Improving Our Tunnel Vision: Tunnel Firefighting Operations in Norfolk Fire Rescue

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Abstract

The problem was Norfolk Fire Rescue (NFR) had not identified best practices to effectively manage and suppress fires in roadway tunnels. The purpose of this research was to identify best practices in order for NFR to respond to and combat fires within the city's roadway tunnels. The ability to utilize resources effectively, manage the incident scene, understand fire dynamics in tunnels, and learn from fires in the past would allow members to increase their level of success in these specific incidents.

In this descriptive research, the following questions were answered: (a) What firefighting challenges are unique to tunnel fires? (b) What best practices have fire departments or other agencies used when arriving on scene and suppressing tunnel fires? (c) What lessons learned have fire departments or other agencies responsible for roadway tunnels experienced when combating roadway tunnel fires?

Data was collected using interviews and a survey. Interviews were conducted with persons responsible for daily tunnel operations, and surveys were sent to departments throughout the United States, Canada, and Europe.

Results indicated that firefighting best practices in tunnel rely heavily on pre incident planning and an understanding of fire dynamics in tunnels, as well as the systems that will affect these dynamics. Recommendations included NFR conducting and maintaining pre-fire plans, better means of communication with the tunnels, and an overall increase in the study of firefighting methods in tunnels in the United States.

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There are several unique challenges that fire service personnel in general, and NFR members in particular, are faced with every single day. Firefighting operations in roadway tunnel fires can pose their own unique challenges that firefighters must be ready to resolve. NFR has three roadway tunnel systems that require its service when accidents occur. Throughout the day, there is a substantial amount of traffic driving through these tunnels. The vehicles range anywhere from passenger sedans to large shipping trucks carrying hazardous materials. The probability of a significant tunnel fire does exist for NFR members and preparation is essential.

The problem was NFR has not identified best practices to combat fires in roadway tunnels. The purpose of this research was to identify best practices that are needed for NFR to combat fires in roadway tunnels that are within city boundaries. The descriptive research methodology was used to identify what steps are needed to ensure effective and successful operations and develop a policy to assist NFR members in their response to tunnel fires. The research questions addressed were: (a) What types of firefighting challenges are unique to tunnel fires? (b) What best practices have fire departments or other agencies used when arriving on scene and suppressing tunnel fires? (c) What lessons learned have fire departments or other agencies responsible for roadway tunnels experienced when combating roadway tunnel fires?

This research will could serve to benefit NFR and their response and mitigation of fires in roadway tunnels. This unique environment offers several complicated factors that firefighters may have to manage to ensure life safety and structural integrity of the tunnel. With a good body of research to help drive the decisions that will be made during the pre-arrival process as well as on scene NFR can implement best practices leading to effective tunnel firefighting operations.

Background and Significance

Norfolk Fire Rescue (NFR) is very proud of its tradition and rich history. The Fire Department has been a paid organization since the merger of volunteer companies in 1871. The department has since evolved and progressed to meet the constant and dynamic demands from the community it serves and its citizens. Norfolk's committed professionals cover an area of 66 square miles of urban city with a population of 246,139 residents (United States Census Bureau, 2013). NFR responds to over 40,000 emergency incidents a year from 14 fire stations located throughout the city, with just over 500 dedicated professionals (City of Norfolk, 2014). It also provides a multitude of community and support services from Administrative Services, Fire Marshal's Office, Training, and the Special Operations Divisions. Within its borders Norfolk houses the world's largest naval base, shipyards, and large international shipping terminals. Norfolk Fire Rescue is committed to maintaining a response time of less than four minutes at least 90% of the time.

NFR staffs 12 advanced life support ambulances (ALS), 14 ALS Engine Companies, 7 ALS Ladder Companies, and 2 ALS Rescue Companies. In addition there are two fire boats that are capable of performing water rescue as well as fire suppression. The operations side of the department is separated into three separate battalions, working under three rotating shifts. Services provided include fire suppression, emergency medical services, technical rescue, and waterborne operations. In addition, some stations serve as specialty shops for small tools, turnout gear, breathing apparatuses, and nozzle repairs.

The City of Norfolk has three tunnel systems that link the surrounding cities to its borders. The first tunnel is the Hampton Roads Bridge Tunnel. This is the oldest tunnel on Interstate 64 and connects Norfolk to other cities such as Hampton, Newport News, and is the major artery to the western part of the state (Virginia Department of Transportation [VDOT], 2014). This tunnel was originally a two lane tunnel in 1957, and in 1976, a second set of lanes was created (VDOT, 2014). Traffic in this tunnel becomes congested almost daily causing motorists to seek alternate routes. On average, nearly 3 million vehicles of all different types travel through this tunnel (VDOT, 2014). The Hampton Roads Bridge Tunnel is 7,479 feet from entry to exit, making it the longest tunnel system in the City of Norfolk (Kozel, 1997).

The second tunnel that feeds into the city of Norfolk is the Downtown Tunnel. This tunnel connects Southern Hampton Roads with the City of Norfolk and Portsmouth. This tunnel first opened in 1952 and also carries more than 3 million vehicles through it each month (VDOT, 2014). The length of this tunnel is 3,350 feet from entry to exit (Kozel, 1997). The third tunnel is the Midtown Tunnel which connects the City of Norfolk to the City of Portsmouth and beyond. This is a two lane tunnel and is heavily traveled and is used as an alternate route when the Downtown Tunnel becomes congested. This tunnel has just over 1 million vehicles that travel through it each month (VDOT, 2014). The Midtown Tunnel is measured at 4,149 feet from entry to exit (Kozel, 1997).

There is a tremendous amount of traffic coming through these tunnel systems every day which could precipitate the chance of NFR responding to a tunnel fire emergency. There are various types of vehicles that travel in and out of these tunnels. The chances for motor vehicle accidents to occur within these tunnel systems are very probable, especially given the high volume of traffic. There have been 15 deaths resulting from tunnel fires in the United States

(Transportation Research Board, 2011). On average, cities that have tunnel systems in or around their borders will likely experience a tunnel fire once or twice a year depending on variables such as the number of lanes in the tunnel, volume of traffic, and the specific design of the tunnel (Transportation Research Board, 2011). With the City of Norfolk having three roadway tunnels and a total of approximately 7 million vehicles passing through them every month, Norfolk Fire Rescue needs to be on the forefront of identifying factors that will contribute to its success in tunnel fires. Most of the fires that occur in tunnels are a result of cars or vans being involved in motor vehicle accidents or having internal problems such as electrical shorts and are generally, smaller fires (Transportation Research Board, 2011). The larger and more damaging and costly fires are the ones that originate in heavy goods vehicles or tanker trucks carrying dangerous cargo (Transportation Research Board, 2011).

The challenges NFR faced in these tunnel systems included: (a) quicker development of fire, (b) limited ventilation, access problems, and (c) longer duration of burn time due to delayed entry (Transportation Research Board, 2011). After the fire is extinguished, there may be economic impacts that could potentially cost the City of Norfolk as well as reach out into the region. In 2001, the City of Baltimore had to payout $1.3 million dollars to cover the clean-up process after a derailment of a rail car and a subsequent fire in the CSX tunnel (United States Fire Administration [USFA], 2001, p.3). This total value did not take into consideration the overtime and equipment costs that may have been associated with events like this. In the current budget climate this could be a devastating blow to an operating budget. With a high probability of tunnel fire incidents in the City of Norfolk, this research project will have a great impact on the way Norfolk Fire Rescue responds to and mitigates tunnel fire incidents. This research will benefit not only the members of NFR, but the population of citizens that use these tunnels everyday as arteries of travel for work and pleasure. Through the skills and education received in the Executive Development course, this research will allow for identification of a solution to a technical problem that exists in NFR.

The United States Fire Administration [USFA] (2014) developed a strategic plan for the fire service that included five goals to help emergency services improve their delivery of service to the communities and the fire service as a whole. Norfolk Fire Rescue has realized that identifying best practices for firefighting operations in tunnels is vital. The third USFA goal was to "improve the fire and emergency services capability for response to and recovery from all hazards" (United States Fire Administration, 2014, para. 4). The problem with NFR not identifying best practices for tunnels fires is it could stifle our ability to provide the best service possible should an event occur. Operations in tunnel fires can be problematic, and NFR has an opportunity to improve response time and performance in the midst of these perplexing incidents in order to share the findings with surrounding jurisdictions.

