and reliable solutions for thermal imaging technology on the market which can be applied to firefighting.

We recommend taking a different approach to imaging technologies by using commercially available smart phones. Smart phones can be paired with add-on modules like the FLIR ONE Thermal Imager. The FLIR ONE takes an expensive technology, thermal imaging, and ports it into an inexpensive platform for widespread deployment. This technology is also easy to use for both new and seasoned firefighters. The thermal imaging device that we observed in Wuhan fire station used a monochrome LCD screen to display the thermal readings. The FLIR ONE however, uses the phone's RGB color capabilities to display results, making the thermal signatures that an obstacle or stranded civilian, easy to identify. Instead of requiring fire stations to pay ¥200,000 for a new thermal camera, they can instead purchase a new smartphone with a \$190 thermal camera add-on for each firefighter. This device, in its current form, still requires a free hand in order to operate. A simple smartphone armband solves this problem, and with

further research and development by fire departments, this technology can be easily integrated into everyday firefighting. The phone would require a thermally insulated case to protect the phone to withstand extreme temperatures. Other than the constraints described above, smartphone thermal camera technology is an excellent addition or replacement over current thermal camera technologies used by firefighters in China.

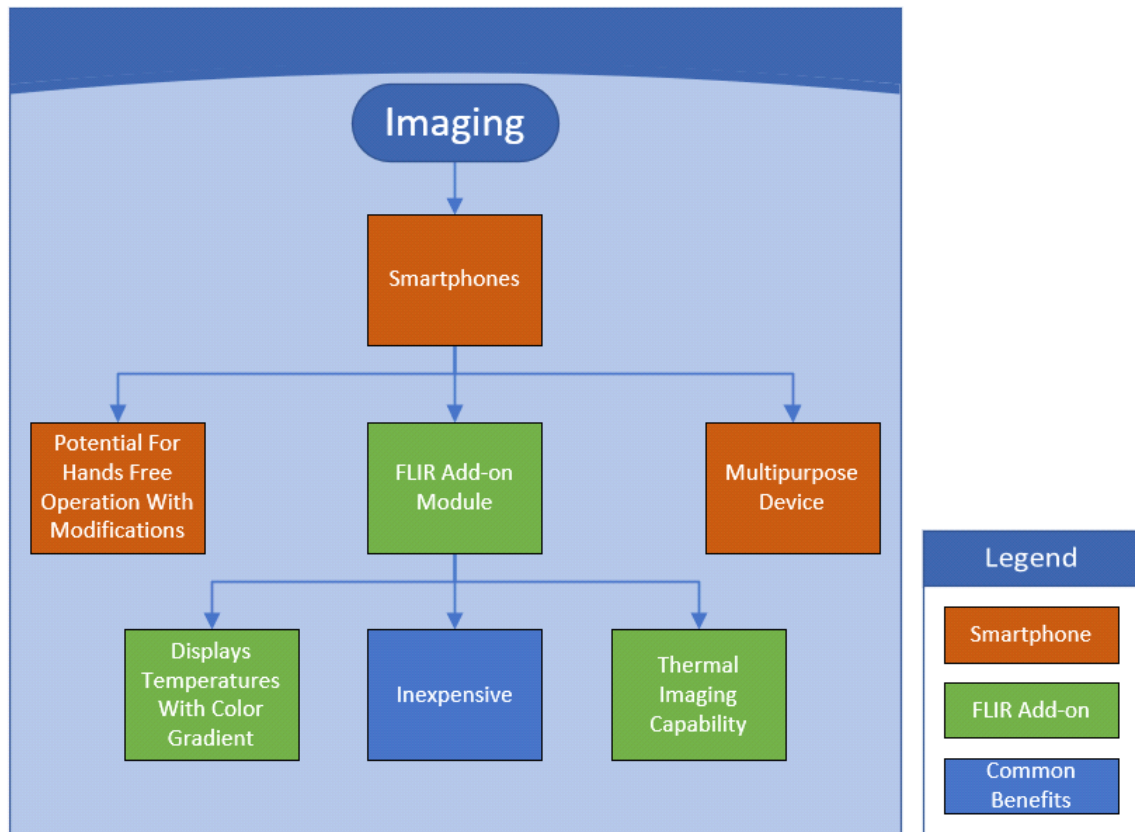


Figure 24. A comprehensive graphic of recommended imaging technologies

5.4 Helmet

According to our research, falling debris, and explosions within buildings is one of the most common causes of injury during firefighting. Helmets, therefore are a vital piece of equipment for any firefighter. The helmet observed in Wuhan worked with the sole purpose of protecting the firefighters head from falling debris. We observed, however, that the helmet itself

does not protect the sides of the head nor does it provide any insulation from the extreme heat of the surrounding environment. We therefore propose that fire stations adopt technologies like C-Thru Smoke Diving Helmet. This helmet integrates more technologies and advanced materials to improve the safety and efficiency of firefighters.

We recommend this helmet because it not only covers the top of the head, but also covers the sides of the head down to the neck. It completely encloses the head of the wearer from dangers of its surrounding environment including protection from the extreme heat. This also means that the facemask would become a part of the headgear design, including the breathing apparatus and integrated display. The breathing apparatus would simply attach and disconnect right off of the helmet, removing the need for bulky valves and nozzles.

The integrated display of the proposed helmet would provide the biggest benefit over the existing helmet. The display uses head up display, HUD, technology that allows for visualization of the surrounding environment with the help of thermal imaging sensors. The display also provides readouts of the wearers oxygen levels, cooling system information, and the firefighter's location inside the building relative to other firefighters.

