OPERATIONAL CONSIDERATIONS WHEN PERFORMING FIREFIGHTING ACTIVITIES IN A TRAIN FIRE THAT OCCURRED IN A RAILWAY TUNNEL

Stefan Iliev
Academy of the Ministry of the Interior, Bulgaria
stefan_iliev_gb@abv.bg

Abstract

The paper presents the state of the railway tunnels in the Republic of Bulgaria, as well as the plans for the construction of new similar facilities. The probability for occurrence of fires in railway tunnels is examined and the accompanying dangerous factors are also indicated. Attention is paid to the operational considerations when performing firefighting activities in rolling stock in cases of fires that occurred in tunnels. The possibilities for improvement of the firefighting activities are analyzed. The results of the work have scientific and applied significance and could be used both by officials involved in the organization, management and implementation of firefighting and rescue activities, as well as by the teaching staff and trainees when organizing and conducting theoretical classes and practical trainings.

Keywords: *Safety; Railway Tunnel; Emergency; Fire; Firefighting.*

INTRODUCTION

Transport plays an essential role in the development of any modern society. It enables population mobility, supports the economy by linking producers and markets, and facilitates foreign trade and tourism. In recent years, demand for freight and passenger transport services has increased, accompanied by rising expectations for both quality and safety.

Rail transport is a key component of Bulgaria's transport system and significantly affects the country's economic development and social mobility. The state of Bulgaria's railway sector is analyzed in details in [1], where the key problems and development directions are identified. Many of the identified problems are directly related to railway safety, chief among them are:

- unsatisfactory condition of the railway infrastructure – most facilities and systems are obsolete and technologically outdated;
- aged and obsolescent rolling stock;
- high staff turnover and insufficient professional qualification of operating personnel.

The current condition of both the infrastructure and the rolling stock does not meet contemporary safety requirements. These circumstances raise the probability of incidents involving passenger and/or freight rolling stock. Notable examples are:

- the derailment of a freight train near the village of Piasachevo followed by a fire on 15 August 2025;
- a head on collision between two freight trains in the railway section between Svetovrachene and Kremikovtsi stations on 15 January 2025;
- the Hitrino railway accident of 10 December 2016;
- the Sofia-Kardam train fire of 28 February 2008.

Such incidents cause severe material losses and, in many cases, fatalities and numerous injuries. While the likelihood of similar events within a railway tunnel is low, the potential consequences are severe. As a rule, if a fire is detected on a train transiting a tunnel, the primary objective is to move all trains – especially the affected one – out of the tunnel. Simultaneously, the rail traffic approaching the incident area must be halted as quickly as possible. The most complex operational situation with the gravest consequences would involve a derailment with a subsequent fire inside a tunnel, or a fire on a train that cannot exit the tunnel and remains trapped inside.

The **aim** of this study is to examine the specifics of firefighting a fire on a train when the incident occurs in a railway tunnel.

Taking into account the above mentioned the following objectives must be completed:

- review the condition of the existing railway tunnels in Bulgaria and the plans for constructing new ones;
- identify the hazardous factors that describe the fires in railway tunnels;
- establish the specific features of firefighting operations involving rolling stock when fires occur in tunnels;
- consider opportunities to improve firefighting and rescue operations in railway incidents.

MAIN TEXT

The state of the existing railway tunnels in the Republic of Bulgaria

The total length of Bulgaria's railway network is 6,517 km, including 2,907 km single track standard gauge lines, 1,978 km double track lines, and 1,480 km of standard gauge station tracks [2]. A significant portion of these tracks was built before the mid twentieth century, with geometric parameters, structures, and facilities suited to speeds up to 100 km/h, and in some places with almost exhausted capacity to maintain speed while ensuring traffic safety. The situation is similar for the railway tunnels. Bulgaria has 186 tunnels with a total length of 47.5 km, most of them built more than fifty years ago. Table 1 shows the number of tunnels by decade of construction [2].

Table 1. Number of railway tunnels by period of construction.

Period	1890 ÷ 1899	900 ÷ 1909	1910 ÷ 1919	1920 ÷ 1929	1930 ÷ 1939	1940 ÷ 1949	1950 ÷ 1959	1960 ÷ 1969	1970 ÷ 1979	1980 ÷ 1989	1990 ÷ 1999.
Tunnels built	13	0	49	12	34	28	15	18	8	4	5

Only three tunnels have undergone rehabilitation or modernization – and even these works were carried out more than two decades ago:

- 275.50 m tunnel, Zemen–Razhdavitsa (1993);
- 235.00 m tunnel, Zemen–Razhdavitsa (1993);
- 212.00 m tunnel, Thompson (halt)–Svoge (2004).