Literature Review

The literature discovered for this research examined topics on (a) fire dynamics in tunnels, (b) incident management, (c) fire protection features and requirements, (d) current standards, and (e) fire suppression operations. In addition, further research was conducted to identify lessons learned from previous tunnel fires and what recommendations had been made to improve fire department operations. The challenge with this literature review was the narrow scope of this topic in the United States. There have been very few significant tunnel fires that have resulted in casualties or lessons learned over the recent years. The majority of the literature comes from resources overseas, specifically in England, Germany, Hong Kong and Sweden.

There have been several deaths related to accidents in road tunnels. The most significant being the Mt. Blanc, St. Gotthard, and Tauren tunnel fires, which resulted in 52 fatalities (Mitchell & Charters, 2005). Fire occurred in two out of three of these roadways as a result of motor vehicle accidents; one being a head on collision and the other being an impact from the front of one vehicles engine compartment to the back trunk of another (Kim, Lonnermark, & Ingason, 2010). Two of these three fires escalated due the fact that coordination between firefighting crews was not performed (Kim et al., 2010). “Catastrophic consequences may result if responsibility is given to only one side of the tunnel” (Kim et al., 2010, p. 39). Depending on the location of the tunnel two separate fire brigades or departments may be responding.

A solid incident command system is essential to any fire department operation. No matter what type of incident is faced, the goal must be to complete all required tactical priorities. The incident commander (IC) is tasked with executing an incident action plan based off the collective efforts of resources. It is up to the IC to analyze and implement and action plan based off of input from subject matter experts in various disciplines (Brunacini, 2003).

The USFA (2012) recommends a pre-incident plan even for complex roadway incidents. In order for a pre-incident plan to be effective, all agencies that will be responsible for responding to emergencies must come to a consensus on how to operate at specific incidents (United States Fire Administration [USFA], 2012). Emergency personnel that are responsible for incident command at tunnel fires may experience a challenging set of circumstances unlike any other roadway event (English, 2010). Not only will different state and federal agencies be involved in a tunnel fire; depending on the location of the tunnel, multiple fire departments may be as well (English, 2010).

In 2011, the Commonwealth of Virginia adopted the National Fire Protection Association, [NFPA], NFPA 502 standard for road tunnels, bridges, and other limited access highways. According to NFPA 502, the agency responsible for the daily operations of the tunnel is ultimately responsible for developing an emergency response plan (National Fire Protection Association, 2014). With the adoption of this standard it included the guidelines for emergency response and operations (Davis, 2011).

NFPA 502 sets forth the recommendation on specific entities that should be consulted when developing this emergency plan. The standard also sets forth how often both emergency responders and other participating agencies must conduct exercises and training. According to this standard: "exercises and drills shall be conducted at least twice a year to allow for first responders to be better prepared for an actual incident" (NFPA, 2014, sec 13.8). Lastly, the standard identifies specific requirements that will assist fire department personnel when responding in to a tunnel fire such as, smoke control, fire department connections, and signage to assist with victim egress.

Training exercises in this environment can be difficult to accomplish, but are necessary, and in some states or countries are a mandated requirement. Almirall et al. (2012), states:

> Most organizations are convinced of the need for real life exercises, but the reality is that this kind of practice is not as consistent as it should be. One main reason is the need for coordination between multiple external agencies.

Ingason (2005) studied several dynamics of fire and smoke in tunnel systems. The study concluded: (a) the feedback of heat coming off single or multiple vehicles involved in fire is intensified due to the confined space that the fire is developing; (b) the way the fire will develop and interact with airflow; (c) the flow of hot gases in a tunnel will complicate firefighting operations as well as cause toxic gas and fumes to travel far from the origination of the fire affecting other victims. Although the fire behaves differently and flashover within the tunnel is not likely, the vehicles distant from the origin of fire can ignite from radiant heat when the flames travel to seek oxygen. Smoke development in a tunnel will almost mimic that of a compartment fire in the early stages of development; as the fire intensifies, this layering of smoke will eventually seek an outlet. The layering of smoke will depend on factors such as tunnel length and type, perimeter, and the velocity of air moving through the tunnel (Ingason, 2005).

Heat release rates during accidents may vary inside of a roadway tunnel based on the type of vehicle involved and the contents; such as (a) flammable liquids, (b) synthetics, or (c) organic products made from wood and paper. Vehicles involved in fire can range from a motorcycle to a heavy goods vehicle, or even a tanker carrying large amounts of fuel (Cheong, Spearpoint, & Fleischmann, 2008). Experiments conducted in the Renehamar tunnel, which is located in Norway, concluded that larger burning vehicles tend to have a high energy output and are being underestimated when taking the design of tunnel fire protection into consideration (Cheong et al., 2008). During these experiments it was noted that fires in small passenger vehicles will produce 5 Mega Watts (MW), buses will produce 20MW, and heavy good vehicles will produce 30-100MW of heat energy (Cheong et al., 2008, p 11). These heat release rates can be significantly increased if the installed ventilation system is used improperly and creates a high velocity of air travel through the tunnel (Cheong et al., 2008).

According to NFPA 502, regardless of tunnel length all structural elements need to be fire protected (NFPA, 2014). Active fire protection systems that may be seen in the Commonwealth of Virginia include a wet based fire protection system and emergency ventilation systems (NFPA, 2014). According to the NFPA (2014) an emergency ventilation system must be installed in all tunnels that exceed 3,280 feet in length. These ventilation systems should be designed to assist emergency responders as well as evacuating motorists.

Ventilation systems are ultimately a beneficial feature to have in a tunnel; they can redirect smoke allowing for areas of refuge and egress for trapped motorists, as well as help firefighters make an approach to the seat of the fire (Kim et al., 2010). Special consideration should be given to the type of ventilation system as well as fire intensity before employing the use of these systems (Kim et al., 2010). The application of specific ventilation systems has been largely controversial amongst engineers, and very few live fire and smoke events have been simulated in various types of tunnels (Kot, Raymond, & Dennis, 1999).

The strategy for smoke removal using an installed ventilation system should be developed in the response matrix for the tunnel officials and fire departments responding, and include factors such as location of the fire and where the firefighters will attempt to make entry and push smoke in the opposite direction (American Public Transportation Association, 2010). The goal of a wet based system, as mentioned in NFPA 502, is to impede the growth of a fire as well as improve tenability for motorists and ultimately lead to a better emergency response and mitigation (NFPA, 2014). Although these systems generally perform well, they remain controversial and more research is needed to develop a clearly defined standard in the United States (Harris, 2013). Harvey (2014) argues that fixed fire suppression systems are not effective in extinguishing fires and only contribute to more panic amongst the trapped motorists inside a tunnel. The argument is made that if life safety of the trapped motorists is the priority, then an installed wet sprinkler system will keep the fire at bay while rescues are made (Kim et al., 2010).

One of the best courses of action fire departments can take is to create a well developed integrated response and evacuation plan for each tunnel location, as well as including fire department personnel in the design phase of new tunnels (Department for Communities and Local Government, 2012). Activation of an installed ventilation system should only be performed after making an educated and informed risk assessment of the incident in the tunnel (Department for Communities and Local Government, 2012). Ultimately, the incident commanders will use their best judgment and, if possible, always try to advance hose lines while coordination is made with the ventilation system, causing the smoke and heat to be drawn away for the advancement (Department for Communities and Local Government, 2012).

In Germany, a very specific firefighting tactic has been developed. When first arriving on scene, the initial attack crew will first identify which end of the tunnel has the least amount of smoke. Once that has been determined, a swift attack is made on the fire with the initial water on board the apparatus in conjunction with positive pressure fans blowing air against the backs of the firefighters as they make their approach (Fiebach, 2002). Robotics inside of tunnel systems may also be an effective approach to combating fires. Having the option to place an unmanned robotic system could be a rapid intervention in the event of a tunnel fire and, often times, takes minimal modification to the existing structure of the tunnel (Celantano, Siciliano, Villani, 2005).

Compartmentation of the tunnel during the design phase is believed to be a preventive measure that will enable more effective firefighting practices and hose line advancement (Tan, 2002). Longer tunnels that are divided into sections or zones was introduced around the 1980s with the concept that gates can be installed to block off sections of the tunnel that are on fire (Reza-zadeh, 2004).

The structural design of a tunnel in the design phase may help overall firefighting efforts. The ultimate problem for firefighters even after the fire has been extinguished, is the potential collapse of spalling concrete affected by the heat (Hoj, 2004). The author suggests that during the design of a tunnel, specifically in the fire protection aspect, that more factors need to be considered. He suggests an integrated approach to design, taking into account “factors such as the environment, geology, and end user requirements” (Hoj, 2004, p. 61).

