Improving the Fire Safety of Road Tunnels. TFR (Tunnel Fire-Fighting Robot): a Proposed Model of a Fire Fighting Robot Designed Specifically to Deal with Fires in Tunnels

M. Ariakia
University of Western Australia, Perth, Australia

1. Introduction:
Many different types of safety systems, including fire detection systems, ventilation systems and suppression systems, are used in tunnels to provide tunnel users with the highest level of safety. However, we are still witnessing disasters which are mostly caused by fires. Consequently, demands are growing for improved safety within tunnels. In this article, the deficiencies of the LUF60, currently one of the best models of fire-fighting robots will be discussed. I will then propose, at a conceptual level, the TFR (tunnel fire-fighting robot), which I will argue can be designed to better deal with fires in tunnels.

2. LUF60 and its deficiencies
2.1. LUF60:
The LUF60, originally designed and manufactured by Austrians, is currently one of the best fire-fighting robots in the market. Some significant features include a high-pressure nozzle and wireless remote control. The LUF60 can be used in aircraft hangers, parking garages, tunnels, etc and is primarily sold in the US. In early 2007, the Virginia Department of Transportation bought four LUF60s, primarily for dealing with fires in tunnels [1]. However, it is questionable whether this is the most useful fire apparatus to fight fires in tunnels.

2.2. Three main problems with LUF60
2.2.1. Massive size and hazardous fuel:
One of the first problems encountered when a fire erupts in a tunnel is jamming caused by burning or abandoned vehicles. Fire apparatuses should therefore be constructed as small as possible to enable them to manoeuvre amongst burning or abandoned cars. Unfortunately, the LUF60 does not provide this feature. The dimensions of the LUF60 stand at 7’7”L x 4’6”W x 6’7”H, which is equal to 2.35 L x 1.4 W x 2 H in metres [2]. As can be seen in Figure 1, a single LUF60 occupies almost one complete tunnel lane.

Figure 1: LUF60 in a tunnel [2]
Clearly, if a fire were to occur in the traffic accident happened in Harvey Tunnel in Louisiana in 2008, it would be almost impossible for the LUF60 to manoeuvre in such a tight space since it moves along the ground (Figure 2).

Figure 2: Accident in Harvey Tunnel in Louisiana in 2008 [3]

The LUF60's dimensions mentioned above do not take into account any extra accessories such as the additional ventilator, which is sold separately. These accessories both increase the cost of the LUF60, which is more than two hundred thousand US dollars [1], and the total size and weight of the LUF60. The weight of the LUF60 without accessories is about 2 tonnes [2]. Two other problems with the LUF60 is its 4-cylinder diesel engine and 13 gallon fuel tank, which make it both a potential fire hazard with a potentially insufficient fuel capacity to fight large-scale fires.

2.2.2. Heat resistance of the rubber track system of the LUF60:
According to studies done by McGrattan and Hamins from the National Institute of Standards and Technology in USA, the temperature of the ground during the Howard Street Tunnel Fire reached more than 420°C and the temperature of the ceiling and the walls reached 1000°C (Figure 3) [4]. Another experiment done by Prof. Bailey from the University of Manchester shows that the temperature of walls during the fire in the Mont Blanc Tunnel reached 1000°C [5]. Considering these cases and the fact that the LUF60 adopts a rubber track system for mobility that is rated to 205°C [2], it can be hypothesized that the LUF60 is very likely to fail if used to fight fires in tunnels.

Figure 3: Temperatures during the Howard Street Tunnel Fire [4]

2.2.3. Speed:
According to Singer Associates’ website, the maximum speed of the LUF60 is 3.75 MPH, which is equal to 6Km/h [2]. This is a relatively low speed for a mobile fire apparatus. If it was employed to fight the Mont Blanc Tunnel fire in 1999, where a fire started at about 6.5 km inside the tunnel, it would take an hour before an LUF60 reaches the fire from the tunnel entrance. The Mont Blanc Tunnel fire had 39 casualties, most of whom were killed within fifteen minutes of the fire first being detected [5]. Adopting the LUF60 would arguably not have decreased the number of deaths.
These problems associated with the LUF60 show that it is not as functional and practical as it has been advertised, particularly when used to fight fires in tunnels. In the following section, a new model designed specifically for dealing with tunnel fires will be introduced.

3. TFR (Tunnel Fire-Fighting Robot):
If we have sufficient knowledge about fire behaviour in tunnels, the TFR would arguably satisfy all the requirements to deal with tunnel fires. It will be used to extinguish or, in some cases, control the scale and intensity of fires until fire crews arrive.

3.1. General Specifications:
Conceptually, the TFR will be a roof-suspended wireless remote-controlled polar robot which can move linearly on the ceiling of tunnels using a rail system. It is fed by two tanks through a 4-inch fire hose pipe and is capable of flowing class “A” and class “B” foams. The TFR can be controlled from the tunnel control centre.

In the following section, the technical specifications of the system will be explained.