Table 2 presents the distribution of tunnels by length [2].

Table 2. Distribution of tunnels by length

Tunnel length	≤ 20 m	20 ÷ 50 m	50 ÷ 100 m	100 ÷ 200 m	200 ÷ 300 m	300 ÷ 400 m	400 ÷ 500 m	500 ÷ 600 m	600 ÷ 700 m	700 ÷ 800 m	800 ÷ 900 m	900 ÷ 1,000 m	1,000 ÷ 1,500 m	1,500 ÷ 2,000 m	> 2,000 m
Count	6	16	40	53	35	15	3	6	3	2	1	0	3	1	2

Currently, only two tunnels longer than 2,000 m are in operation: the Galabets single track tunnel (Dolno Kamartsi–Mirkovo), 3,034.00 m, and the Koznitsa single track tunnel (Koprivshtitsa–Stryama), 5,812.16 m. The main problems affecting existing tunnels include: lack of waterproofing in almost all tunnels; absence of lighting installations in many tunnels; high levels of infrastructure wear; and non compliance with contemporary fire safety requirements.

The absence of newly built tunnels after 2000, coupled with the minimal efforts to modernize existing ones, underlines the need for investment and upgrades to ensure safety. Under Article 170 of Ordinance No. 55 of 29 January 2004 [3], additional safety measures are required when constructing new or reconstructing existing tunnels longer than 1,000 m. Bulgaria has only six such tunnels. Any future reconstruction of these facilities must be guided by a safety and firefighting and rescue operations concept, which should at least include the following:

- fire safety requirements and water supply for firefighting;
- the need and the possibilities for construction of emergency exits, their signage and lighting;
- provisions for emergency telephone points;
- first aid stations and their equipment;
- justification for rescue platforms at tunnel portals including access roads;
- the possibility of helicopter landing at such platforms.

Planned new tunnels

Several tunnel projects are at various stages of design or construction, funded through different programs and projects:

- Sofia–Plovdiv railway modernization project (Elin Pelin–Kostenets railway section):
  - several single track twin bore tunnels totaling 15.4 km of bores, including what is planned to be Bulgaria's longest railway tunnel between Elin Pelin and Vakarel (6.8 km);
  - eight double track single bore tunnels totaling 5.48 km [4];
- Plovdiv–Burgas railway rehabilitation project: one 835 m tunnel would be constructed in the Orizovo–Mihaylovo section [4];
- Vidin–Sofia railway modernization project (Medkovets–Sratsimir railway section): one single track tunnel 2,975 m long is going to be build [4], [5];

- Sofia–Pernik–Radomir railway modernization project: a twin bore "Vladaya" tunnel, with the north (Line 1) bore 4,820 m and the south (Line 2) bore 4,754 m [6] will be constructed.

For all of these new tunnels that exceed 1,000 m, a safety concept and operational plan for effective tactical response must be developed. Implementing such measures will significantly reduce risk and mitigate adverse consequences during fires or other incidents involving rolling stock in tunnels.

Typically, railway tunnels up to 500 m are considered short [7], by analogy with [8], where road tunnels shorter than 500 m are defined as short. This value can be adopted as a threshold risk criterion [9]. Conversely, for tunnels longer than 500 m, quantitative risk analysis must be performed to assess fatality risk due to mechanical events, fires, dangerous goods, etc., and to determine the need for additional safety measures [8]. However, a length of ≤ 500 m must not lead to risk underestimation: incidents can escalate rapidly even in short tunnels, with hazardous factors approaching those in much longer tunnels. This underscores the need for timely risk assessment and fire safety measures [10], [11].

Structural characteristics of tunnel facilities

Most railway tunnels in Bulgaria are single track, i.e., bi directional traffic runs through the same bore, creating a risk of head on collisions. Double track tunnels generally offer higher safety than single track ones. The highest safety is afforded by twin bore single track tunnels with unidirectional traffic. If cross passages connect the two bores, the unaffected bore can serve as an evacuation and rescue route during an incident. It can also provide firefighter access, enabling two sided attack.

Almost all Bulgarian railway tunnels rely on natural ventilation, i.e., airflow depends on ambient weather conditions at both portals and on the piston effect of passing trains. Consequently, in an incident, airflow direction may change at any time. For long tunnels, mechanical ventilation is often planned and installed as an additional safety measure [12], primarily to control smoke and heat during a fire. Its use must be judicious because mechanical ventilation can create turbulence that prevents smoke stratification, hot smoke then spreads throughout the tunnel cross section more rapidly than it would without ventilation. Longitudinal ventilation may increase fire growth intensity. In twin bore tunnels, smoke exiting one portal may reverse back into the unaffected bore. In such cases countermeasures include coordinating ventilation in both bores to drive air in the same direction.

