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INDUSTRIAL FIRES - A CRUCIAL FACTOR FOR MEGA INCIDENTS

Abstract: *The risk of an uncontrolled fire can seriously threaten the corporate security and stability of every company in the industry. Two-thirds of the refineries and installations in the Republic of North Macedonia that faced a major fire (which affected 50% of the company's assets) ended up in bankruptcy. Therefore, timely identification, analysis and assessment of fire threats, along with the selection of the most appropriate control measures, should be considered as a challenge and a red line for every safety manager in the industry. This process can be viewed as a comprehensive conceptual framework that effectively integrates various areas of corporate operations, focusing on identifying all potential risks, dangers, and threats to the company. It guides the effective use of company resources in order to prevent losses, reduce failures and errors in operations and thus increase profits and improve the stability of the company. In this paper, we will present a worst-case fire scenario for the Skopje region in the Republic of North Macedonia, due to the presence of industrial facilities in the area. Furthermore, the paper outlines the stages undertaken to address the ongoing fire hazard at the OKTA company and presents a fire risk reduction strategy that has been successfully implemented in practice.*

Keywords: fire risk, vulnerability control, treatment of fires

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INTRODUCTION

Current events in the last decade of the 20th century, as well as the beginning of the new millennium, point to numerous risks and dangers arising from accidents, incidents, malfunctions, natural disasters, and other forms of destructive impacts on human life, natural and material assets, and the environment as a whole.

Emergency events such as industrial accidents, fires, floods, earthquakes, and other natural disasters not only threaten the lives and property of individuals but can also disrupt the ecological balance of entire regions and affect overall socio-economic development.

Fire is an uncontrolled combustion that occurs when three basic elements combine (Group of Authors, 2010): a combustible material (any flammable substance such as wood, paper, plastic, oil, fuel, etc.), oxygen (present at a concentration of about 21%), and a source of heat (a spark, open flame, friction, electric arc, etc.).

The fundamental principles of fire protection include measures and actions aimed at preventing the outbreak and spread of fire, as well as ensuring effective fire extinguishing and the rescue of people and property (Erić, 2003).

Fires in railway transportation can cause dramatic and long-lasting adverse effects on the environment and the population, and the serious consequences of such disasters confirm a real threat that requires a systematic approach to resolution.

The causes of fires in railway transport can be numerous and varied, resulting from technical failures, lack of equipment maintenance, human error, or external factors (Cote, 2023; Klinoff, 2019).

The most common **technical failures** that lead to fires include:

- *Short circuits in electrical installations* (faulty or worn-out electrical systems in the train or infrastructure, e.g., the overhead contact line).
- *Overheating of components* (engines, braking systems, transformers, or other electrical parts can overheat due to malfunction or lack of maintenance).
- *Fuel or oil leaks* (in diesel locomotives, leaks of fuel or lubricants can lead to ignition, especially in the presence of sparks).
- *Malfunctioning heating systems* (stoves or heating devices inside train cars can cause fires if not properly maintained).

Human error is also a common cause of fires in railway transport. Human factors that lead to fires include:

- *Smoking in prohibited areas* (discarding cigarette butts in or around the train).

- *Improper use of equipment* (inexpert handling of electrical devices, cables, or flammable materials).
- *Failure to follow maintenance procedures* (skipping mandatory inspections and servicing can lead to latent failures).
- Among the **external causes** that can lead to fires in railway systems, the following can be identified:
    - *Wildfires* (smoke and flame can spread to trains or railway infrastructure).
    - *Sparks from wheels or brakes* (under dry conditions, sparks from braking systems can ignite dry grass or vegetation alongside the tracks).
    - *Sabotage or vandalism* (intentional setting of fires, for example, by throwing flammable objects).

Fire protection in railway transportation should be organized and implemented at all locations and facilities exposed to fire hazards, encompassing the application of regulatory, administrative, organizational, educational, and other measures.

In this paper, we will present a worst-case fire scenario in the Republic of North Macedonia. This scenario has been developed as a worst-case fire threat situation for the Skopje region since those industrial capacities are located within the area. If there is a fire hazard among them, it may significantly threaten the city with serious consequences.