Concrete has been the primary structural material used in roadway tunnel systems for several years, and the effects of fire on concrete have been studied in great detail (Smith & Atkinson, 2010). A polypropylene monofilament microfiber is new technology that has been added into concrete to prevent explosive spalling. The addition of these fibers does not allow for the moisture in the concrete to expand and cause an explosive reaction (Smith & Atkinson, 2010). The addition of these fibers in concrete may be a cost effective solution when compared to other protective features such as a spray on fire proof coating (Smith & Atkinson, 2010).

In summary, the purpose of this literature review was to examine and summarize the research findings of others on the topic of current firefighting practices in roadway tunnels. The search identified very few tactical procedures or particular firefighting strategies. The literature review was centered mostly on fires that have occurred in previous roadway tunnels and the use of installed systems to help keep the fires under control prior to firefighting forces arriving. In addition, there was a large amount of literature on fire dynamics, suppression systems, and design fires.

Procedures

This applied research project used a survey and interviews with officials from each of the three roadway tunnels that are in the City of Norfolk, Virginia. The purpose of these procedures was to gain as much information from various sources to answer the research questions and help identify best practices needed to combat roadway tunnel fires.

The Internet search included key subjects such as roadway tunnel fires, tunnel fire protection systems, and tunnel fire dynamics. Websites that were examined were state and local departments of transportation and various government agencies. Much of the data gathered through the Internet was from websites that included technical journals and the research of others on the same topic. Data on firefighting practices in tunnel was difficult to obtain through the Internet and had to be pulled from other sources such as interviews and a survey,

A survey (Appendix B) created on the Internet site Survey Monkey was sent out to over 200 firefighters, and it captured 60 respondents from fire departments from around the country, as well as Germany, England, Canada and Hong Kong. Prior to the dissemination of the survey departments with roadway tunnels in their jurisdictions were identified. This was accomplished by performing an Internet search as well as calling multiple departments around the country and contacting departments overseas via email. A total of 60 days was allowed before the survey was closed. The purpose of the survey was to gather data about current practices being used worldwide to combat fires in roadway tunnels.

A letter was attached to the email link with the survey explaining the purpose of this research and what the survey would entail (see Appendix A). The survey consisted of 13 questions which included check boxes, fill in the blank and short answer responses (see Appendix B). When the survey was sent out, it did not target any particular subject matter expert within a department. The recommendation in the letter was to have a training officer or chief officer complete the survey.

Interviews were conducted with three roadway tunnel officials. The Downtown Tunnel and the Midtown tunnel fall under the responsibility of the private agency, Elizabeth River Crossing. This interview took place in Portsmouth, Virginia, and included the traffic management supervisor (M. Hicks, personal communication, July 22, 2014) and tunnel engineer (D. Francis, personal communication, July 22, 2014) for both tunnels. The third tunnel called the Hampton Roads Bridge Tunnel (HRBT) falls under the responsibility of the state agency, Virginia Department of Transportation (VDOT). The interview for this tunnel was conducted with the tunnel operations program manager (R. Fitzhugh, personal communication, July 28, 2014) in Hampton, Virginia. All interviews were conducted on site at each tunnel in the event that further clarification was needed or a walkthrough of the facility might assist the researcher and the interviewee. In order for the interviewees to be prepared for the questions that were asked, these 13 questions (see Appendix E) were sent to them via email one week prior to the actual interview. This allowed an opportunity for each of the individuals to be interviewed with time to prepare for each of the questions they were going to be asked.

Limitations that existed during the data collection included the lack of current information in the United States regarding tunnel firefighting operations research. There has been little focus on researching fires and fire dynamics in roadway tunnels in the United States along with identifying firefighting practices to match those dynamics. The lack of data may be due to the small number of fires in the United States when compared to Countries overseas that have had multiple, and often fatal tunnel fires. Other limitations that existed during this research was the inability to run full scale exercises with multiple jurisdictions to help identify best practices as well as identify any pitfalls that NFR may encounter. With an exercise only being conducted annually it was difficult to be a part of that event and used results from the exercise to help answer the research questions. The sample size was very limited in this research. Very few fire departments have roadway tunnels in their jurisdictions. The ability to identify departments throughout the country that respond to fires in roadway tunnels was challenging. There was no database that existed or a timely way to select multiple agencies that could create a focus group in which to send the survey. Other measures used to collect data could have been used in this research. If conducted again, it may be beneficial for the researcher to conduct interviews with tunnel officials or fire department members that responded to a significant tunnel fire. This could lead to an opportunity to gain firsthand knowledge on best practices and lesson learned.

Results

Research question one asked: What types of firefighting challenges are unique to tunnel fires? The data collected in the survey (Appendix B), and the interviews (Appendix C and D) clearly identified very unique challenges in tunnel firefighting compared to any other firefighting operations. The incident command system should be very structured for a roadway tunnel event, and the incident commander should have a detailed and well developed pre-fire plan or incident action plan prior to the response to this type of incident. Fire dynamics inside of a roadway tunnel also offer a unique set of challenges. Fires that start from passenger vehicles up to heavy goods vehicles will generate heat release rates sometimes in excess of what the tunnel's fire protection features can handle. The design of a tunnel itself can result in a complicated fire operation. Communications as well as apparatus access can be problematic. Smoke travel through the tunnel can also play a vital role in the outcome of the incident. Ventilation systems are installed in most tunnels and coordination has to be made between tunnel officials and emergency responders. The continued controversy surrounding fire suppression systems in roadway tunnels will have a continued impact on firefighting operations. The lack of an installed system may or may not be beneficial depending on the size and type of the fire and the capabilities of the fire department responding. The survey specifically captured 15 departments that had similar challenges when responding to a roadway tunnel fire. The top four challenges included: (a) apparatus access, (b) communications, and (c) fire extinguishment and (d) incident management.

The second research question asked: What best practices have fire departments or other agencies used when arriving on scene and suppressing roadway tunnel fires? The fundamentals of how to attack a fire in a tunnel are left to the best judgment of the firefighters as well as the incident commander. Data collected through the survey revealed that very few fire departments have a guideline or policy to follow for best practices during a tunnel fire operation. Most of the factors that will result in a successful outcome at a roadway tunnel fire should be considered and planned for well ahead of time and planned for. These factors include: a communication plan, coordination of ventilation and fire suppression, a place to establish the incident command post and the best way to make access to the tunnel. All of these proactive measures can lead to a safer and more effective approach to the firefighting effort. Interviews with tunnel officials identified that while they have a response plan in place that is continually evaluated; their means of cooperating with responding agencies needs to be improved. Some departments found success with using the fast attack vehicle option, such as a response truck with multiple dry chemical extinguishers. The use of a LUF 60, which is mobile firefighting support unit is being widely used by departments across the world as a rapid response option and is capable of extinguishing a fire in a tunnel using a combination of water mist and fans (Giamex, 2008). The literature review also revealed that in fire departments overseas there has been a small push to educate others in tunnel firefighting tactics. European journals have published material on this topic, but it has not reached the literature in the United States.

The last research question asked: What lessons learned have fire departments or other agencies responsible for roadway tunnels experienced when combating roadway tunnel fires? The available data on lessons learned at roadway tunnel fires captured in the survey was scarce. As identified in the survey (Appendix B), lessons learned included: (a) there will be the need to call for additional resources early in the incident, (b) pre-planning may be one of the most important factors in the response to a tunnel fire, and (c) tunnels in the United States need to be able to handle rapid fire growth. Radio checks are also not being conducted on a daily basis to ensure a good communication medium is in place prior to response (R. Fitzhugh, personal communication, July 28, 2014). Much of the lessons learned on these types of fires have not been widely broadcasted. Of the multiple tunnel fires that have occurred over the last two decades, only the significant fires usually receive attention and reveal lessons learned. The limited amount of information collected on lessons learned identified that not having a pre-fire plan and a familiarization with the tunnel system prior to a response could end with a poor result. It also identifies that a lack of coordination between the fire department responding and the state or private agency responsible for the tunnel could lead to more complications at the incident. A good working relationship as well as clear communications between all agencies involved is crucial.