The helmet also integrates communication devices within it. This makes communication easier between firefighters along with transcribing the conversations into a chat box displayed in HUD for future reference. This would allow for firefighters to never stop and look down at their communication devices while navigating treacherous terrain and fighting fire.

We conclude that the combination of a head-encapsulating helmet, integrated HUD and communications unit, and carbon fiber materials would sufficiently protect firefighters. As such, we believe C-Thru Smoke Diving Helmet is the perfect solution for implementation in China.

This specific helmet is currently new and very expensive. As such, wide spread implementation may be difficult in the near future.

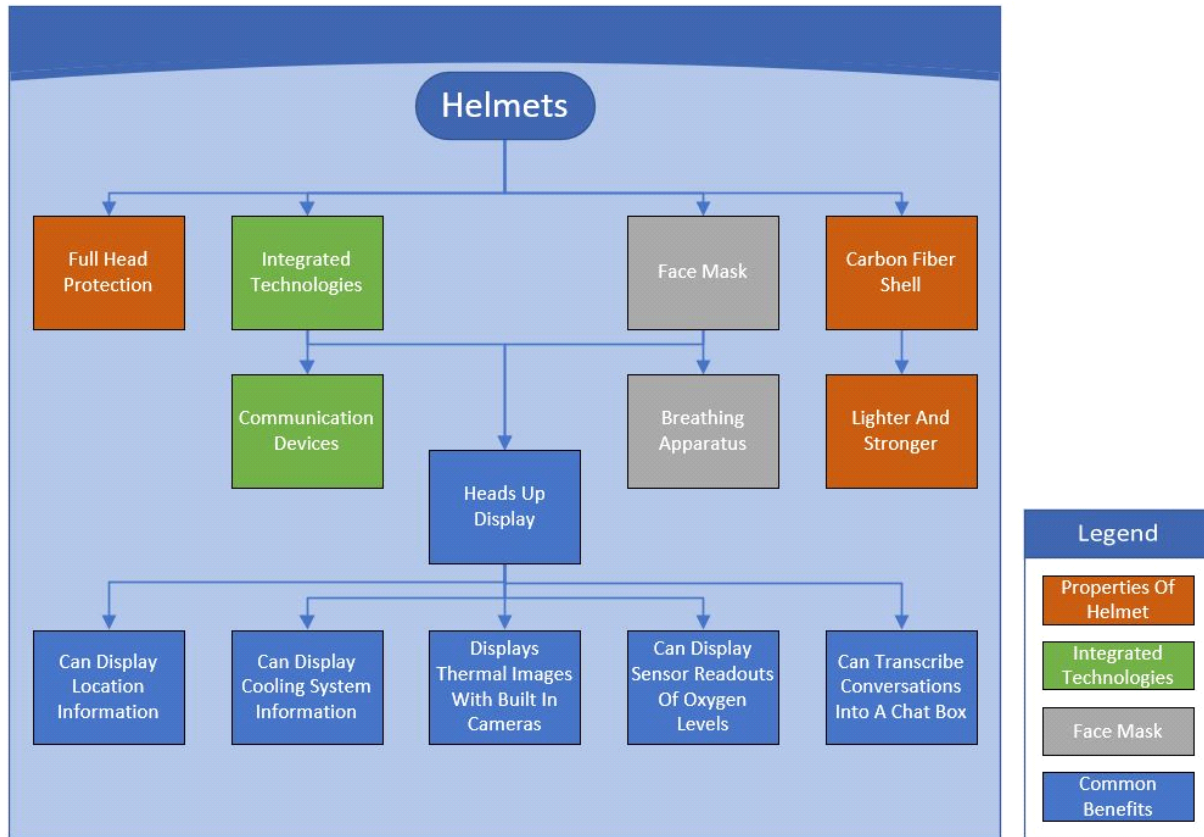


Figure 25. A comprehensive graphic of recommended helmet technologies

5.5 Tracking

Firefighters navigate burning buildings to search for people while at the same time putting out the fire. This means that firefighters must travel long distances in a short amount of time, leading to the possibility of getting lost in the building. This leads to the necessity of effective tracking systems for locating civilians as well as firefighters in hazardous environments. Currently, the most up-to-date tracking technologies include tying ropes to

firefighters and communicating position using walkie-talkies. Both of these methods are terribly outdated because fires can easily disrupt them. Ropes can get caught in obstacles and radio signals can be smothered by flames. We therefore recommend utilizing readily available technologies including smartphones and smart wrist watches.

Smart devices already contain well developed sensors that can track a person's motion in real time, including accelerometers, gyroscopes, magnetometers and GPS receivers. These smart devices also have communication capabilities through the use of Wi-Fi and Bluetooth. Smart watches, in particular, are compact and have many design features implemented specifically with tracking in mind. One such example includes using the smart watch's accelerometer to track the wearer's footsteps used to predict their location. The magnetometer and gyroscope maintain magnetic north and orientation respectively which help improve the predictions. Smart watches also have integrated GPS units, allowing them to communicate with satellites to predict the exact location and elevation of the wearer, with a small margin of error, on a larger scale. The smart watch can then transmit the wearer's location to other devices within a short distance using the communication capabilities of the watch.

A smartphone, however, emits more powerful Wi-Fi and Bluetooth radio signals than smart watches. This allows for the smartphone to transmit data a wider distance than the watch. By combining the smartwatch of a firefighter with the smartphone's more powerful radio, a firefighter can be tracked in real time with a more reliable and stable radio signals. The combination of these sensors in smartwatches and smartphones allows for efficient tracking of firefighters in dangerous environments. These smart devices also allow for custom apps to be written to communicate location information to the fire chief without the interference of the firefighter wearing them.