The situation has been chosen for a specific city area due to records of fire-related events over five years (2016-2020). Based on the reviewed information for this period, the risk of fire is assessed as very serious for the City, for two main reasons: a high likelihood of a fire occurring and a major potential impact in case of a fire, with the ability to escalate quickly over a large area, potentially leading to loss of life, damage to property, and disaster for nature.

CASE STUDY - INDUSTRIAL FIRES

Due to the extended period of transition in the Republic of North Macedonia, unfortunately, a lot of negative impacts have been felt across many sectors of industry. One of the most affected is the railway sector. This paper will try to look at it specifically from a fire hazard perspective. The Railway Infrastructure Public Enterprise has been greatly financially exchequer, so it has minimized routine railway corridor maintenance, especially in terms of spraying and vegetation control. This negligence has directly led to a significant increase in the number of wildfires along the railway lines.

The description of the scenario

The international train service running on the Budapest–Belgrade–Niš–Skopje–Thessaloniki line, after passing through the city of Kumanovo on its way to Skopje, travels 20 kilometers as it descends from the highest point of 459 meters above sea level (Romanovce Toll Station) to 280 meters, a vertical drop of 179 meters in less than 15 minutes (Figure 1).

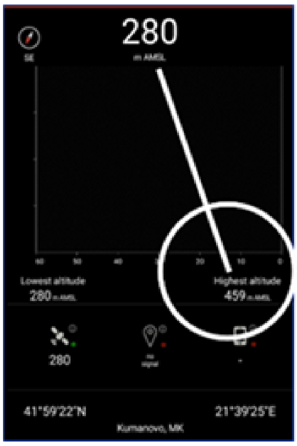

Figure 1. *Train height distance - vertical (179m)*

For this segment, the train driver must apply continuous braking, which concludes near the village of Miladinovci, where large fuel storage facilities are located (Figure 2). These facilities house petroleum derivatives and liquefied gas for the two largest suppliers, which together account for approximately 90% of the domestic market share in petroleum products.

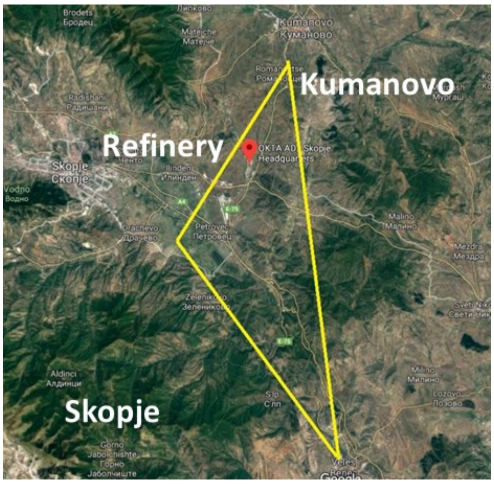

Figure 2. *The location of large fuel storage facilities (the critical triangle)*

On this stretch, fires often occur in the summer, on average 4-6 per year, and in dry years, this number can rise to as many as 10, of which at least one is severe (Figure 3).

Figure 3. *Total number of fires by 2020*

The steep descent, coupled with continuous braking and friction, leads to the generation of sparks, which ignite the dry vegetation along the railway line. During the summer period, this vegetation becomes highly flammable and susceptible to rapid combustion. The principal concern is the potential for uncontrolled fire propagation, exacerbated by persistent winds in the area, which could allow the fire to reach and breach the external perimeter of the fuel storage facilities, posing an extreme risk of escalation into a major industrial fire or explosion.

The braking reaches its climax at the height of the Central Administration Building of the refinery, which is located on the right, and the LPG installation of the other oil company positioned on the left.

Incident Cause Analysis

A freight train on the Belgrade–Skopje route experienced a mechanical failure after an extended braking sequence (Sunday, 25 July 2021, 11:47 a.m.). One of the locomotive's wheels got locked and created a lot of friction and sparks along the track for a significant part of the railway (Figure 4). This created multiple ignition points and fires along the railway.