The interviews that were conducted for the Midtown Tunnel and the Downtown Tunnel revealed that each of the tunnels, although different length and age, both have the exact same features (see Appendix C). The interviews for each of these tunnel concluded that most of the firefighting efforts rely solely on the fire department once they arrive. The tunnel official expects that once the fire department shows that up they have been trained in tunnel firefighting and are capable of dealing with this emergency. Coordination between the fire attack and ventilation can take place once fire units arrive on scene. With the installation of new fans in these tunnels, there is the ability to move a lot of smoke and allow for evacuation as well as fire suppression. These fans are able to withstand heat of up to 40MW (M. Hicks, personal communication, July 22, 2014). As discovered by Ingason (2008) the heat release rate of some larger vehicles may exceed this in a roadway tunnel. The fans in the Downtown and Midtown tunnels may be affected if there was fire impingement. In this case, an activation of a deluge sprinkler system would follow. The first action the fire department can do when responding to these two tunnels is to contact the tunnel official in the control room and gather as much information as they can about the fire. Exercises in these tunnels are not taking place on an annual basis which could lead to complications in future tunnel fire events.

The interview (R. Fitzhugh, personal communication, July 28, 2014) at the Hampton Roads Bridge Tunnel (HRBT) revealed one major area of concern: communications. Currently, there is no way for the tunnel officials in the control room to relay information to the responding firefighters. They have the ability to closely monitor conditions in the tunnel as well as the ventilation system, but have no means of communication to update incoming units. Due to the fact that there have been little to no updates in the fire protection of the tunnel, a large fire here may cause significant damage. Due to the lack of protection, a large fire may cause an increase in the spalling of the concrete inside the tunnel and become a hazard to firefighting crews (Smith & Atkinson, 2010). When it comes to emergency preparedness, the HRBT has a well developed emergency response plan that is reviewed on an annual basis. Additionally, they use this emergency response plan when conducting their annual training exercises.

Collectively, both interviews identified that the largest firefighting challenge is the coordination between the tunnel officials and the responding agencies, followed by management of fire attack and ventilation. All tunnels recommend that fire departments conduct thorough walkthroughs at least annually to stay up to date on design changes in the tunnel as well as offer input to officials on fire department response capabilities. There were very few lessons learned in each of the three tunnels in the City of Norfolk according to the tunnel officials.

Discussion

Based on the information gathered, primarily at the local level through interviews, Norfolk Fire Rescue has a high potential for a significant tunnel fire in one of the three named tunnels. This study proved to be beneficial in helping Norfolk Fire Rescue identify some steps to be better prepared for a tunnel fire response, as well as steps it could take to implement best practices that will contribute to a successful outcome should these events arise.

Norfolk Fire Rescue generally has a very strong incident command system at any event to which it responds. In the case of a tunnel fire, there is currently nothing in place to coordinate efforts for a mutual response. Coordination between fire departments or fire brigades is essential or the end result could prove to be fatal (Kim et al., 2010). Currently there is no established mutual aid agreement to facilitate a coordinated approach to mitigating a tunnel fire when responding with other agencies. The surrounding cities also have policies in place when responding to a fire in the tunnels.

As set forth by NFPA (502), tunnel fire exercises should be conducted on an annual basis. The private agency that is responsible for the Midtown and Downtown tunnels have not conducted an exercise in some time (M. Hicks, personal communication, July 22, 2014). This could lead to ineffective operations if a tunnel fire were to occur. Additionally the lack of exercises does not allow for a true evaluation of the emergency response plan that is developed and reviewed annually. Since this is a private agency that is not regulated by the state, there may be a gap in oversight in this NFPA document. In 2011, the Commonwealth of Virginia adopted the NFPA 502 standard (Davis, 2011). Under this standard the Hampton Roads Bridge Tunnel has been conducting annual tunnel fire exercises and has included the appropriate stakeholders when conducting the training (R. Fitzhugh, personal communication, July 28, 2014).

The fire protection features in the tunnels are very minimal. With the design of the tunnel and the probability of a heavy goods vehicles catching fire, all three tunnels may not have suitable fire protection to handle a large fire. The Downtown and Midtown tunnels have fire proofing inside the tunnel walls and also have a deluge system in the overhead fans; however, these fans will fail over a fire that is generating any heat above 40MW (M. Hicks, personal communication, July 22, 2014). As noted in the study by Cheong et al. (2008), fires can release much more energy. 40MW of energy can be released from a large heavy goods vehicle or multiple passenger vehicles that may be involved in one of these tunnels. In the HRBT, there is no fire proofing whatsoever in the tunnel and the concrete that lines the tunnel has nothing to protect it from the amount of heat energy that can be released, making it susceptible to spalling and collapse on top of evacuees and firefighters (R. Fitzhugh, personal communication, July 28, 2014). There have been improvements in technology in regards to how concrete is poured, as well as improving structural integrity. There has been an increase in the use of polypropylene monofilament in concrete to help prevent the spalling and cracking that has occurred in this tunnel over the last several years (Smith & Atkinson, 2010). Should this tunnel be up for reconstruction or improvements, the Virginia Department of Transportation should consider an option such as this, which has proven to be cost effective, especially in the absence of fire proofing or other fire suppression systems.

The literature found on tunnel fire suppression systems did not prove to support any one system over another. Much controversy still surrounds the use of sprinkler systems in roadway tunnels. Harvey (2014) concluded that wet based fire protection in tunnels only cause an increased panic amongst the occupants trapped as well as impede firefighting efforts due to low visibility. Tunnel officials in all tunnels were in agreement that a wet based fire suppression system would do more harm than good based off of the size and design of each tunnel.

It was found that a pre-fire plan is highly recommended to assist firefighters when responding to a tunnel fire. Survey results concluded that the majority of factors that led to a successful outcome all pointed to having a well established pre-incident plan (Appendix B, question 7). Currently NFR has no pre-fire plan for any of the three tunnels in its response area. It is left up to the individual fire stations that are in close proximity to these tunnels to conduct their own walk through. There is no requirement as to how often a walkthrough should be performed. The Department for Communities and Local Government (2012) stated that for all tunnel fire events, the best thing fire departments can do is to create a well developed integrated response and evacuation plan for each tunnel location, in addition to including fire department personnel in the design phase of new tunnels.

Smoke removal from tunnels can become very complicated if not handled appropriately. Ventilations systems ultimately are a benefit in a tunnel fire, but the scope and size of the fire needs to be examined before employing these ventilation systems (Kim et al., 2010). In all three of the tunnels, the coordination of smoke removal and firefighting efforts is one of the priorities of tunnel officials. As mentioned in interviews with each tunnel official, the coordination of ventilation and fire attack is extremely important, and each tunnel official will wait to hear things such as what units will be coming in from what side of the tunnel, as well as take suggestions from the Incident Commander when firefighting crews need to make entry (R. Fitzhugh, personal communication, July 28, 2014), and (M. Hicks, personal communication, July 22, 2014). A potential problem exists with ventilation systems in tunnels because there have been very few live fire tests that could replicate the tunnels that exist within the City of Norfolk (Kot et al., 1999).

The literature review as well as surveys that were conducted offered very little to the specific application of tactics that firefighters could take to extinguish tunnel fires. In a structural fire, there are multiple ways to extinguish a fire including different hose sizes, entry points and other tactics. In tunnel fires, the success is contributed to what happens before the fire. Pre-fire plans, site visits, and a well established emergency plan developed by multiple agencies are the primary contributing factors to success. Hoj (2004), found that when firefighters are making entry into the tunnels, it is not the fires that cause them trouble; instead, the risks that exist after the fire is extinguished are problematic. The fundamentals of firefighting rarely change as far as suppression. The area for concern is the structural integrity of the tunnel after extinguishment. In the case of the HRBT, there is no fireproofing in the tunnel. This may lead to a potential collapse of large concrete onto firefighters or occupants. The fire protection features need much more attention during the design phase of roadway tunnels (Hoj, 2004). Specialized equipment is being used to be able to attack fires without sending firefighters directly into the tunnels. The use of robotics is also being experimented within tunnel fires to keep firefighters away from the seat of the fire (Celentano et al., 2005). Norfolk Fire Rescue does carry a LUF 60 which a few other departments that have roadway tunnels use during a tunnel fire (see Appendix B). This specialized piece of equipment acts as a robotic machine that is capable of entering a confined space such as a tunnel and extinguishing it with a water mist system and an attack line. Firefighters could make a safer approach to a fire when using this type of equipment. The cities that surround Norfolk, that are responsible for a mutual response to a tunnel fire all carry this specialized piece of equipment.

The research and results that were derived from this project will be beneficial in helping NFR identify best practices in roadway tunnel firefighting. This body of research will allow NFR to make educated recommendations to its members when responding to a fire in one of its three tunnels. Other agencies outside the fire department will benefit from this research as it has shown the need for a good working relationship to ensure successful outcomes. The study indentified gaps in the area of firefighting strategies as noted in the survey and literature review. The date from the research further concluded that little research has been done in the United States and further design fire testing will help the City of Norfolk and surrounding jurisdictions to execute a better developed response plan. This research paper may be among few other papers that have tried to target specific firefighting practices to aid fire departments in combating roadway tunnel fires.