We recommend fire stations to equip firefighters with smart phones and smart watches with custom apps so that the software can be tailored to the needs of the station. The software can even consider a specific firefighter’s traits, like stride length and weight to give a more accurate estimation of their location. Current cost of these smart devices are quite low and they are well developed. As such, they can be widely implemented in China immediately with minor modifications to make them suitable for firefighting.

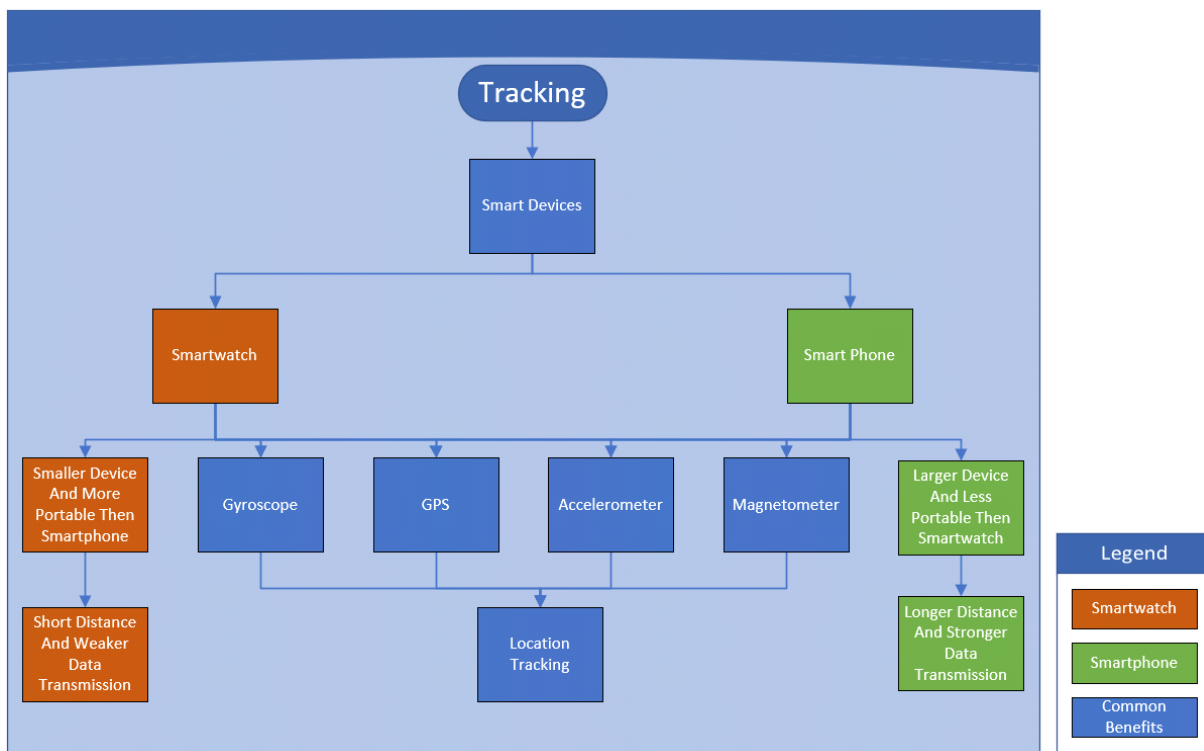


Figure 26. A comprehensive graphic of recommended tracking technologies

5.6 Training

The recommendations mentioned earlier specifically pertain to actual firefighting, however. It is believed that training is a major part of improving the safety and efficiency of firefighters as concluded from our data. As such, we suggest the use of newer training technologies such as Virtual Reality. Virtual Reality, abbreviated VR, creates a new environment

with characteristics similar to the physical realm. The user has the ability to interact with features and characters that the headset adds to the environment. Using VR in training would allow for firefighters to train in any preprogrammed environment with a set of predetermined equipment according to whoever is running the simulator. Specifically, firefighters could use VR to learn how to fight fires effectively in live situations by using controllers to navigate and interact with objects using simulated hands. An instructor could then evaluate the firefighter on their performance and tell them where they need to improve. The use of VR headsets can allow for complete control of a training scenario in a safe and cost-effective way.

There are various headsets that can achieve this previously described training simulation. The HTC Vive VR headset uses room sensors along with headset-mounted cameras to accurately determine gestures in the computer-generated environment. The closed loop sensor system works well for accurate simulations; however, it is limited to only indoor settings due to the external room sensors required for position and motion tracking. Given these extra sensors that come with the Vive, the entire solution costs \$1000. This headset is good for fire stations with a larger budget and dedicated room space for VR-specific applications.

A less expensive alternative to the Vive headset is the Acer VR. Acer's headset has two inside-out cameras mounted on the front of the headset that act as motion and gesture sensors. This means that it does not need the same room-mounted sensors the Vive requires to track a person's actions. Using the inside-out cameras, the Acer headset can recreate the original environment with new, simulated features. The sensors on the Acer headset provide the capability to track motions like any other VR headset for \$300. This is an entry level VR device, so it does not support the enterprise features or security that higher end devices come with, but for budget VR, this headset provides an entry point for fire stations to test VR integration.

If the fire station requires a more durable VR headset suitable for outdoor environments, then the military-spec zSight 810 headset becomes the most optimal choice. This is a completely waterproof headset designed for ruggedness. The price of the headset is not openly advertised, but it is safe to assume the specialized features come with a higher price. The combined use of these VR headsets has the ability to accelerate training and development of firefighters without demanding expensive live fire tests.