Depending on tunnel type and ventilation design, the system can also prevent or limit smoke ingress into evacuation routes and enable self rescue. A common concept is to maintain positive pressure in the unaffected bore or emergency gallery and in any refuge safety areas, supplying fresh air via large axial fans. The pressure differential prevents smoke transfer even when cross passage doors are opened. However, such solutions complicate firefighting and rescue, necessitating integrated analysis of all safety elements and their interactions during emergencies.

Tunnel dimensions (length and cross section), single vs double bore, single vs double track, presence of cross passages and existence of emergency ventilation all directly influence firefighting tactics.

Hazardous factors in train fires within railway tunnels

Fires in railway tunnels involve rapid and dense smoke production, high temperatures, the presence of flammable liquids and gases (in locomotives and tank wagons), explosion risk, constrained evacuation paths, and potential passenger panic – all of which make such fires substantially more dangerous than incidents in the open.

The primary hazard is the smoke. When a fire develops outdoors, smoke can rise unhindered due to the movement of convective flows while in tunnels, smoke travels horizontally. The hot smoke rises to the ceiling above the burning train then move with the airflow to the ventilation system's openings or to a portal. As smoke cools, it descends and spreads along the ground at some distance from the place of fire.

Tunnel fires can reach peak temperatures within 10–15 minutes of ignition [13], [14], depending on fuel type and quantity. The maximum temperature is typically in the 900–1,300 °C range [14], [15].

Passenger behavior may be irrational, including panic. In a worst case scenario, passengers will self evacuate towards both portals, potentially traversing smoke filled sections.

Another major hazard that should not be underestimated is the possibility of fire and rescue personnel being electrocuted. The catenary voltage is 25 kV, a decisive factor at the incident scene.

Finally, leaks of flammable or combustible liquids, acids, toxic gases, and other hazardous substances can further complicate the firefighting and rescue operations and prolong the response.

Fundamental principles and tactical actions for train fires in railway tunnels

General operational and tactical procedures when firefighting fires in trains within tunnels are governed by [16] and described in [17]. Actions to be taken immediately – and on which both the outcome and responder's safety largely depend – include:

- to stop rail traffic in the affected railway section;
- to isolate and de energize electrical installations and equipment and obtain written confirmation;
- to earth (ground) the catenary on both sides of the rolling stock involved in the incident;
- to determine whether the tunnel has fire suppression, water supply, and ventilation systems, whether they have been activated, and how they may be used to facilitate mitigation;
- to order and conduct evacuation;
- to assess feasibility of moving individual wagons and, if necessary, organize their withdrawal from the danger zone;
- to identify the types of burning cargo, appropriate extinguishing agents, and required personal protection equipment (PPE);
- to conduct simultaneous firefighting and search and rescue (SAR) for casualties.

Specifics of firefighting train fires in railway tunnels

The principal difficulty is the potential for rapid fire growth and deterioration of conditions due to high temperatures and smoke. Because of these the main tactical principle is the rapid concentration of sufficient resources at the scene and the swift application of extinguishing agents to the seat of the fire. This aims both to control and then extinguish the fire, and to reduce or halt smoke production and to create better conditions for subsequent operations.

High temperatures can hinder firefighter access to the seat of the fire. With ventilation operating, conditions differ on the upwind and downwind sides: on the smoke downstream side, radiant and forced convective heat fluxes are intense; on the upstream side exposed to incoming cooler air, conditions are more tolerable, enabling closer approach and more effective attack. This requires a system capable of generating airflow with a defined direction and sufficient volume. A critical rule once suppression begins: do not reverse the airflow direction during operations without the Incident Commander’s explicit approval. Doing so endangers firefighters and can delay or halt suppression. Moreover, due to airflow inertia, a reversal may take up to ten minutes, depending on the system and tunnel profile and length [7].

A further challenges are the limited access and the long travel distances responders must cover to reach work areas – known as penetration depth. Distances over 80 m are considered large penetration depths [7]. For comparison, building fires rarely require covering of penetration depths more than 35 m. European road tunnels often entail penetration depths from 300 to 500 m. In new railway tunnels, penetration depth is also limited to 500 m, but in existing tunnels it may be several kilometers [2], [18].