Recommendations

The first recommendation as a result of this research is for NFR to improve the way communication is handled during an emergency. Radio checks are being conducted with the tunnel officials at the Midtown and Downtown tunnels. This is not being done, nor do we have the capability to do it with the Hampton Roads Bridge Tunnel. It is recommended that NFR provide a radio to the operations manager at the Hampton Roads Bridge Tunnel to ensure that accurate and timely information is passed along to incoming units responding to a fire in this tunnel. The manager would receive training on the specific radio to include how to operate all channels and how to directly communicate with incoming units in the event of a fire.

The second recommendation is to have NFR conduct a thorough pre-fire plan of each tunnel within the city. This plan should include information about access, water supply, ventilation, and coordination of efforts between the tunnel officials and our responding personnel. This pre-fire plan needs to be reviewed on an annual basis by the fire department and all responsible parties that could be associated with a tunnel fire response.

The third recommendation would be for NFR to improve the working relationship with surrounding agencies when performing a mutual response to a tunnel fire. In most cases Norfolk will be responding with the City of Hampton or Portsmouth. As identified in the survey (see Appendix B), these departments along with NFR lack a policy that incorporates a joint response and identifies primary and secondary responsibilities of each department based on the situation in the tunnel. NFR should create a standard operating procedure for a tunnel fire response and include the City of Hampton and Portsmouth in the operational portion of this policy. The improvement of working relationships can be strengthened through conducting annual training exercises. The tunnels have been conducting exercises in the past, yet NFR has not been included. NFR needs to take a proactive approach to become involved and ensure that our members are involved in tunnel fire exercises to maintain readiness and evaluate policy if implemented.

Another recommendation would be to conduct further research on the potential economic impact of a significant tunnel fire in one of these three tunnels. With each of these tunnels serving as the major arteries of travel in the Hampton Roads area, there may be a chance for a large economic impact should one of these tunnels be shut down for an extended period of time following a fire. Other means of transportation such as ferries would be needed to move travelers back and forth across surrounding rivers and ocean.

Further research should be conducted in the United States on different tunnel firefighting tactics. Limited research has been done to identify various strategies and tactics in the different types of tunnels that exist. There are many different sized tunnels throughout the United States; all having different design features based on their length, age, design, and location. Firefighting efforts could be very problematic in the future if a lack of test fires in roadway tunnels is not given serious consideration.

Though tunnel fires do not happen on a regular basis throughout the country, or specifically in NFR, they can be placed in a high risk/low frequency event. This research should encourage not only NFR but all departments that have tunnels in their response area to conduct further research into the dangers that exist during a tunnel fire. With three tunnels to protect in NFR's jurisdiction, an effort to be made on the forefront of identifying technology changes in tunnels as well as implementing firefighting practices as noted in this research should be made as a response to findings of this study.

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Appendix A

Survey Explanation Letter

July 1, 2014

Dear Chief or Training Officer,

On behalf of the National Fire Academy's Executive Fire Officer Program I would like to respectfully request your participation in the following research. The purpose of my research is to identify a standardized system for my organization to respond to tunnel fire emergencies.

The purpose of your participation in this survey would be to provide information on how your department currently manages and controls fires in tunnel systems. In addition, the survey will ask you about specific challenges that you have faced at these emergencies. Lastly, if you have an existing policy or procedure in place to respond to and combat tunnel fires it would be greatly appreciated if you could include a copy when sending this survey back to me. If it would be easier, you could also send the policy to my email which is written below.

The information that is obtained will help my research and allow for me to find implement a standardized way for Norfolk Fire-Rescue to approach and manage tunnel fire emergencies. Please feel free to contact me if you have any questions or concerns. Thank you very much in advance for your help.

Respectfully,

Lt. Jarrod Sergi
Norfolk Fire Rescue
Norfolk, Virginia
7120 Granby Street
Norfolk VA 23505
757-438-2534
Jarrod.Sergi@norfolk.gov

Appendix B

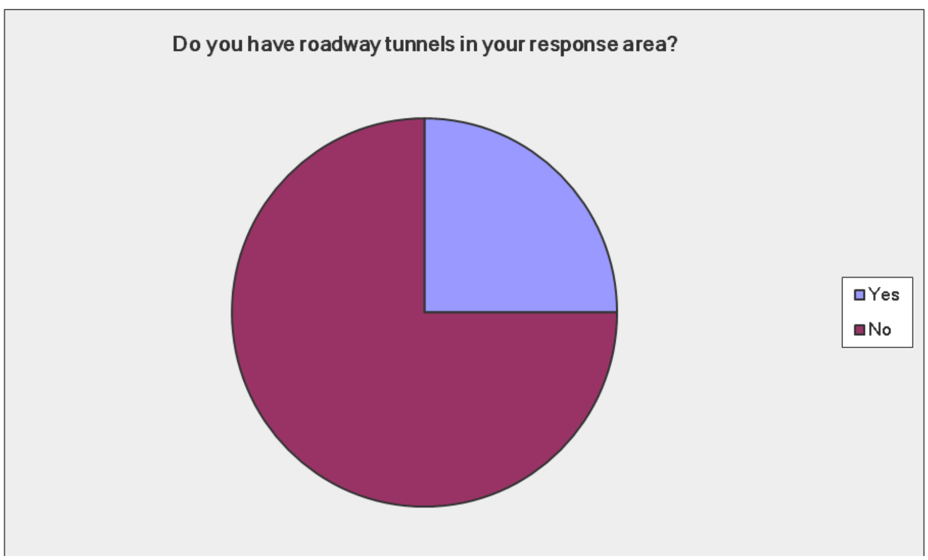
Tunnel Fire Survey

Question 1: What is the name and location of your department?

1. Wakefield, Ma. Fire Dept.
2. City of Holland Department of Public Safety
3. City of Watertown Fire Department, Watertown ,New York
4. Fairfax County Fire & Rescue Department, Fairfax, VA
5. Copper Mountain Fire Department, Colorado
6. Fort Lauderdale Fire Rescue, Fort Lauderdale, FL
7. Grand Junction Fire Department, Grand Junction Colorado
8. Marshall Fire Department, Marshall, Texas
9. Bolingbrook Fire Department, Bolingbrook, Illinois
10. Mobile Fire-Rescue Department
11. Fayette County Fire/EMS, Fayetteville, GA
12. Roanoke rapids FD
13. City of Albemarle, NC
14. Rochester Fire Department, NY
15. Worthington Fire Department, Louisville, KY
16. FDNY New York City, NY
17. Excelsior Fire District, Shorewood, MN
18. City of Rocky Mount Fire Department in North Carolina
19. Fire Protection District No. 1, West Feliciana Parish Louisiana
20. Knightdale Fire Department Knightdale, NC
21. East Lansing Fire Department
22. Surrey Fire and Rescue Service, United Kingdom
23. Littleton Fire Rescue, Littleton, Colorado
24. Portsmouth Fire, Rescue, And Emergency Services
25. Hampton Fire Department Hampton VA
26. Surrey Fire and Rescue Service United Kingdom
27. Portland Fire & Rescue
28. Tuscaloosa Fire Department, Tuscaloosa AL
29. West Metro Fire Rescue Lakewood, CO
30. Virginia Beach Fire Department, Virginia Beach, VA
31. Chesterfield Fire and EMS - Chesterfield County Virginia
32. City of Ann Arbor FD (MI)
33. Redwood City Fire Department, California
34. City of Santa Fe Fire Department, Santa Fe, NM
35. Warner Robins Fire Department, Warner Robins, GA
36. Pierce County Fire District #5 located in Gig Harbor, Washington.
37. Wyoming Fire Dept., Wyoming, MI
38. Davenport Fire Dept, davenport, Iowa
39. Orcas Island Fire and Rescue
40. Avondale Fire-Medical, Avondale, AZ
41. Hong Kong

