Fire Detection in Metro and Railway Tunnels

Walter Costa Teixeira Pinto, Fábio Mori, Cia do Metropolitano de São Paulo, São Paulo, Brazil
Jorge Rady de Almeida Junior, Escola Politécnica da Universidade de São Paulo, São Paulo, Brazil

Keywords: fire, detectors, tunnels

1. INTRODUCTION

The growing concern about safety in underground transportation systems, exacerbated by recent occurrences of accidents in metro tunnels at a worldwide level, represents a great safety challenge to most of the metro and railway systems. Among those accidents, there is the occurrence of fire in metro and railway tunnels. It is thus a great challenge to be protected against fire in such conditions, and it is very important to have means to detect any signal of fire as early as possible.

In order to provide safety for the railway transport, different types of equipment are used that allow better supervision and control of the various events that may occur during its operation. A very important system is fire detection, which in metro and railway tunnels may be considered a complex and a challenging issue, as discussed in (MICLEA, 2009):

1. The variation in air speed coming from the main ventilation system and the piston effect of the trains may mask occasional focus of fires by decreasing the temperature, and by interfering with optical detectors.

2. It is difficult to transmit the signals to the fire central detection because of the long tunnels.

Hence, the aim is to present a study on several kinds of fire detection equipment, and employ them in metro and railway tunnels. The research was conducted on smoke, optical, photoelectric, ionization, flame, ultraviolet and infrared detectors, surveying their main positive and negative features.

One of the important technical aspects of fire detectors is their ability to transmit signals over long distances, enabling the communication of these detectors with the supervisory system located in the nearest station. Moreover, it is necessary to examine the equipment efficiency, in a hostile environment, such as a metro or railway tunnel.

All metros and railways that have tunnels are potential candidates to receive a system as the one proposed.

Finally, the impact on metro and railway business is very great, because a safer transportation system always means a system that has a greater potential to be more profitable.

1.1 Objectives

A study of the existent solutions for fire detection in metro and railway tunnels is conducted. An inventory of the available equipment that can be applied in such situation is made, pointing the technical characteristics of each detector type and its main applications.

Starting from those data, the proposal is to use a combination of two or three fire detectors types, seeking to obtain an adequate fire protection system, considering their main features.

1.2 Structure of the Work

Section 2 makes an explanation of fire in general. A brief definition of fire is presented, as well as how it is formed and which are its main effects. The risks involved in the event of a fire, especially if it happens in a railway tunnel, are shown. In section 3, the existing standards related to fire detection are discussed.

Section 4 shows the state of the art of the equipment available for fire detection. The various types of detectors are described, along with their operation, their main features, the advantages and disadvantages of each and an analysis is made of the devices considered, seeking their application in metro and railway tunnels. Finally, section 5 presents the conclusions.
2  **FIRE**

2.1  **Fire Definition**

Fire can be defined as heat and flame that arise in function of a chemical transformation of combustible materials reacting with the oxygen contained in the air [ARAGÃO].

The three essential components indispensable to the emergence and maintenance of fire are fuel, oxygen and heat. When a chemical chain reaction (transfer of thermal energy in combustion) occurs, flames spread, causing a fire.

Thus, a fire is defined as a strong and uncontrollable exothermic combustion reaction (oxidation-reduction). Usually in a fire, there is smoke emission, flames and combustion gases.

If the oxidation is too slow, there are not flames, as in the case of iron oxidation or organic material putrefaction. If it is too fast, it is called deflagration. When it occurs almost instantly, it is called explosion or detonation.

2.2  **Fire Loads**

Various materials that are found in railway tunnels may behave as fuel in case of fire, as for example: garbage, such as paper, probably thrown by train users; wires and cables, components of the medium voltage systems; tunnel lighting; telecommunication equipment and others; the trains themselves and yet other rolling stock materials.

Hence, in the equipment design, it is important to specify non-combustible materials, flame-retardant and that do not emit smoke or toxic gases.

The fire load of each passenger car is estimated to be from 15 to 20 MW. Thus, in the planning and designing of railway tunnels, an average power generation of 30 MW is considered in case of fire inside the tunnel.