Firefighters with average level of physical training can manage up to 500 m of penetration when using SCBA with twin cylinders. Greater depths lengthen all work cycles and impose extreme physical and psychological stress. At such distances, the stress and personal risks for firefighters equipped with breathing apparatus increase dramatically. When penetrating deep into smoke, small mistakes can have fatal consequences.

Another challenge during train fires is related to the need for a large number of firefighters and rescuers to carry out the activities of limiting and working out the accident. Rapid suppression is essential. SAR must commence immediately in smoke filled sections. A two sided attack is commonly employed: extinguish from the side opposite the smoke flow as quickly as possible to reduce smoke production and improve SAR conditions on the downstream side. This approach requires substantial manpower. The number of teams required depends on:

- type and number of wagons;
- time for free development of fire;
- access possibilities;
- tunnel length;
- penetration depth;
- smoke conditions;
- the extent of areas to be searched.

These features necessitate the need for a large number of teams of firefighters and rescuers to work to limit and eliminate the accident. Dedicated reconnaissance/size up teams are mandatory. An important rule is that they do “only” reconnaissance and do not perform SAR because they are not equipped for performing such activities. Exceptions are limited number of situations in which a victim is found adjacent to an emergency exit and can be removed without specialized transport means.

Command and control are challenging. With at least two operational sectors (one at each side), the Incident Commander or operations chief must coordinate geographically separated teams, often under communications constraints. Effective information exchange about performed activities and evolving conditions is essential to maintain a shared situational picture and to coordinate tactics and decision making under time pressure and hazardous conditions. Only then the teams, the on-site manager and the rest of the management team will have the same understanding of the overall situation of the incident. Only under these conditions the tactical decisions and the performed actions will be able to be coordinated in an adequate manner, and their implementation will give the expected results. It sounds simple, but at the same time the members of the operational headquarters, on-site managers, team commanders, firefighters and rescuers are under enormous pressure from the time, from the dangerous factors of the fire, from the decisions they have to make and from the actions they have to perform. That is why all of them must have sufficient means of communication in order to be able to receive and transmit information about the development of the incident in a timely manner.

Enhancing tactical capabilities by using specialized fire equipment

Usually fire and rescue teams have difficulties when coping with the implementation of various tactical activities at penetration depths greater than 500 m. Their capabilities can be augmented by the use of firefighting rail vehicles (fire trains or rail capable fire appliances) that transport personnel, extinguishing agents, and equipment. Some of them even provide smoke tight cabins. Additional specialized equipment which could be used includes:

- mobile smoke ejectors for airflow management;
- basket stretchers with wheels for long distance casualty movement;
- LED flashing beacons for route marking in reduced visibility and smoke conditions;
- thermal imaging cameras for orientation and rapid victim location;
- closed circuit oxygen rebreathers for extended operations in irrespirable atmospheres.

Preparedness for effective firefighting

Sound decision making, safe and effective operations in tunnel incidents depend on pre incident planning [19] – developing pre plans and conducting regular training for increasing the level of professional qualification.

Fire tactical training typically follows a certain sequence. The goal is first to acquire theoretical knowledge, then operational-tactical study of the relevant tunnel facility is carried out, and only then tactical exercises and live drills are conducted [20].

Pre planning and practical trainings help to estimate the approximate number of firefighting and rescue teams required to work out the accidents. The results of the trainings and drills then confirm or refine these estimates.

Maximum training effect is achieved when commanders and crews are exposed to conditions as close to real as possible. In this way they will experience first hand the psychological and physical burdens of long penetrations and the associated hazards, understand what is realistically achievable, and develop a sense of their operational limits.

It is considered a good practice to conduct practical trainings as often as possible, even if they are with small duration or less ambitious tactical design [18]. This leads to better results in terms of the effect of the exercises, such as gathering knowledge of the peculiarities of tunnel facilities, possible accident scenarios [21] and last but not least practicing the tactical activities of the firefighting and rescue teams.

CONCLUSIONS

A fire on a train located inside a railway tunnel is unlikely but entails potentially catastrophic consequences in terms of life safety and property damage. This is the most challenging scenario involving railway rolling stock. That is why the institutions and the personnel responsible for railway transport and infrastructure safety must continuously identify and implement additional safety measures and periodically review existing procedures to ensure that fire safety provisions remain in place and that they are effective enough.

Timely and effective operational response in case of fire or other accident in a railway tunnel depends on pre established conditions for successful firefighting and on the level of professional qualification of the fire and rescue personnel.

While many operational activities in tunnel train fire scenarios mirror general firefighting and rescue tasks, there are also distinctive features that must be well understood and embedded in procedures and training programs.