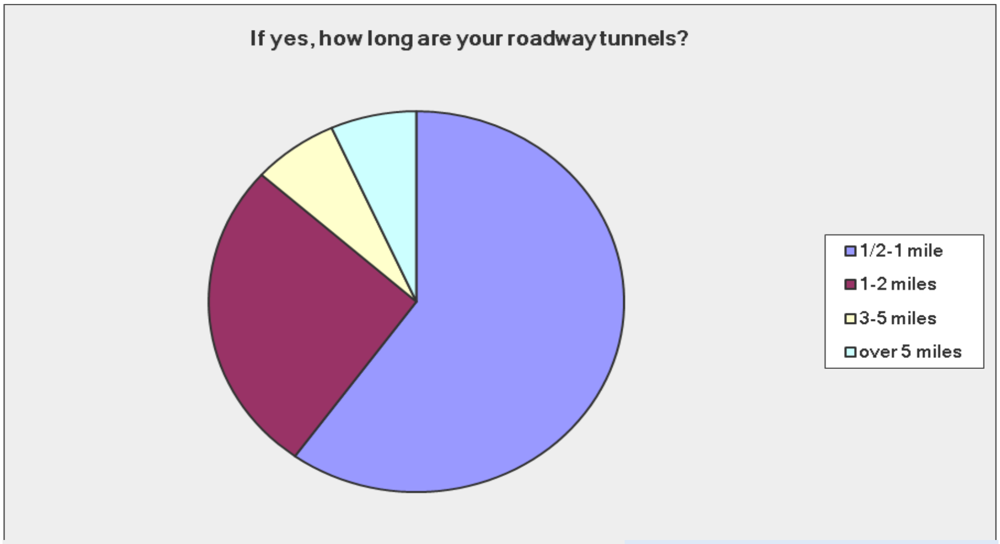
42. Wünschendorf, Germany
43. Vancouver Fire & Rescue Services
44. Bartlett Fire District, Bartlett, IL.
45. Gilford Fire Rescue. Gilford, New Hampshire
46. Branson Mo.
47. Las Vegas Fire/Rescue, Las Vegas, NV
48. Kalamazoo Department of Public Safety, Kalamazoo, MI
49. Citrus Sheriff Fire Rescue, Citrus County Florida
50. City of Sycamore Fire Department, Sycamore, Illinois
51. Gurnee Fire Department, Illinois.
52. Augusta Fire Department, Augusta, GA
53. Henry County FD. Georgia
54. Springfield Fire Rescue Division Springfield, Ohio
55. Hillsborough County Fire Rescue, Gulf Coast Florida (Tampa)
56. Aurora Fire Department Aurora Colorado
57. Iona-McGregor Fire District, Fort Myers, Florida
58. Baltimore City Fire Department, Baltimore MD
59. Seattle Fire Department, Seattle WA
60. Denver Fire, Denver CO

Question 2:



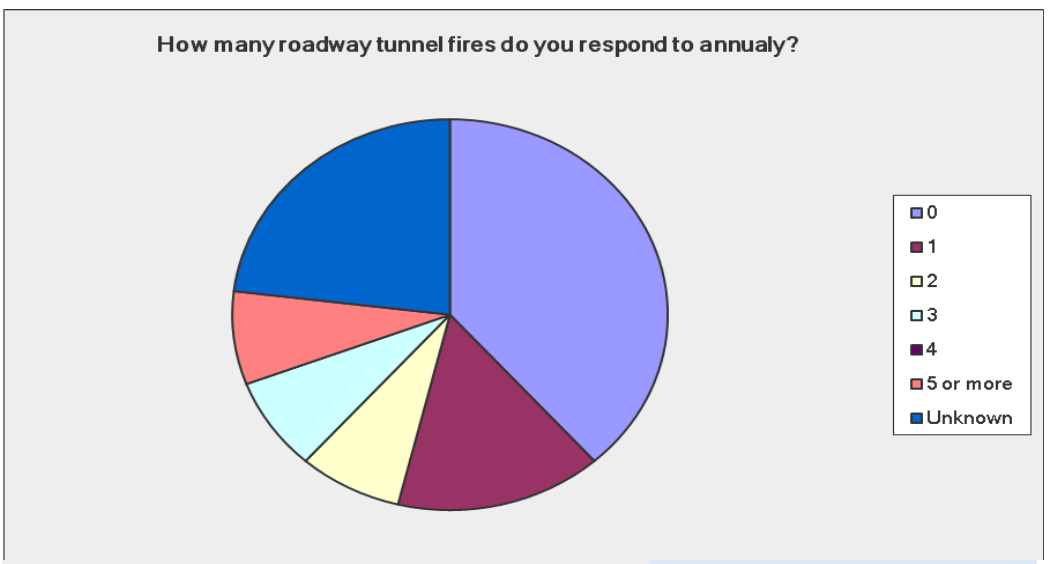
Yes	25.0%	15
No	75.0%	45

Question 3:



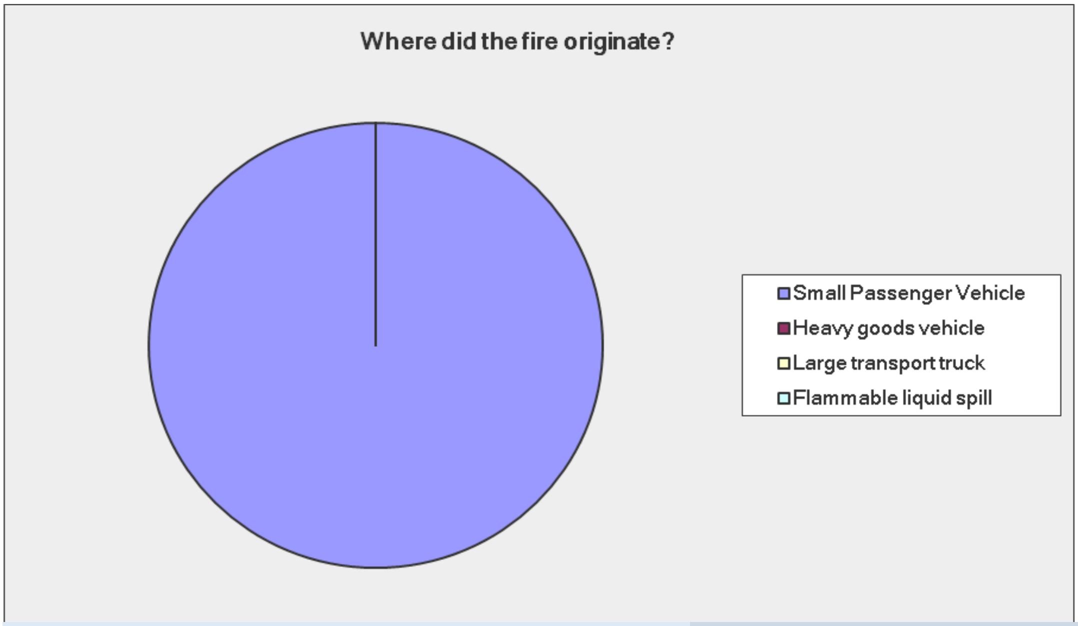
1/2-1 mile	60.0%	9
1-2 miles	26.7%	4
3-5 miles	6.7%	1
over 5 miles	6.7%	1

Question 4:



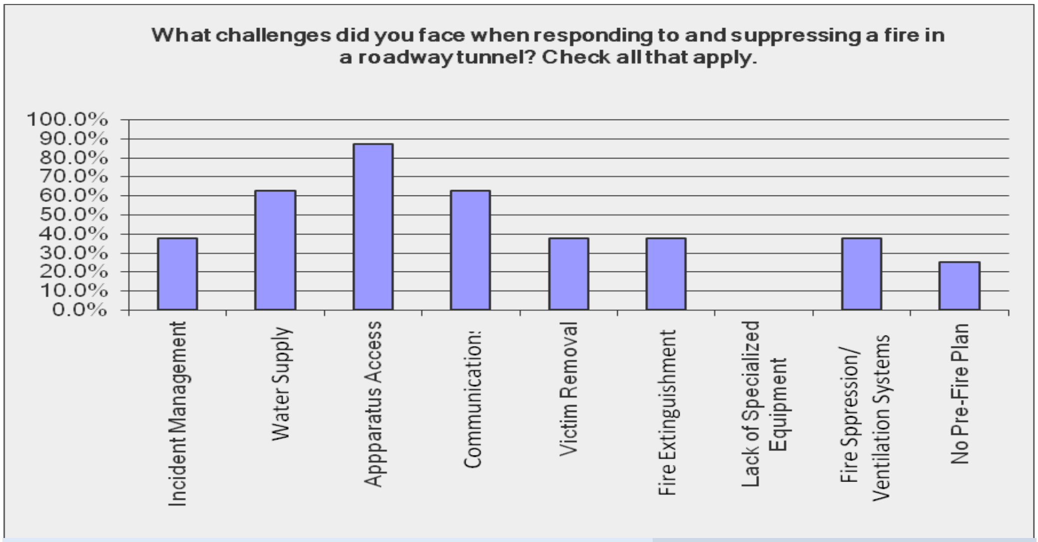
0	38.5%	5
1	15.4%	2
2	7.7%	1
3	7.7%	1
4	0.0%	0
5 or more	7.7%	1
Unknown	23.1%	3

Question 5:



Answer Options	Response Percent	Response Count
Small Passenger Vehicle	100.0%	8
Heavy goods vehicle	0.0%	0
Large transport truck	0.0%	0
Flammable liquid spill	0.0%	0

Question 6:



Answer Options	Response Percent	Response Count
Incident Management	37.5%	3
Water Supply	62.5%	5
Apparatus Access	87.5%	7
Communications	62.5%	5
Victim Removal	37.5%	3
Fire Extinguishment	37.5%	3
Lack of Specialized Equipment	0.0%	0
Fire Suppression/Ventilation Systems	37.5%	3
No Pre-Fire Plan	25.0%	2

Question 7: What specific factors contributed to succesful outcomes at roadway tunnel fires?