2.3  **Fire Phases**

The evolution of the fire undergoes several phases (FIGUEIREDO, 2010):

- The **latency phase** that has an activation energy in quantity and quality enough to create a thermal favorable condition, with enough fuel and oxygen in sufficient concentration;
- The **start-up phase**, the duration of which depends on the flammability, on the possibility of flame spread, on the decomposition rate of the materials involved in the fire, on the geometry and volume of sites, on the ability to dissipate heat, on the ventilation, on the surface materials type (structure, porosity) and on the existence of contact points between the materials;
- The **acceleration phase**, at which toxic and corrosive gases are emitted; the burning rate, the temperature and the radiation emitted increase;
- The **combustion phase** at which the temperature and the combustion speed rise exponentially, the amount of gases increases, and some materials reach the point of self-ignition, producing gases and vapors;
- The **decline stage** or extinction, at which the whole place is on fire and if there is no feedback from the outside, the fire decreases.

The main effects of a fire are:

- **Thermal effect** (the flames can reach temperatures of 2,500 degrees Celsius);
- **Optical effect**, visible light with ultraviolet and infrared radiation is emitted;
- **Smoke**, consisting of gases made opaque by solid particles of burning material;
- **Miscellaneous**, noises, ionized particles that derive from various combustion products.

The detector chosen should be the one that can provide the quickest and most reliable responses, taking into account the fire type most likely to occur.
2.4 Fire in Metros

Although unusual, fires in metro and railway have killed several people since 1903, when about 90 passengers died intoxicated by smoke in the Couronnes metro station, in the Paris Metro. In this case, there was a fire in a locomotive at the station, but users did not leave the station waiting for a ticket refund.

One of the most famous cases is the one that happened in 1987 at Kings Cross Station in England. 31 people died due to a fire inside the station, more precisely in a wooden escalator (FIRETATICS, 2005).

One of the worst tragedies happened just inside a metro tunnel in Baku, Azerbaijan (former Soviet Union): 285 people were killed and 256 others injured as a result of a fire on October 28, 1995. The fire reached the crowded cars when the train was between two stations, which aggravated the output of the train. Most deaths were caused by carbon monoxide intoxication. The tunnel was known to be equipped with great capacity fans, but it is unclear whether they were used at the time of the fire. A fault in the power network and an abundance of combustible material in the cars are the most likely causes of this fire.

Another notorious case was the attack occurred in Daegu, South Korea, on February 18, 2003 (BBC NEWS, 2003). A mentally disturbed man fired a gallon of gasoline in a stationary train at a metro station platform. Because of several operational failures, the passengers were prevented from leaving the train, causing 198 deaths.

In the Sao Paulo Metro, there are also cases of fire reported, and the most recent was in September 2009 in a train located in the Sé Station, causing only some operational disturbances. However, in August 2001 a death occurred due to the fire originated in electrical cables located near the Marechal Deodoro Station. The victim died of cardiac arrest, and there were more than 20 intoxicated people.

3 MAIN STANDARDS

The NFPA (National Fire Protection Association) and ABNT (Brazilian Association for Technical Standards) standards are analyzed herein.

The NFPA is an international regulatory authority in its area of operation, which already covers the people transportation in underground railways in metropolitan areas (NFPA, 1999). The ABNT is a Brazilian Association that develops a wide variety of standards. One committee of ABNT is the EC-24: 301.13 that discusses fire protection in tunnels (ABNT, 2011).

In general, the standards which focus on safety in tunnels began to be adjusted in several countries after a remarkable fire occurrence, with several deaths in the Mont Blanc tunnel in 1999. In the following year, in November 2000, there was another fire in a tunnel in an Austria cable car, which killed 155 people.

The NFPA standard that specifies the metro tunnels is the NFPA 130 (NFPA130, 1999). NFPA 130 is about all transit systems in fixed rails, be they surface, elevated or underground. Despite covering the minimum requirements for safety in case of emergency situations, the standard does not address fire detection in tunnels, restricting it to the stations and locations, involving electrical equipment, such as power substations. The greatest merit of this standard is to determine the minimum time of abandonment to an area considered safe in a station, determining the ventilation requirements, smoke control equipment and fire fighting procedures.

The NFPA 130 standard also sets the maximum distance to reach an emergency exit as 381 meters. In case of parallel single track tunnels, passages between the tunnels are accepted as emergency exit routes, since they are provided with fireproof doors, located at most 244 meters between them and the ventilation system supplies the necessary amount of non-infected air.