Given all of the proposed VR devices, we recommend primarily using Unity game engine software to develop the training simulations. Unity game engine uses the Microsoft C# programming language, which is well developed and field tested. This language also has an extensive data base and support already available for use in developing. Use of Unity will lead to easier collaboration between fire stations and programmers when creating simulations tailored to the firefighter's specific needs.

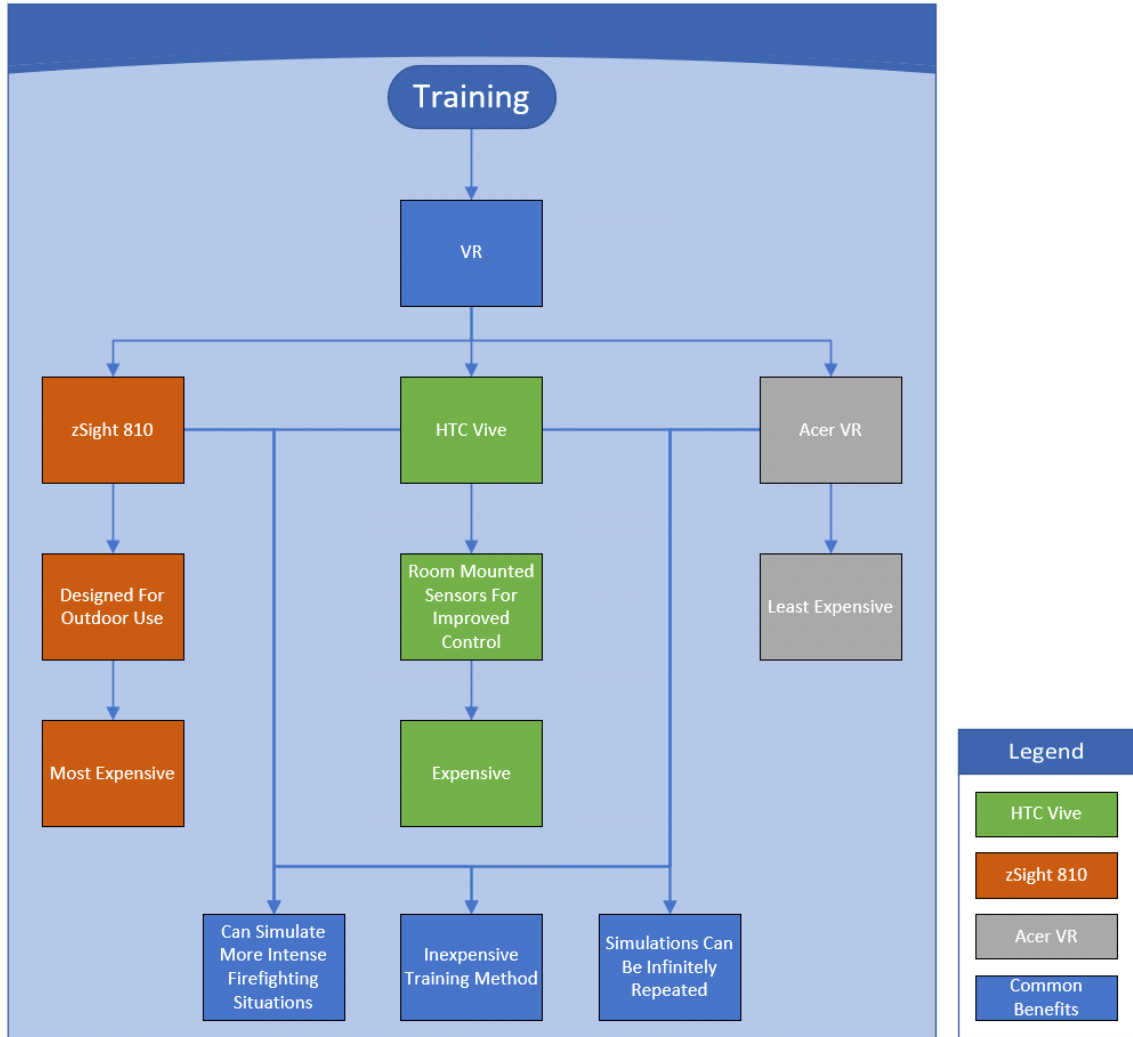


Figure 27. A comprehensive graphic of recommended training technologies

5.7 HoloLens

All of the previously mentioned headsets provide a wide array of uses for fire departments, but the headset we believe to be the easiest to adopt is the Microsoft HoloLens. The HoloLens is a system that allows for the use of Mixed Reality. Mixed Reality, abbreviated as MR, takes simulated objects and animates them into the surrounding environment for live interaction. As such, HoloLens can be used to simulate equipment and display real-time events. HoloLens also provides all of the features that VR headsets provide but in a more interactive

way. Furthermore, the HoloLens carries the same set of sensor arrays that are embedded inside smartphones and smartwatches. This allows HoloLens to remove the need for extra hardware which makes it much easier to integrate into existing training programs. The integration of HoloLens into training programs however, still need to be researched and tested before widespread implementation.

At \$5000, the HoloLens is an expensive standalone system, but we believe the initial cost is outweighed by the benefits. In particular, VR headsets require a host computer to run the simulations. This can be costly when analyzing all the components needed to run VR simulations properly. A HoloLens, however, can be used on its own. The only time HoloLens would require the assistance of another device is during simulation development process. Given the computer infrastructure required for VR, the advantages of a HoloLens surpass the cost.

Furthermore, HoloLens shares the same software development methods used for VR headsets. This means that, no matter the hardware platform used by HoloLens, simulation development will have the same benefits as described for VR headsets.