7 responses out of the 15 that had roadway tunnels.

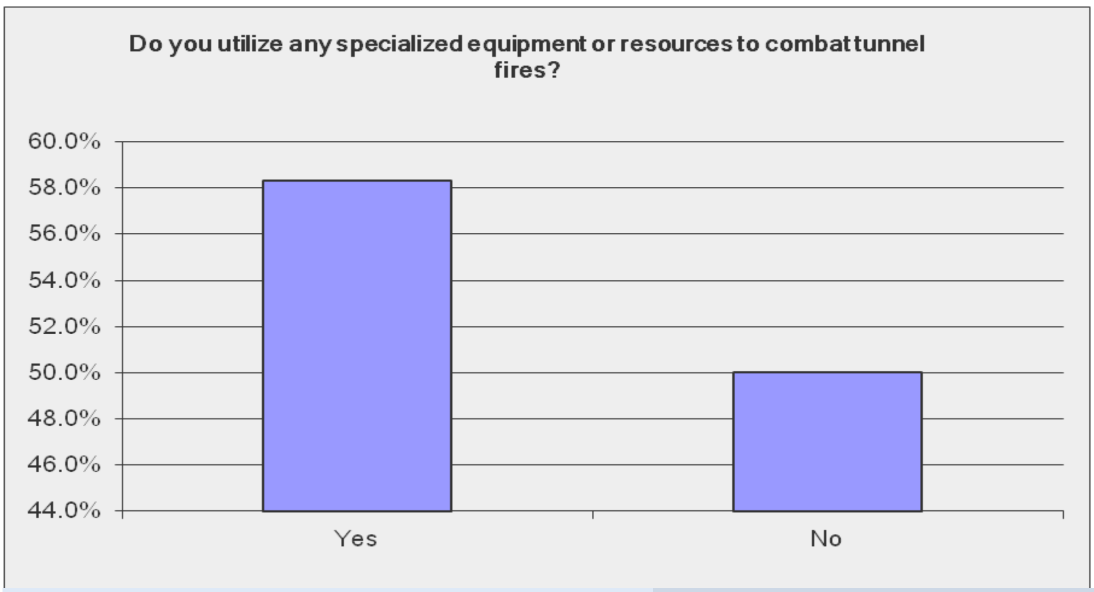
1. Quick attack; knowledageble officers.
2. Pre-planning and dispatching more than two companies.
3. Pre-planning and drilling in these situations.
4. Site visits. Good liason and working relationship between other emergency services and stakeholders.
5. Size of the vehicle involved and exposures. Water supply and time of response because of traffic.
6. Ventilation systems that is in place is a great assest for the fire department.
7. Understanding the size and scope of the problem. Understanding of fire protection systems.

Question 8: What specific factors if any led to a poor outcome?

5 responses out of the 15 that had roadway tunnels.

1. Too much traffic causing longer response times.
2. Traffic played a major role.
3. Bad traffic management
4. Bad traffic, no water supply to the tunnel and poor ventilation.
5. Water supply is always an issue due to us only having wall hydrants.

Question 9:



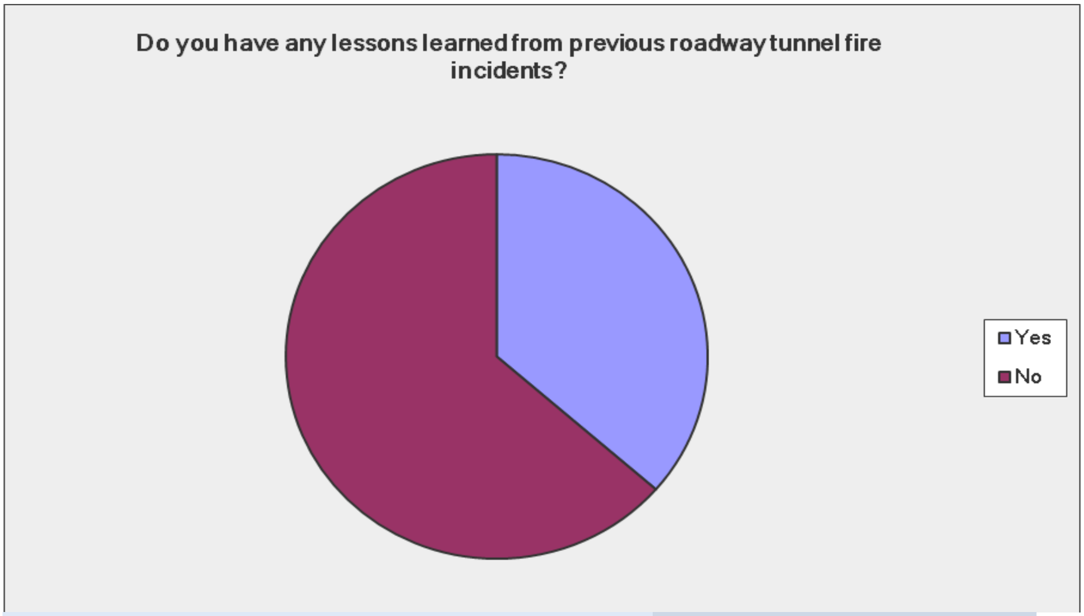
Answer Options	Response Percent	Response Count
Yes	58.3%	7
No	50.0%	6

Question 10: If yes to question 10, what equipment do you utilize?

5 out of 15 that had roadway tunnel responded.

1. Foam
2. LUF 60
3. LUF 60 Mobile Ventilation Unit
4. Water Tender
5. Rapid response truck carrying 250lbs of purple k powder. Tow vehicles with firefighting capabilites used by port authority.

Question 11:



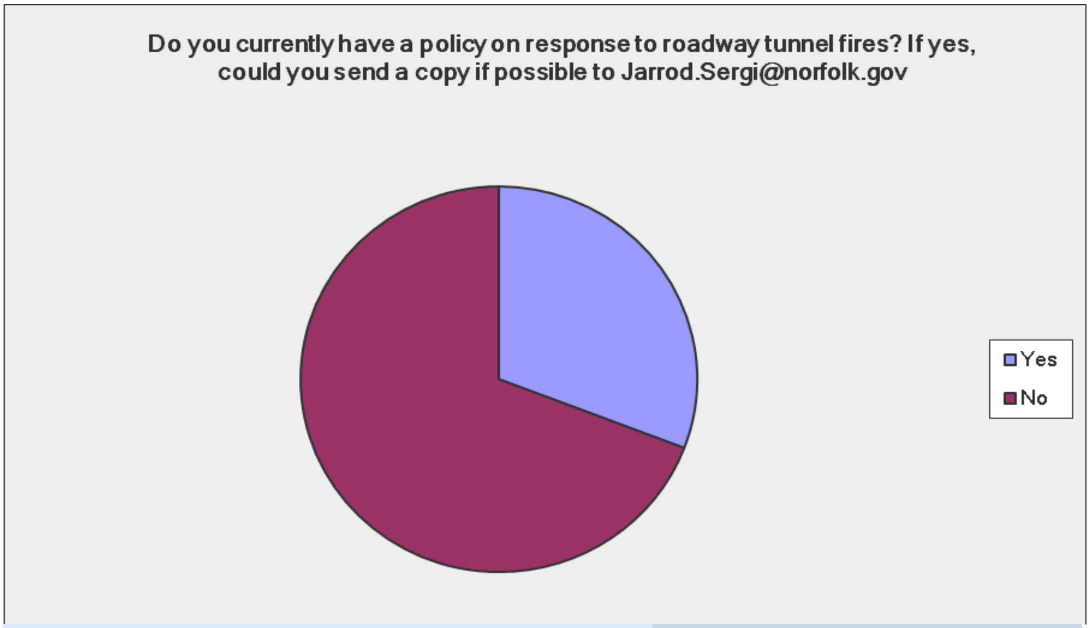
Answer Options	Response Percent	Response Count
Yes	36.4%	4
No	63.6%	7

Question 12: If yes to question 11, what would they be?