Figure 4. *The braking and friction/sparks*

In addition to the sparks from the locked wheel, hot brake lining fragments detached from the locomotive. One of these fragments acted as an ignition source and set fire to a wooden railway sleeper and the surrounding vegetation (Figure 5). It was Sunday, a day when the company was operating with minimum staff which was an unfavorable circumstance for effective firefighting.

Figure 5. *The fire on a wooden railway sleeper*

The fire developed fast – in 12 minutes – and was detected by the company's Monitoring Center via surveillance cameras. According to the procedure, the Monitoring Center alerted the Firefighting Unit's team leader via radio and public address system.

The reaction time from the moment of alert to on-site arrival was 150 seconds. The Firefighting Unit Commander, Safety and Fire Protection Manager, and duty personnel arrived 25 minutes after the alert was issued. This marked the start of the coordinated response to contain the fire within the company premises.

At 12:33 p.m., the Territorial Firefighting Unit of the City of Skopje arrived on site, 49 minutes after the alert.

By 1:55 p.m., the fire had reached its peak in terms of spread. Four active fire fronts had developed in the northeastern sector, extending over 2 kilometers in length (Figure 6).

The spread of the fire significantly endangered the coordination of suppression efforts, which in turn divided the available firefighting resources across four separate locations. Due to the variable and unexpected progress of the fire, it was necessary to continuously reorganize personnel, equipment, and suppression resources in real time to respond effectively.

Figure 6. *Four active fire fronts and direction of fire spread*

Wind was out of the south at between 5 and 8 m/s. The wind, which played a role in slowing the fire's advance down the rail line at times, also directed the flames toward the perimeter of the OKTA AD petrol station.

Given the variable wind conditions, the fire reached the facility's perimeter in 17 minutes. The ignition and initial growth phase of the fire lasted 12 minutes, and within a total of 29 minutes from its initial outbreak, the fire had reached the perimeter, posing a significant threat. During this period, internal alert systems were activated, response teams were mobilized, and the remaining personnel reported to the site. It is important to note that the minimum response time for the national (public) fire service is 45 minutes.

This indicates that whenever a northerly wind—commonly originating from the slopes of Mount Skopska Crna Gora—blows at speeds exceeding 15 m/s, a critical risk scenario for OKTA AD arises. In such a scenario the fire may reach the perimeter of the facility in less than 15 minutes. This creates a 14-minute gap needed for the company's internal fire team to assemble, equip and become operational, rendering a timely and effective response operationally infeasible under standard conditions.

Fire suppression operations lasted for a total of 2 hours and 21 minutes, and were conducted under extremely bad weather conditions, with an ambient temperature of 42.5ºC.

A total of 17 company employees participated in the firefighting efforts, including:

- 7 professional firefighters from the internal fire protection unit,
- 4 security officers,
- 2 operators from the tank storage area,
- 2 logistics/grounds workers, and
- 1 maintenance technician.

The City Firefighting Unit deployed one fire engine with a three-member crew.

At 14:30, the fire was fully extinguished, ending the intervention 2 hours and 30 minutes after it started.

Risk Analysis

The case under review identifies the key variables for risk assessment:

1. Time required for the fire to spread from the railway track to the company's perimeter (a distance ranging from 40 to 90 meters depending on the sector) and subsequently to breach the premises — in the present case, the fire reached the perimeter within 29 minutes, under ambient conditions of 42.5ºC and wind speeds ranging from 5 to 8 m/s.
2. The on-duty internal fire response team is capable of conducting initial fire suppression operations within 2.5 to 3 minutes from the moment of alert.
3. The full mobilization of the internal firefighting unit, including off-duty personnel (home standby), requires approximately 25 to 30 minutes.

If the wind velocity exceeds 20 m/s, the fire is projected to reach the company's perimeter boundary in less than 10 minutes (hypothetical scenario).

The estimated fire spread time is shorter than the full deployment time of internal fire response resources, which indicates a critical response gap and highlights the need for enhanced preventive measures and faster initial suppression capabilities.

The following figure shows the fire risk assessment matrix used in the OKTA Company in North Macedonia.

OKTA - Threat & Hazard Assessment Matrix

Threat & Hazard	Probability				Vulnerability Company resistance	Impact				Risk Level
	Incidents per year			Index of Probability (High 5 ↔ Low 1)	External resources ↔ Internal resources (Weak resources ½ ↔ Strong resources 1)	Human impact	Property impact	Business impact	(High impact 5 ↔ Low impact 1)	Index of jeopardize (High level 10 ↔ Low level 1)
	2019	2020	2021							
Risk of explosion	1	/	1	2	¼	5	5	5	5	2.25
Risk of fire	6	4	5	5	⅓	3	4	5	7	5.25

Rating scale		
Low >1	Medium - 3	Hight - 5
minor	tolerant	unacceptable

Figure 7. *Threat and Hazard Assessment Matrix (OKTA, 2022)*

Implemented mitigation measure

As part of the 2022/2023 fire risk mitigation strategy, the company installed a remote-activated water curtain system along the perimeter adjacent to the railway (Figure 8). The system is remotely controlled via SCADA by the Operational Monitoring Center.

Figure 8. *Water curtain system adjacent to the railway*

Key technical specifications of the system include:

- Length: 1,225 meters;
- Operating pressure: 5–7 atmospheres;
- Total number of sprinklers installed: 520;
- Coverage width of water barrier: 3 meters.

This water curtain serves as a rapid-response containment barrier, designed to inhibit or delay fire ingress, thus buying critical time for the mobilization of internal and territorial firefighting units.

CONCLUSION

Fire protection is organized and continuously implemented in all facilities and locations exposed to fire hazards. The fundamental elements of fire protection include (Sekulović, Bogner, Pejović, 2012):

- Prevention, planning, and implementation of preventive measures to reduce the risk of fire outbreaks and limit their spread;
- Detection and reporting of fires;
- Installation of smoke detectors and other early fire detection systems, as well as ensuring clear procedures for fire reporting;
- Fire extinguishing and provision of adequate firefighting equipment, such as fire extinguishers, hydrants, and trained firefighting personnel;
- Evacuation of people from endangered facilities, including clearly marked exits and staff training for evacuation procedures;
- Training and informing personnel;
- Educating the public about fire hazards, preventive measures, and procedures to follow in case of fire.
- Prevention of potential fires in railway transportation involves:
- Regular technical maintenance of trains and tracks;
- Installation of smoke detectors and fire protection systems on trains;
- Staff training and passenger education;
- Strict adherence to safety procedures.

Based on everything presented in this case study, we can conclude the following:

- The railway line between Kumanovo and Skopje, although operating at a moderate traffic frequency, is expected to remain active with regular freight movement. Given the unchanged topographic and environmental conditions, the probability of future fire incidents remains high.
- The proximity of two major industrial installations—both with large storage capacities of petroleum derivatives and liquefied petroleum gas (LPG), which are highly flammable and energy-dense substances—results in the highest fire load per unit area within the urban territory.
- The presence of multiple rural communities (village settlements) within the designated risk zone, with a fluctuating population numbering in the thousands, introduces a critical third parameter in the risk assessment matrix – the human impact factor – which further elevates the overall risk classification to the highest level.

REFERENCES

Cote, A. E. (2023). *Fire protection handbook (21st ed.)*. Vol. 2., Quincy, MA: National Fire Protection Association.

Erić, M. (2003). *Protivpožarna i preventivno-tehnička zaštita*. Inženjersko-tehnički priručnik. Čačak: “Jel&Mil.

Grupa autora (2010). *Osnove zaštite od požara.* Priručnik. Varaždin: Centar za integralnu sigurnost d.o.o.

Klinoff, R. W. (2019). *Introduction to fire protection (6th ed.)*. Burlington, MA: Jones & Bartlett Learning.

OKTA (2022). *An internal document of the OKTA AD Company.* Republic of North Macedonia.

Sekulović, Z., Bogner, M., Pejović, S. (2012). *Preventivna zaštita od požara*. Autorsko izdanje.