The ABNT NBR 15661 (ABNT 145661, 2009) standard specifies the safety requirements for fire prevention and protection in tunnels for transporting passengers or cargo. This standard covers new tunnels, or those that need modernization. However, this standard does not address specific types of tunnels (roads, metros, railways) and each one has different characteristics in terms of cargo transportation, environmental and operational features, and especially in terms of user’s behavior.
Some specific points of the standard require further clarification or review, as regards the impact on implementation, mainly concerning safety.

The NBR 15775 (ABNT 15775, 2009) standard is a complement to NBR 15661. The NBR 15775 specifies testing requirements for commissioning, inspections of the electrical and mechanical equipment, operating systems, measurement devices and civil constructions related to prevention and protection of incidents in tunnels.

The ABNT NBR 9441 (ABNT 9441, 1998) standard contains details about projects, installation, operation and maintenance of fire alarm detection systems, setting criteria for the installation of these devices in various environments.

The ABNT NBR 11836 (ABNT 11386, 1992) standard determines the conditions and methods for testing and performance criteria required for automatic punctual smoke detectors.

4 FIRE DETECTION SYSTEMS

4.1 Fire Detector Types

There are several fire detector types, each one with a specific operating principle. Basically, they can operate by detecting temperature differences, smoke particles or by light detection (DEWITT, 2007).

The fire detectors can also be classified according to the constructive type and coverage area. In this study, the fire detection devices are classified into two types: punctual and linear.

The punctual detectors are compact units, with all the devices contained in a single housing, and installed at a single point. They are intended to cover an area around the point where they are installed. For a more inclusive coverage, it is necessary to install these devices in more than one point, spaced at a technical criterion, depending on each detector type.

Linear detectors consist of linear cables, or even light beams, usually suspended from the roof of the protected area. They are intended to cover a linear range, that is, a region in which the length is more important than other physical dimensions (APSENSING, 2009).

4.1.1 Thermal Detectors

Thermal detectors can be punctual or linear. They operate based on the difference in temperature that exists between the external and internal device regions. They can be classified into two types: fixed temperature detectors and thermo-velocimetric detectors. Thermo-velocimetric detectors can be sub-classified into two types: with compensation and combined temperature sensor.

Another classification of these devices is about their nominal operating temperature, also called the device thermal classification. The operational nominal temperature is the temperature at which the internal element of heat-sensitive detection must be heated before acting.

a) Fixed Temperature Thermal Detector

The operation principle of the fixed temperature thermal detectors is based on the use of bimetallic strips or fusible links for temperature detection. They generate an alarm signal when the temperature of their sensing elements reaches its programmed nominal temperature.

The bimetallic strip consists of two different metals, with different thermal expansion coefficients. This strip, when subjected to heating, presents a physical distortion, due to the unequal expansion of the two metals. This distortion is planned to occur in such a way that it acts on a set of contacts. Upon return to room temperature, they also return to their original dimensions and are able to operate again.

Detectors based on materials that use fusible links when exposed to heat, melt, releasing the operation of contacts by a coil. In this case, the fusible link is destroyed and these devices have to be replaced. Fixed temperature thermal detectors can be either of the punctual or linear type.

b) Thermo-Velocimetric Detector
The thermo-velocimetric detectors are able to operate in function of air temperature change rate around their sensors. They are usually calibrated to operate when this variation is about 9 °C per minute.

They work with two thermistors, one with an ambient temperature, and the other in a sealed chamber. Under normal conditions, both record similar temperatures. When there is a fast heating condition in the environment, the external thermistor heats up faster than the encapsulated thermistor.

These devices respond more efficiently than the fixed temperature detectors, because they are not subjected only to an absolute temperature, but change rate. However, their installation near heat variable sources not responsible for fire may cause false alarms. Therefore, these devices are not suitable to be installed next to boilers, ovens, refrigerators, welding machines or other locations where great changes in temperature occur.

c) Thermo-velocimetric Detector with Compensation

A thermo-velocimetric detector with compensation works with a pneumatic element. It consists of a diaphragm that involves a pair of expandable contacts. When subjected to a sudden temperature change, they expand into a sealed chamber. The air escapes through a calibrated opening, according to the device operation temperature. It is suitable for minor variations of up to 2.7 °C.

d) Combined Temperature Detector

Combined temperature detectors consist of a combination of thermo-velocimetric with fixed temperature detectors. They are mounted to allow the installation of thermo-velocimetric detectors near heat variable sources, such as furnaces, boilers or refrigerator chambers.

In case of fire with slow temperature change rate, the fixed temperature component is responsible for generating the alarm signal. When the temperature change rate is high, the thermo-velocimetric device acts to prevent fire.

When the device is activated by its thermal component, the fusible link must be replaced, enabling another operation of the detector.

4.1.2 Smoke Detectors

According to the standard NFPA 72E (NFPA 130, 1999), smoke can be defined as "the totality of visible or invisible combustion particles carried by air". Combustion visible particles, such as dense and heavy smoke have a small amount of large particles per volume unit. On the other hand, the combustion invisible particles have a large amount of small particles per volume unit. Smoke detectors may operate based on optical, ionization or aspirating principle (MVFRA, 2011).

a) Photoelectric or Optical Detectors

The photoelectric or optical smoke detectors have a light source and a photocell. They are generally used where a fire is expected to generate large amounts of combustion visible particles. The dense smoke prevents the light from reaching the photocell, which generates a signal that can be considered a fire alarm.

Photoelectric detectors can be either punctual or linear. The punctual detector type includes all the elements into one small unit, while the linear type consists of a light source and a photocell located at opposite ends and usually installed near the roof of the protected area.

The application of an optical sensor requires the area to be protected to be straight, without barriers that may interfere with its operation.

b) Smoke Detectors by Ionization

Smoke detectors by ionization work by means of a continuous power source (a battery or a rectifier), which feeds an ionization chamber. This chamber contains a small radioactive source of alpha particles. The air molecules inside the chamber are split into positive and negative ions (electrons), by the alpha radioactive source in a process known as ionization.

The charged particles flow between the plates inside the chamber, generating an electric current. When combustion particles enter the ionization chamber, they are joined with charged...
particles, reducing its current. This reduction is detected, generating a signal, which can be used as an alarm.

Although smoke detectors by ionization are able to detect the presence of combustion visible and invisible particles, they are more sensitive to invisible particles. The smoke is also required to contain a minimal amount of particles per volume unit, allowing the electric circuit to detect the presence of smoke particles.

**c) Aspirating Smoke Detectors**

Aspirating smoke detectors are ideally suited in cases in which a great advance is needed to signal the fire. They are suitable for detecting fire in the start-up phase. These detectors operate continuously aspirating the air environment into a pipe network. A sample of this air goes through a two-stage filter. The first stage removes dust and dirt. The second complements the first, through a very fine screen, removing foreign particles as much as possible. After that, the air is led into an optical or ionizing detecting chamber.

In most detectors, this smoke chamber analysis works with a laser light. The air sample is exposed to a controlled and stable source of laser light. If smoke is present, the light is scattered within the detection chamber, and this dispersion is instantly identified by optical sensors. These detectors, nowadays, are employed in emergency exits of metros.

### 4.1.3 Flame Detectors

The flame is composed by visible or invisible combustion gases produced by a fire. Flame detectors are linear sight devices that generate an alarm signal when exposed to the radiant energy of a flame. As this radiant energy travels at the light speed, flame detectors have the potential to act very fast.

These devices cannot have obstructions such as structural elements or even the presence of dense smoke or gases. Considering their fast action, flame detectors are generally used where there is a significant risk of fire, such as storage and fuel transfer areas and in industrial processing installations [Kaneshiro] [DeWitt]. The operating time of these devices is around a few milliseconds.

**a) Ultraviolet Radiation Detectors**

Among the flame detectors, ultraviolet detector (UV) responds to invisible radiant energy in the ultraviolet range (below 4000 Å). Typically, UV detectors are designed to respond in the range of 1800 to 2500 Å [DeWitt]. This narrow band allows a reduction in the incidence of false alarms from electrical discharges, lightning and solar radiation.

The UV detectors have some limitations. One of them is that they can generate some alarm because of the radiant energy of X-ray, welding machines and lightning.

Smoke also hinders the use use these detectors, because it filters radiant energy. Thus, they are not suitable for areas in which a dense volume of smoke can occur before the appearance of the flame.

**b) Infrared Radiation Detectors**

Infrared detectors (IR) use photovoltaic or photo resistive cells with filters and lenses, responding to invisible radiant energy, above 7700 Å [DeWitt]. As the UV detector, IR detector also acts fast. IR detectors can respond to many heat sources. Therefore, they are also susceptible to false alarms. These detectors are also affected by high humidity [DeWitt].

**c) Flicker Flame and Photoelectric Detectors**

Flicker flame and photoelectric detectors respond to visible radiant energy, with wavelengths in the spectrum between 4000 to 7700 Å. The photoelectric device has a photocell, allowing the generation of an alarm signal when exposed to the radiant energy of a flame.

The flame flicker detection device, which also operates in the photoelectric principle, contains a filter that allows adjusting to limit its action only in case of radiant energy modulated at a characteristic frequency of a flickering flame [DeWitt].
4.1.4 Optical Fiber Detectors

This system can work for kilometers, measuring the temperature values at every specified period (for example, 10 seconds). The system takes temperatures over the optical fiber, which acts as a linear sensor. These temperatures are recorded continuously along the optical fiber. This ensures a good precision of temperature measurement over large distances in a short time. The system uses the so-called Raman Effect to measure the temperatures in optical fibers (PROTECTORWIRE, 2011).

4.1.5 Detection System by Video Camera

In the detection by a video-camera system, an analysis of the scanned images produced by surveillance and monitoring cameras is made. This analysis allows detecting the image of fire and smoke, in addition to detecting other types of unsafe events, such as an accidental invasion of a person or foreign objects on the track.

The cameras surveillance images are processed, allowing a continuous analysis of the images, verifying the colors and the radiation, the light intensity, and mainly the expansion of these phenomena within each framework of the image. It may be necessary to subtract the background of the image, allowing a better analysis of the interest area.

The cameras should be equipped with devices that allow horizontal and vertical movements, as well as zoom in and zoom out, reducing possible blind points.

4.1.6 Sensor Cable Detector

The sensor cable detector has small temperature sensors placed at regular intervals along a cable used as a data and power bus. The sensors are continuously monitored. Evaluation logic uses the values to determine when to report an alarm. The system can be connected to a PC or fire control panel.

4.2 Detector Application Examples

4.2.1 São Paulo Metro

In the São Paulo Metro, there are some fire detectors installed. They are located at several points of the stations. Public areas such as platforms and mezzanines, subjected to a large flow of people, are not equipped with fire detectors. It is considered that the people themselves are in charge of detecting any incidents and of reporting them to the operational staff (METRO, 2009).

Below the platforms are the aspirating smoke detectors. In the technical rooms are the punctual optical detectors. In the operating rooms, thermal detectors are more commonly used.

4.2.2 Road Tunnels

In Brazil, there are optical fiber cable and resistive cable detectors installed in road tunnels. The main applications are in the Imigrantes Highway tunnels, and the Cidade Jardim Tunnel, in Sao Paulo. (TELVENT, 2009).

4.2.3 Other Metros

CoMET (Community of Metros) is an organization that brings together key rail transportation systems in the world. Currently, it is formed by the metros of several cities: Beijing, Berlin, Hong Kong, London, Mexico City, Madrid, Moscow, New York, Paris, Santiago, Shanghai and Sao Paulo. It promotes a benchmarking between these systems, allowing experience exchange (CoMET, 2011).

Considering the subject of this paper, a question was asked to the CoMET community about which fire detection equipment the metro companies are using in tunnels. The response was provided only by one metro company. According to them, fiber optics is used in tunnels, and linear thermal systems at stations, especially in the escalators engine room.

4.2.4 Trains
In the São Paulo Metro, the Line 4 - Yellow trains are being designed with an aspirating smoke detector system inside the passengers lobby. In the future, the intention is to employ the same fire detection philosophy in the modernization of existing trains. However, these systems are not used to detect fire in the tunnel, caused by other materials outside the train.

4.3 Comparative Study

Considering all the descriptions made, it is possible to analyze the application viability of fire detectors in metro tunnels.

Due to the track geometry, the distances, curves, slopes, among other factors, such as environmental characteristics, the presence of dust and soot, and the strong air currents caused by trains passing and also the action of the fans, it can be said that the punctual type sensors are not recommended for use alone in metro tunnels. Considering the coverage area of each sensor, a large amount of sensors would be required to cover the entire tunnel length. Another reason is that the effectiveness of these sensors suffers interferences caused by the air flow. In addition, the tunnel environment is subjected to spark in track changes. There is also the possibility of interference of the maintenance equipment in the detectors.

The linear systems are more appropriate for long distances, especially in tunnels, because they allow better remote monitoring and the easy localization of the problems.

Thermo-velocimetric detectors by compensation work when there is a certain linear variation in temperature. If the ambient temperature changes linearly, for some reason unrelated to fire, the sensor can also generate a false alarm.

The combined temperature detectors have a better response to fire as compared to each one separately. However, the drive mechanism may be impaired due to the presence of soot and dust from the tracks.

Smoke optical detectors have a higher efficiency for the detection of visible particles. They are more subjected to environmental conditions such as humidity, external temperature and pressure, which could generate false alarms or loss of sensitivity in environments such as metro tunnels. External agents such as dust can also interfere with the working of these devices. However, they are usually inexpensive and suitable for indoor environments such as offices.

Ionization detectors are most susceptible to the smoke invisible particles. Therefore, they operate faster than optical detectors. However, they are not suitable for environments with high levels of dust.

The aspiration detectors have faster response in the detection of particles than the ionization and optical detectors. They can be calibrated according to environmental conditions. However, as the combined temperature detectors, they can suffer interferences from the air flow and environment pressure. They are currently employed close to emergency exits, seeking to drive the pressurization system of escape route ladders. However, they do not effectively apply in tunnels.

Ultraviolet flame detectors (UV) can also be susceptible to false alarms, because of the sparks that the tunnel is subjected to when a train uses a pointing machine and the tracks have voltage difference. Another source of these devices false alarms may be the use of some equipment in track maintenance, such as welding machines.

Infrared detectors (IR) are most suitable for the detection of invisible flames. But the possible flammable materials present in a metro tunnel do not produce invisible flames. Therefore, they may be discarded for this purpose.

Temperature detectors that use optical fibers can cover a large area in terms of longitudinal distance. They are therefore indicated for use in tunnels, and show good accuracy to indicate the accident location.
The video camera detectors have the possibility of integration with the monitoring system and CCTV (Closed Circuit TeleVision) as an advantage. However, they can suffer interference due to soot and dust in the tunnel. The occurrence of sparks can also generate some false alarms in these systems. The need for implementing cameras in areas not covered by CCTV, especially in metro tunnels, also weighs against the installation of this system.

As the fire becomes more severe, the sensors to be used are aspiration smoke detectors, ionization detectors, optical smoke detectors and even thermal detectors.

The main challenge in the application of fire detectors in tunnels is to overcome the long distances and the interference that they may suffer in them. Because of this, the punctual detectors are not applicable. The large number of sensors installed along a tunnel, the need of maintaining them and the long distances between stations, hinder the maintenance of such devices.

A linear system can be well suited for long distances. However, there is not significant experience with the use of such devices. The known experience was in Bangkok, with the application of optical fiber as a linear detector. The maintenance of this fiber is made by software, allowing a constant monitoring of its state, including the precise location in case of disruption.

However, there is not a perfect system, and this is why it is important to combine two or more systems, in order to complete them.

Thus, the system proposed after all these studies is a linear system, allowing the precise localization of a fire occurrence. A fiber optic system or a cable sensor system meets these requirements applied to long tunnels, because of their good accuracy and the possibility of self-diagnosis in real time. The combination of this fiber optic system and the track monitoring with video cameras can be further exploited, especially in situations in which the trains are moving without the presence of a conductor. The fiber optic system automatically finds the accident location and the system operator himself checks the image of the place, after being alerted by the linear system.

5 CONCLUSIONS

Some possible alternatives for fire detection in metro tunnels, based on the characteristics of some existing systems and on experiences that have occurred in other places, such as road tunnels, are shown. Several high-capacity metros share this concern, but also lack experience in this sector. The correct equipment selection can preserve several people lives in the event of a fire.

Based on the analysis presented herein, it can be said that it is possible to use some fire detection technologies in metro tunnels. There is already technical viability to detect and to determine the fire location. Thus, the suggestion made in section 4.3 (combination of fiber optic system and track monitoring with video cameras) seems to be more technically feasible with minor implementation difficulties and this is also expected to have lower individual maintenance requirements.

For the next steps, we suggest an economic viability study, taking into account acquisition, installation and maintenance aspects. Maintenance features such as maintenance facility and the availability of spare parts must be considered, since the metro systems have a very long life. The field test is also important to validate this study, since it can prove the effects presented.

6 REFERENCES


Challenge H: For an even safer and more secure railway


CoMET (Comunity of Metros), available in http://www.comet-metros.org, access in 20/01/2011.


METRÔ – COMPANHIA DO METROPOLITANO DE SÃO PAULO, Internal Document DE-2.13.02.02/6J2-005 Projeto Executivo de Túneis km 28.7 - NATM, 2009