4 out of the 15 with roadway tunnel responded.

1. Be very safety conscious and do not take chances.
2. Send additional resources, don't hesitate to call for addition resources, communicate with the tunnel control room for ventilation, search and rescue, evacuate at crossways too.
3. Pre plan and make sure you have the most possible correct dispatch info when responding.
4. Nearly all tunnels in the US are not designed to handle fire growth or fire size due to incorrect estimates of design fires.

Question 13:



Answer Options	Response Percent	Response Count
Yes	30.8%	2
No	69.2%	11

Appendix C

Tunnel interview Midtown and Downtown Tunnels

Michael Hicks, Daniel Francis

1. How many vehicle fires do you see on an annual basis in the tunnel?
On average we have about 2- 3 vehicles fires a year in each of the tunnels. Most of them occur in small passenger vehicles and most times they are not significant fires.

2. Do you currently have an emergency response plan in place in the event of a fire?
Yes, we have a response plan that we use that includes initial actions that out members will take. The biggest being we try to gather as much information as possible to pass along to the fire units that are responding. Much of the emergency response plan is not centered on fire department actions or interface between us and the fire department.

3. If yes, what agencies did you include during its development?
When we developed the plan we included the state fire marshals office, Virginia Department of Transportation, outside contractors and engineers, the fire departments that would normally respond as well as Simplex Grinnell who handles out fire protection systems.

4. Is there an installed fire suppression system in this tunnel?
There is only fire suppression systems located in the control rooms and ventilation buildings. There are no sprinklers located inside of the tunnel itself. The closest thing is a deluge system that is located in each of the ventilation fans that will activate if there is a fire that starts to be sucked into the system. There are standpipe systems available for fire department use every 75 to 100 ft. They are tested annually and are connected to both the City of Norfolk and Portsmouth water supply.

5. Based off of the controversy that surrounds fire protection in tunnels, do you feel that in this particular tunnel it is more of a benefit than a hindrance?
We feel that is it beneficial not to have sprinkler system in the tunnel itself because of the low visibility that is caused when activated over top of a fire. It makes it harder for the person in our control room to see what is going on and pass along good information to the fire department.

6. Are the construction materials in the tunnel fire rated or fire proofed with a retardant material?
Yes the tunnel does have fire protection on the interior shell of the tunnel. It covers from 30 degrees on up to the ceiling level.

7. If yes, what type?
   We use what's called Pro-Mat fire proofing which has had a lot of positive results and is made specifically for tunnels.

8. Do you have an installed smoke removal/ventilation system?
   Yes we do, we use the installed fans that are in the tunnel for smoke removal. This can all be controlled from our main control room.

9. If yes, do you know what type?
   It is a longitudinal system that uses 8 total fans, each capable of moving 65,000 cubic feet of air per minute.

10. In the event that ventilation activation is needed, is there coordination with the fire departments attack on the fire?
    Yes, we used to not do it, but now we wait to activate the ventilation system until we hear from the fire department what they would like us to do. In the past we always just activated the fans, but that led to larger fires. Based on what city is responding to the tunnel, we will activate the fans on a certain side of the tunnel to facilitate better access for emergency crews as well as allow people to escape. Our biggest goal is to shelter them in place when this happens.

11. What recommendations do you have for the fire departments responding to a tunnel fire event?
    The first would be to gather as much information from us as possible while enroute. We serve as the person in charge until you show up. It is our expectation that once the fire department arrives they are trained to handle the fire in a tunnel. If using special equipment such as truck mounted fans, you should coordinate that with us so we aren't blowing smoke in two different directions. The last thing I would say is to feel free to come over any time to conduct a walkthrough of the tunnel and conduct your own training.

12. How often do you conduct tunnel fire exercises or training drills?
    I have been here for almost two years and we have yet to conduct a tunnel fire exercise, so probably not as often as we should be doing it.

13. If conducted, what agencies do you include in the training?
    When we conduct any type of training whether practical or in a classroom setting we invite state police, fire department, and our folks from Elizabeth River Crossings.

Appendix D

Tunnel Interview Hampton Roads Bridge Tunnel (HRBT)

Rusty Fitzhugh

1. How many vehicle fires do you see on an annual basis in the tunnel?
   I would say that on an annual basis we see about 5 to 10 vehicle fires in the tunnel. These can range from small engine compartment fires to something that gets much larger.

2. Do you currently have an emergency response plan in place in the event of a fire?
   Yes, our response plan has been created and is looked at every year for accuracy and also to see if we need to change anything.

3. If yes, what agencies did you include during its development?
   The initial development included very few agencies but as we revised the plan over the years we have included agencies such as fire departments, state police, coast guard, private contractors, and the Department of Environmental Quality.

4. Is there an installed fire suppression system in this tunnel?
   This is a very old tunnel that was built in the 50's. There is very little fire suppression. We have a small amount of sprinkler systems in the control rooms as well as the upper and lower ducts in the tunnel. Inside the tunnel we don't have any type of sprinkler system. We do have standpipes that come off the city water supply that also have an extinguisher located next to each outlet.

5. Based off of the controversy that surrounds fire protection in tunnels, do you feel that in this particular tunnel it is more of a benefit than a hindrance?
   There is no suppression system in this tunnel so I wouldn't know for sure. I would say that if we did have a suppression system in this tunnel I wouldn't want a very large one just because it could cause for low visibility and the ventilation system might not extract the smoke very well because the water from the sprinklers would cool the smoke and keep it low in the tunnel.

6. Are the construction materials in the tunnel fire rated or fire proofed with a retardant material?
   No, there have been no upgrades to the tunnel fire protection since the tunnel was built. There is just concrete in the shell of the tunnel that has been repaired over the years due to age and spalling, but has no fire protection or fire proofing.

7. If yes, what type?
   N/A

8. Do you have an installed smoke removal/ventilation system?
   Yes we do, and its use is still controversial in this tunnel. What we use is large fans that mover over 60,000 cubic feet of air per minute.

9. If yes, do you know what type?
   Unsure of the type but it can supply fresh air and also exhaust smoke by using multiple fans. We can also exhaust smoke in very specific areas of the tunnel once we find out where the fire is.

10. In the event that ventilation activation is needed, is there coordination with the fire departments attack on the fire?
    Yes, we expect that once the fire department arrives they will direct someone in our control room to manage the smoke system. Our members will exhaust smoke based off of what they see in the tunnel but may need further guidance once the fire department arrives.

11. What recommendations do you have for the fire departments responding to a tunnel fire event?
    The most important thing you guys can do is get someone to the control room quickly. The quicker a fire department supervisor gets in the control room, the quicker they can have a bird's eye view of what is going on. They would be able to utilize cameras to see where the fire is and what it would take to extinguish it. We have zero communication when you respond here for a fire. If your department gave us a radio that we could monitor we could easily pass along information to the incoming units. Right now you are in the dark until you arrive and it may be too late to implement whatever tactics you need to.

12. How often do you conduct tunnel fire exercises or training drills?
    We conduct annual drills in our tunnel.

13. If conducted, what agencies do you include in the training?
    We invite all of the surrounding fire departments in the region. We also include state police, coast guard, private contractors and other members from the Virginia Department of Transportation. We try to summarize the exercise and publish what we learned throughout the region and the state really.

Appendix E

Interview Questions for all tunnels

1. How many vehicle fires do you see on an annual basis in the tunnel?
2. Do you currently have an emergency response plan in place in the event of a fire?
3. If yes, what agencies did you include during its development?
4. Is there an installed fire suppression system in this tunnel?
5. Based off of the controversy that surrounds fire protection in tunnels, do you feel that in this particular tunnel it is more of a benefit than a hindrance?
6. Are the construction materials in the tunnel fire rated or fire proofed with a retardant material?
7. If yes, what type?
8. Do you have an installed smoke removal/ventilation system?
9. If yes, do you know what type?
10. In the event that ventilation activation is needed, is there coordination with the fire departments attack on the fire?
11. What recommendations do you have for the fire departments responding to a tunnel fire event?
12. How often do you conduct tunnel fire exercises or training drills?
13. If conducted, what agencies do you include in the training?