The HoloLens can also be implemented for firefighting in the real world. With all of the sensors and benefits described above, it would make a perfect addition to the equipment used by firefighters. The device itself is very compact and this allows it to be integrated with current firefighting equipment without the need for major modifications. The device itself can be worn right underneath the helmet and over the face mask.

Overall, HoloLens is a great all in one solution that solves many challenges as described in figure 21. It is currently very a expensive technology for wide spread implementation in China. However, if implemented, it will greatly assist in overcoming many challenges firefighters currently face in both training and live firefighting situations.

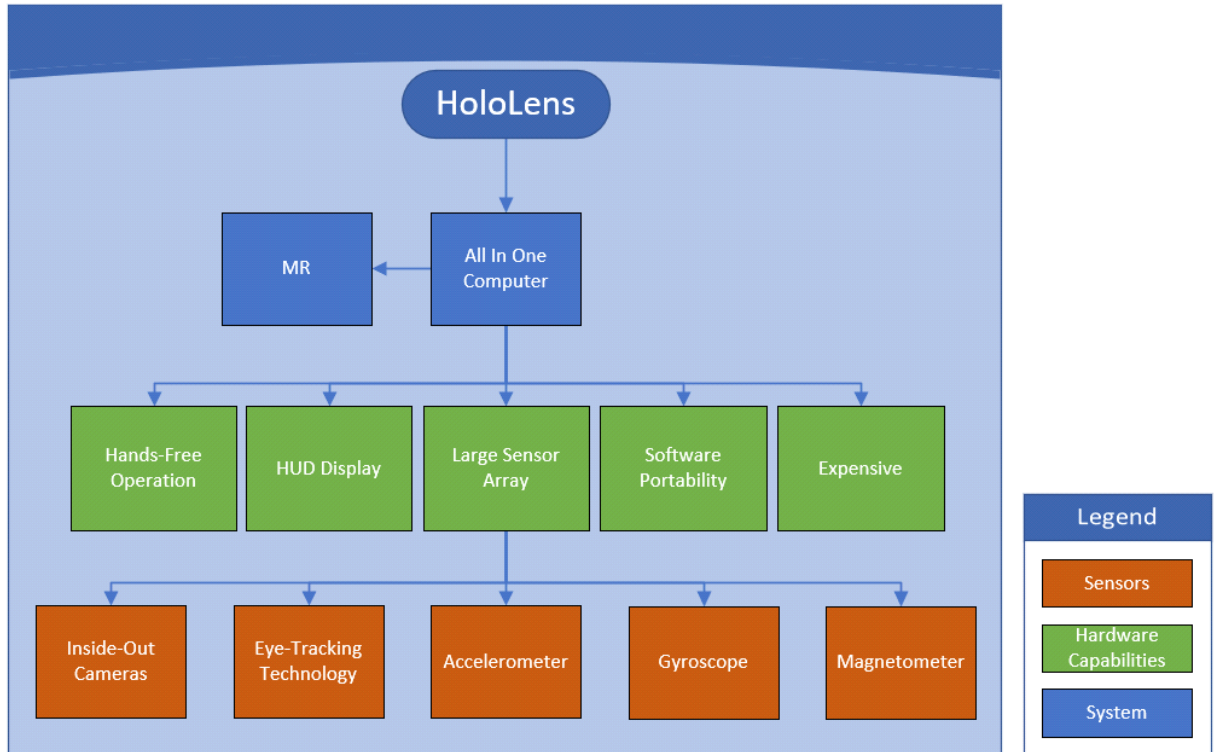


Figure 28. A comprehensive graphic of recommended HoloLens technologies

5.8 Creative Technologies

Current technologies can bring immediate impact to Chinese firefighting that have already been implemented globally. They are useful due to the fact that they have already been tested in the field and have proven effective. However, technologies still in development should also be considered for implementation in China because they have the potential to address specific challenges more effectively.

As cities grow, so does the need for more advanced and creative technologies, like the exploding fire extinguisher. The extinguisher removes the need to call firefighters for situations that ordinary citizens can handle by putting out the fire before it becomes large, dangerous, and difficult to manage. This technology, if deployed in large proportions within public buildings, would allow for more rapid and convenient fire prevention in urban environments. The

exploding fire extinguisher is currently being developed in other countries. We therefore recommend the use of the exploding fire extinguisher in the near future, after it is fully developed.

We also recommend the use of the sonic fire extinguisher. This fire extinguisher design exists only in research labs as of now, but the technology behind it equates to that of a simple sound system. The extinguisher simply outputs a 30 to 60 hertz sound wave that has the ability to put out a fire. Testing of this technology has only been done on small alcohol-based fires but with further research into this device, it can revolutionize the methods used for firefighting. It would do this by eliminating the need for physical suppressants needed for putting out various fires. We believe this technology would be a great addition for firefighting in China in the near future.

Lastly, our group recommends the integration of drone technology. Drone technology is very advantageous and reliable for firefighting. Drones have the ability to survey buildings and communicate site information to firefighters. They also have the ability to find survivors and trapped firefighters in an efficient way. Overall, the mobile platform of drones and their unique abilities will make firefighting safer and more effective in China if implemented. Currently, drones that can withstand the high temperatures necessary for firefighting cost several thousand dollars to acquire, making implementation impossible on a large scale. However, as time passes, this technology will become readily available and less expensive making wide spread implementation possible in the future.

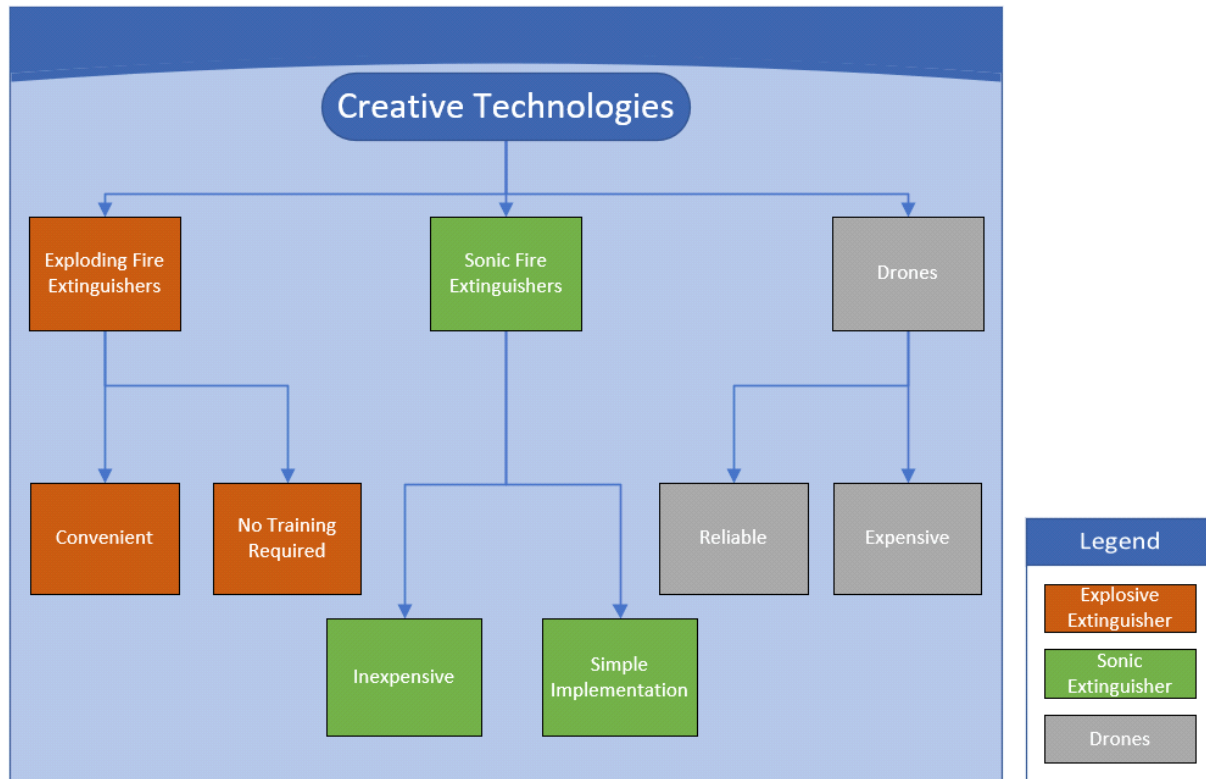


Figure 29. A comprehensive graphic of recommended creative technologies

6.0 Conclusion

As urbanization in China promotes rapid population growth, urban areas become increasingly densely populated. The distribution of citizens, the spatial organization of these cities, and the rate of development all present unique challenges to Chinese firefighters and disaster responders. Our project addressed these growing firefighting challenges by developing recommendations for our sponsor organization the WPI-Tsinghua University Center for Global Public Safety that integrated new smart technologies to make firefighting safer and more efficient in densely populated urban areas within China. In this report, Beijing, Wuhan, and Shanghai were used as a case studies to represent the general densely populated urban areas in China. We achieved this goal through the research of current and emerging smart firefighting

technologies globally and in China, identification of the current limitations of firefighting technology in urban China, and analysis of our findings to determine the best suited technology to help address the challenges. Our group successfully identified issues with current firefighting technologies and tactics and addressed them in our recommendations. The technologies we researched can also be implemented in fire departments where city growth and urbanization exceeds spending on the safety and security of citizens globally.

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8.0 Appendix

8.1 Survey 1: Beijing

Note: The number inside the parenthesis next to the questions and answers indicates the number of responses to that question and answers. Not all questions are displayed in this section, because we discovered some questions weren't relevant to the project. Only those that add to our project are displayed here.

What department are you in?

- A. Brigade
- B. Detachment (2)
- C. Squadron (3)
- D. University (13)
- E. Others

What is your position in your department?

- A. Combatant
- B. Squadron commander (4)
- C. Communicator
- D. Squadron and above commandeer (1)
- E. Driver
- F. Fire field investigator
- G. Students (12)
- H. Others (1)

How long have you worked as a firefighter?

- A. 0 --- 1 year
- B. 1 --- 2 years
- C. 2 --- 5 years (4)
- D. 5 --- 8 years (1)
- E. More than 8 years

Is unplanned or planned training for effective?

- A. Unplanned training (2)
- B. Plan training (2)
- C. Both are equally effective

What affect does unplanned training have on your abilities within your firefighting discipline?

- A. Is very effective (2)
- B. Has a good effect (2)
- C. Has little effect (1)
- D. Has no effect

How many times per month do you typically participate in unplanned training?

- A. 0 time
- B. 1 time (1)
- C. 2 times (3)
- D. 3 times
- E. More than 3 times

What aspects of firefighting should non-combatant firefighters be trained in? (multiple selection)

- A. Theoretical knowledge (4)

- B. Command and training (3)
- C. Physical training (2)
- D. skill training (3)
- E. Tactical training (3)
- F. Equipment training (2)
- G. Fire field safety training (3)
- H. Others

What aspects of firefighting should commanders be trained in? (multiple selection)

- A. Theoretical knowledge (4)
- B. Command and training (4)
- C. Physical training
- D. Skill training
- E. Tactical training (3)
- F. Equipment training (2)
- G. Fire field safety training (4)
- H. Others

What size training group typically participates in unplanned training? (multiple selection)

- A. Combatants
- B. Team (1)
- C. Single squadron (2)
- D. multiple squadron (2)

Where does unplanned training typically take place? (multiple selection)

- A. squadron barracks (2)

B. squadron training tower (1)

C. training base (3)

D. district unit

What aspects of firefighter training should commanders be assessed on? (multiple selection)

A. theoretical knowledge (1)

B. command ability (3)

C. Physique (2)

D. Skill operation (3)

E. Tactics Application (3)

F. Morale (3)

G. Equipment operation (2)

H. Fire safety (3)

I. Coordination guarantee (3)

J. Group cooperation (3)

K. Other

What aspects of firefighting should be trained with planned training? (multiple selection)

A. theoretical knowledge (4)

B. command ability (3)

C. Physique (3)

D. Skill operation (4)

E. Tactics Application (3)

F. Morale (3)

G. Equipment operation (3)

- H. fire safety (3)
- I. Coordination guarantee (3)
- J. group cooperation (1)
- K. Other

What aspects of firefighting should each duty squadron be trained in? (multiple selection)

- A. theoretical knowledge (2)
- B. command ability (2)
- C. Physique (2)
- D. Skill operation (2)
- E. Tactics Application (2)
- F. Morale (3)
- G. Equipment operation (2)
- H. Fire safety (2)
- I. Coordination guarantee (3)
- J. Group cooperation (3)
- K. Other

What factors restrict unplanned training? (multiple selection)

- A. Training time (4)
- B. Vehicle equipment (2)
- C. Training field (1)
- D. Logistics support (2)
- E. Others

What are the following equipment needs to be upgraded and improved? (multiple selection)

- A. Smoke alarm induction (4)
- B. Protective clothing (4)
- C. Fire engine (2)
- D. Fire pipe (2)
- E. Carrying metal objects (such as lightening the load) (1)
- F. Portable communication facilities (3)
- G. Others

Which of the following new smart firefighting technologies could improve the effectiveness of firefighter training? (multiple choice)

- A. Use VR (4)
- B. Use AR
- C. Online training courses (3)
- D. Others

8.2 Survey 2: Wuhan

1) What is your current position? (Pick One)

- | | | | |
|--------------------------------------|-----|--|-----|
| <input type="checkbox"/> Commander | (2) | <input type="checkbox"/> Tactical support personal | (0) |
| <input type="checkbox"/> Firefighter | (2) | <input type="checkbox"/> Professor | (1) |
| <input type="checkbox"/> Student | (1) | <input type="checkbox"/> Someone not listed | (2) |

2) Do you believe current firefighting techniques and equipment are safe and effective for firefighters? (Pick One)

- | | | | |
|--|-----|---|-----|
| <input type="checkbox"/> Yes (it does not need to be improved) | (8) | <input type="checkbox"/> No (it needs to be improved) | (0) |
|--|-----|---|-----|

3) What do you think are the major challenges in firefighting currently? (Rank Top 5 In Order with 1 being the most significant)

- A. Fighting fires in tall buildings
- B. Lack of stable communication
- C. Tracking firefighters
- D. Visibility and maneuvering the building
- E. Lack of enough oxygen supply
- F. Fatigue (carrying heavy equipment)
- G. Suppressing different types of fires
- H. Finding survivors
- I. Sufficient firefighting training
- J. Funding

Question 3	#1	#2	#3	#4	#5
A	3	1			
B		1	1	1	2
C	1		2	1	1
D		1	2		2
E		2		2	
F	1	2	2		
G		1		1	
H			1		2
I	2			1	
J	1			1	

4) What technologies do you think are the most outdated, unsafe or in need of an upgrade? (Rank Top 5 In Order with 1 being the most significant)

- A. Helmet / facemask
- B. Air tank / air supply
- C. Cooling system for firefighters
- D. Visibility equipment
- E. Communication devices / walkie-talkies
- F. Firefighter tacking devices
- G. Firefighting suits / gloves / boots
- H. Firefighting equipment / suppressants types

Question 4	#1	#2	#3	#4	#5
A	4				
B	1	3	1		1
C	1	2	2	1	
D	2	1			1
E			3	1	
F		1	1		4
G				1	1
H				4	

5) What technologies do you think must be implemented to make firefighting safer and more effective? (Rank Top 5 In Order with 1 being the most significant)

- A. Visibility technology (more and improved thermal cameras)
- b. Improved communication devices
- c. Improved sensors to track and monitor firefighters
- d. Hands free technologies -> helmet integrated communication and visibility devices
- e. Drone technology to scout the burning building / support units for firefighter
- f. Cooling systems for firefighting suits to reduce burns and exposer to heat
- g. Lighter firefighting materials and equipment

- h. Technologies to improve maneuverability and reduce delays
- i. Improve firefighting training methods and technology (virtual reality training)
- j. Better fire suppressing technology
- k. Software and technology to predict the spread of fire and how to suppress it

Question 5	#1	#2	#3	#4	#5
A	1	1	3	1	1
B		1	1	2	
C	2	3	1	2	
D					
E			1		
F	3	1			1
G			2	1	1
H		1			1
I	1				2
J		1		2	
K	1				2

8.3 Chinese Fire Station Standardized Equipment Inventory

We have summarized data listing the standardized inventory of equipment in Chinese fire stations. We received access to this data through our sponsor. This gave us hard, quantitative data useful for generalizing results and the development of a concise problem statement.

Standard for Basic Firefighter Protection Equipment

Number	Equipment	Technical Purpose	Amount Ordinary Station	Typical Amount per Service Station
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			On Hand per firefighter	Backup per firefighter	Matching	Backup Ratio
1	Protection helmet	Head, face, neck protection	2	4	2	1
2	Protective clothing	Body protection	2	2	2	2
3	Gloves	Hand protection	2	1	2	1
4	Fire safety belt	Climbing for self-rescue	1	4	1	4
5	Protective boots	Calf and feet protection	2	2	2	2
6	Positive pressure air respirator	Oxygen	1	4	1	4
7	Wearable flameproof lamp	Single person operation lighting	1	5	1	5
8	Firefighters caller	Communication, asking for help	1	4	1	4
9	Azimuth lamp	Location of fire fighters in the dark and smoke	*	-	*	-
10	Safety Line	Emergency escape	1	4	1	4
11	Fire waist ax	Manually break apart obstacles and debris	1	5	1	5
12	Antistatic underwear	Inner layer body protection	2	-	2	-
13	Fire goggles	Eye protection	1	4	1	4
14	Rescue helmet	Head protection	1	1	1	1
15	Emergency rescue protective clothing	Body protection	2	4	2	4
16	Elbow and knee pads	Knee and elbow protections	2	4	2	4
17	Rescue Boots	Calf and feet protection	2	4	2	2
18	Signal receiver	Receive the wireless alarm signal of firefighter's rescue device	*	-	*	-

19	Bone conduction communication device	Communication, wearable voice transceiver	1 for 2 firefighters	/	1 for 2 firefighters	/
20	Handset radio	Communication, between firefighters	1	/	1	/
21	Single position device	Locate position of firefighters	*	/	*	/

Standard for Special Protective Equipment for Firefighters



Number	Equipment	Technical Purpose	Amount Ordinary Station		Typical Amount per Service Station	
			On Hand per firefighter	Backup per firefighter	Matching	Backup Ratio
1	Heat insulation protective clothing for firefighters	Whole body protection from strong heat radiation	4 suits per team	4	4 suits per team	2
2	Fire protective clothing	Whole body protection for short term heat exposure	2 suits per station	-	4 suits per station	1
3	Level 2 chemical protective suit	Physical protection from volatile chemical solids and liquids while responding to chemical disasters	8 suits per station	-	1	4
4	Level 1 chemical protective suit	Physical protection from highly concentrated of strongly permeable gas	4 suits per station	-	16 suits per station	-
5	Special chemical protective suit	Whole body protection for the disposal	*	-	4 suits per station	-

		of biochemical agents				
6	Nuclear contamination protective suit	Prevent radiation contamination damage	-	-	*	-
7	Chemical protective gloves	Protection of the hands and wrists from chemicals	4 per station	-	8 per station	-
8	Built-in labor protective gloves	Inner layer hand protection	1	1	1	1
9	Heat protective gloves	Hand protection under high heat	4 per station	-	9 per station	-
10	Bee suit	Protection against bee insects	4 per station	-	4 per station	-
11	Electric insulation fitting	Full body protection during operation of high voltage electric field	2 suits per station	-	2 suits per station	2
12	Anti-static clothing	Full body protection	2 suits per station	-	2 suits per station	2
13	Fire retardant sweater	Inner layer protection during operation in winter	1	4	1	4
14	Cooling vest	Reduces temperature to prevent heat stroke	4 suits per team	-	4 suits per team	-
15	Moving air supply	Respiratory protection for small spaces and large fires	1 suit per station	-	2 suits per station	-
16	Positive pressure fire oxygen	Respiratory protection in long term operation,	*	-	4 suits per station	2

	breathing apparatus	high altitudes, underground, tunnels, and high-rise buildings				
17	Forced air breathing apparatus	Respiratory protection in open space toxic areas	*	-	4 suits per station	—
18	Fire filter type integrated gas mask	Respiratory protection in open space toxic areas	*	-	1 for 2 firefighters	4
19	Diving equipment	Special protection for underwater rescue operations	2 suits per station	1	4 suits per station	-
20	Fire jacket	Special protection for water rescue operations	1	-	1	2
21	Fire seat safety harness	Rope rescue operation	2 suits per team	2	4 suits per team	2
22	Full body safety sling	Rope rescue operation	2 suits per team	2	4 suits per team	2
23	Light safety rope	Self-rescue and escape	*	-	*	-
24	Utility safety rope	Rope rescue operation	2 suits per team	2	4 suits per team	2
25	Fall protection auxiliary parts	Works with safety ropes, harnesses, belts. Includes: 8 rings, type D hook, portable fixtures and pulleys	2 suits per team	2	2 suits per team	2
26	Portable bright lights	Lighting of disaster and rescue sites	2 suits per team	2	2 suits per team	2
27	Light sticks	Lighting	2 suits per team	2	2 suits per team	2

28	Water rescue floating lifeboat	Water rescue operations	200m per station	-	400m per station	-
29	Water rescue protective suit	Protection for water rescue operations	*	-	8 suits per station	2
30	Water rescue helmet	Head protection for water rescue operations	*	-	8 suits per station	2

8.4 Current Firefighting Technologies at Wuhan Fire Station

Current Technologies at Wuhan Fire Station	
Helmet	Facemask
	
Firefighting suit	Firefighting suit (cont.)



Sole Tracker

Boots



Beeper Tracker



Rope



Robot Tank



FLIR K45 Thermal Camera



Jaws of Life



Walkie-Talkies