The features of the activities that must be performed during firefighting and rescue operations, as well as the risk under which the firefighters and the rescuers do their duties, require a continuous search and implementation of opportunities for increase of the safety level and the quality of their professional qualification.

REFERENCES

1. Strategy for the Development of Railway Transport in the Republic of Bulgaria and Recovery and Development Plan of the BDZ Holding Group, 2015–2022, Sofia, 2015.
2. Network Statement 2024–2025, valid 15.12.2024–13.12.2025, Version 11/07.07.2025.
3. Ordinance No. 55 of 29 January 2004 on the design and construction of railway lines, stations, level crossings and other railway infrastructure elements.
4. National Railway Infrastructure Company [Национална компания "Железопътна инфраструктура"] (project documentation and updates). Available at: https://www.rail-infra.bg/ (last view: 26-09-2025)
5. Neykova, Zh., Fire extinguishing installations for Railway Tunnel 2 on the Vidin–Medkovets line, UABG Yearbook, 2020, Sofia.
6. Neykova, Zh., Fire Water Supply for the "Vladaya" Railway Tunnel, Proc. VIII International Conference. "Civil Security 2017", Academy of the Ministry of Interior, Sofia.
7. Shotarov, K., Ivanov, G., Actions of the GDFSCP teams in road tunnel incidents and interaction within the Unified Rescue System, Proc. Jubilee International Scientific Conference "50 Years of Higher Education at the Academy of the MoI," 3–4 Oct. 2019, Sofia.
8. Ordinance RD 02 20 2 of 21 December 2015 on technical rules and norms for the design of road tunnels.
9. Arabadzhieva, S., Parvanov, S., On the significance of mathematical methods for assessing the risk of major industrial accidents, Proc. 48th Spring Conference of the Union of Bulgarian Mathematicians, 2019. ISSN 1313-3330
10. Parvanov, S., Hrischev, L., New approaches to improving emergency safety during construction, Proc. XII International Conference "Design and Construction of Buildings and Facilities", NTS Bulgaria. ISBN 1314-6955
11. Parvanov, S., Botev, G., A new approach to determining the need for fire safety and civil protection units in facilities on the territory of the Republic of Bulgaria, Proc. "Civil Security 2017," Academy of the MoI, Sofia, 2017. ISSN 1313-7700
12. Neumann, C., Bopp, R., Harer, G., Burghart, M., Koinig, J., Incident management in a very long railway tunnel, Third Int'l Symp. on Tunnel Safety and Security, Stockholm, 12–14 Mar. 2008.
13. Stoyanov, D., Fire Safety of Tunnels, Fplus LTD, Sofia, 2016.

14. Chochev V., Arabadzhieva S, Numerical study of the hazardous factors of a fire in a passenger railway car, Mathematics and Education in Mathematics / Section B: Mathematical Modelling and Informatics, Vol. 54 (2025), Sofia, pp 91-100, DOI: https://doi.org/10.55630/mem.2025.54.091-100, ISSN 1313-3330 (Print), 2815-4002 (Online)
15. Chochev V., Arabadzhieva S, Protic M, Modeling of fire in a coupe with a closed door in rolling stock, Scientific Journal Safety Engineering, ISSN 2217-7124, 11, pp 15-21, 2021 г.
16. Ordinance No. 8121z 1006 of 24 August 2015 for performing firefighting and rescue activities by the Fire Safety and Civil Protection bodies of the Ministry of the Interior.
17. Rules of action for the Incident Commander in characteristic incidents (Order reg. No. Iz 2219 of 28.09.2010, Secretary General, MoI).
18. International Fire Academy (training practices and guidance). Available at: https://www.ifa-swiss.ch/en/ (last view: 26-09-2025)
19. Prodanov, H., Development and suppression of fires in multi family residential buildings, 2022, 202 pp., ISBN 978 954 348 234 4.
20. Chochev, V., Operational Tactics for Firefighting, Ogneborec, Sofia, 2003.
21. Parvanov, S., Challenges to the assessment of fire safety and protection during fires, disasters, and emergencies in facilities, Proc. Jubilee International Scientific Conference "50 Years of Higher Education at the Academy of the MoI," 2019. ISBN 978-954-348-184-2

Received: 29-09-2025 Accepted: 15-12-2025 Published: 29-12-2025

Cite as:
Iliev, S. (2025). "Operational Considerations when Performing Firefighting Activities in a Train Fire that Occurred in a Railway Tunnel", Science Series "Innovative STEM Education", volume 07, ISSN: 2683-1333, pp. 226-234, 2025. DOI: https://doi.org/10.55630/STEM.2025.0720