3.2. Technical Specifications:
3.2.1. Heat resistance:
The heat resistance of a fire-fighting apparatus is critical to its functionality. The main concern for a roof-suspended robot within tunnels is that the smoke and hot gasses from the fire will accumulate in the upper section of the tunnel, thus exposing the robot to a very high temperature and potentially causing failure. To make the TFR highly heat-resistant, it will be insulated thoroughly using different insulators which will be explained in section 3.2.2. Furthermore, the motor and pumps are located outside the tunnel so as to be kept out of direct contact with the fire. The motor will be connected to the TFR through a connection belt. The connection belt, wires, fire hose pipe etc will be connected to the TFR through a 6-inch insulated pipe as shown in Figure 5. The body, rails and connectors will be made of steel melting at a very high 1370°C.

The TFR will not be touched by flames during operation. Also, the foam, which is pumped through the fire hose pipe, will keep the wires, belt and other parts cool enough to prevent heat-related malfunction.

Therefore, the probability of failure due to heat-related problems is extremely low.

Figure 4: TFR can rotate up to 60 degrees to each side. (A): Xenon light. (B): Camera

Figure 5: Side view of MCR. (A): all pipes and the connection belt will be connected to MCR through this 6-inch-insulated pipe.
3.2.2. Insulation:
In order to adequately insulate various parts of the TFR, different insulators can be used. The body will be insulated using Fiberfrax Duraboard which is used for persistent temperatures up to 1430°C. To protect the pipe and other internal parts including the belt and wires, Fiberfrax Durablanket will be used which is made of calcium-magnesium-silicate fibre which can resist persistent temperatures up to 1400°C. Fiberfrax Durablanket is very flexible, and can easily be wrapped around the pipes. Both materials, which are made by Unifrax Company, have met European regulatory requirements and have very low thermal conductivity. At 600°C, the thermal conductivity of Durablanket is 0.09 W/mK and 0.11 W/mK for Duraboard. These values will decrease significantly when the TFR is exposed to lower temperatures [6].

3.2.5. Manually Controlled:
Another feature of the TFR is that it can be managed remotely from the tunnel control centre. Tunnel operators are trained to usher the tunnel users to the nearest exit doors during a fire emergency incident in a tunnel, but they can also play more important roles by helping to extinguish fires using the TFR. As mentioned earlier, most casualties occur during the first fifteen minutes of a fire being detected [7], which is a very short time for a fire crew to arrive and extinguish the tunnel fire.

To facilitate clear vision in the tunnel, the TFR is equipped with a high resolution camera and two 300Watt Xenon lights in the 6000K-colour temperature. Xenon lights in the 6000K range generate a blue light, which is best for the human eye as it is akin to daylight [8]. Xenon lights and the camera are insulated and surrounded by heat-sinks to conduct the heat to extinguishers flowing out. Figure 6 shows, how the camera can be insulated. Also, a heat-resistant Neotherm Observation Glass, which can resist commercial furnace temperatures with a very low thermal conductivity, will be placed in front of the xenon lights and the camera [9].

![Figure 6: Insulator and heat sink in the cylinder in which the camera is located](image)

Also, although smoke will obscure vision in the upper half of the tunnel, this will not cause any problems to the TFR’s operation because TFR will approach the fire alongside the direction from which jet fans work. As illustrated in Figure 7, all smoke will be pushed away from the TFR and it will not obscure the operator’s observation of the fire.
3.2.6 Polar Robot:
Polar type robots have a phenomenal supremacy over other robots due to its low weight and minimal structural complexity, short joint travel for many motions and its good resolution [10]. All these features are necessary and they will help the TFR meet all tunnel fire-fighting requirements.

3.2.7 Extinguishers:
The TFR has been designed to be able to flow class “A” and class “B” foam so that it can fight ordinary combustible fires such as wood, and also combustible liquids such as gasoline. Most current fire-fighting robots are capable of flowing these two types of foams. In the next part, the major advantages of the TFR will be explained.

3.3. Advantages:
The advantages of the TFR can be classified into four categories:

i) High Speed:
As the TFR moves on rails and is powered by high-power-electric motors, it can travel at high speeds.

ii) High Mobility:
As mentioned above, the TFR moves via a rail system installed on the tunnel's ceiling. This means that it will not have to contend with heavy vehicular traffic in the tunnel to reach the fire's location.

iii) Compatibility:
A problem with many contemporary fire-safety systems is that changes need to be made to the structure and design of existing tunnels specifically for those systems. Although some changes are possible, most changes incur heavy costs, making it impractical to pursue. [11] However, the TFR is compatible with almost all contemporary tunnels because there is adequate space on most tunnel ceilings for the TFR to be installed. The TFR can be easily installed in different types of tunnels, including arch, cube, rectangular and circular tunnels by simply modifying the rail system to match the tunnel.

iv) Safety and reliability:
Electricity, unlike various types of fuel, is an endless and much safer source of power. This enhances the TFR’s overall reliability and safety.

4. Conclusion:
Fires in tunnels are still a cause for international concern [11] as with current technology, we are still unable to act quickly enough to control large-scale tunnel fires and prevent casualties. The best way to control fires in tunnels is to extinguish them rapidly or, at the very least contain them until the supporting fire crew arrives. This is feasible only if tunnel operators in tunnel control centres start fire-fighting operations promptly and efficiently. The TFR can be a fast and safe fire-fighting robot which will be compatible with most tunnels around the world.
References:


