Methodology for Assessing Fire Risk in Double-Deck Trains

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Abstract. The authors explore the problem of ensuring fire safety and assessing the expected risk to life in double-deck trains. Statistical data of fires on railway transport in Russia are presented, their main causes are revealed. A method for assessing expected risk to life in double-deck trains is proposed. The results of the assessment can be used in the future to justify the adoption of additional measures aimed at reducing the level of fire hazard for people in double-decker trains.

1. Introduction

Railway transport continues to be one of the most popular and accessible modes of transport throughout the world [1]. Creation of high-speed railways, development and implementation of new double-deck trains significantly increase passenger traffic and reduce travel time. These factors lead to growing the popularity of the use of rail transport [2]. This requires significant attention to safety issues, despite the fact that most people consider this mode of transport to be the safest.

One of the main hazards on trains is fire (Figure 1). Potential emergencies pose a significant threat to human life and health, as well as significant material damage. This is due to the large length of railway tracks, a huge amount of dangerous goods transported, as well as the complexity of the prompt response of rescue services. The fire on the train is terrible because of the poisonous combustion products of synthetic finishing materials. Already in the fourth minute after the outbreak of a fire, their concentration exceeds the maximum permissible. In normal conditions without panic, passengers have the opportunity to leave a regular carriage within one and a half to two minutes. However, in most cases, fires occur in carriages while driving along the route. And the evacuation time from double-deck cars will obviously be much longer [3, 4].

Figure 1. Fires in railway transport.
The level of the expected risk to life (ERL) values in double-deck trains may exceed the standard value. Unfortunately, the present unified scientific approach to solving this problem is still in the stage of formation.

2. Methods
At present, a large number of studies have been devoted to the problems of the fire hazard of railway transport. White N in the article [5] presented an overview of fire safety standards in railway transport, Shuo Ma and others studied the combustion characteristics during a train fire at different speeds [6], Ramesh N V K and others proposed a method for preventing fires in trains using GSM technology [7], Xiao W investigated the rate of heat release during fires in high-speed trains of the Chinese Railway [8], Aher S B and Tiwari D R explored in detail the causes and consequences of railway accidents in India, including fires [9], Camillo A and others analyzed the risks of fires and evacuation events on the European railway transport network [10], Capote J A and others analyzed the procedures for evacuation in case of fires in high-speed trains [11], Matveev AV and others investigated the problem of emergency response to emergency situations in transport [12, 13], Chunlan W U, Yuxin S O N G & Chen L I proposed a method for assessing the indicators of safety risks of high-speed trains using fuzzy logic and the construction of a Bayesian network [14].

Gradually, many types of hazards on railway trains become more and more significant, becoming global, affecting the interests of a large number of people. In recent years, large fires around the world have become the reason for scientific research to solve the problems of minimizing and preventing large fires in transport. Emergencies associated with train fires have a negative impact on people.

Due to the development of the use of double-decker trains, additional research is required on the problems of ensuring their fire safety. It is necessary to develop methods for assessing the level of risk for people, scientific justification of measures aimed at reducing the level of ERL in double-deck trains. The development of a methodology for determining the ERL level in double-deck trains is the purpose of this article.

3. Results and discussion
The research of fires on passenger trains shows that the majority of people (78%) die due to high concentrations of smoke in the early stages of a fire [15].

A complex analysis of fires in railway transport made it possible to conclude that the main reasons were:

- malfunction of electrical equipment;
- careless handling of fire (including arson);
- malfunction of heating devices;
- various technical faults (traction motor, fuel line, exhaust tract);
- short circuit.

To estimate the ERL value in double-decker trains at the first stage, it is necessary to determine the frequency of fires. Statistical data on fires on railway transport in Russia for 2017-2020 are presented in Figure 2.

Figure 2. Statistics of fires in railway transport in Russia.
Despite a slight decrease in the number of fires, the indicators of economic damage remain high. So over the past 4 years, material damage from fires in Russia amounted to more than 110 million rubles. The algorithm of the analysis and evaluation of ERL in double-deck trains is shown in Figure 3.

**Figure 3.** The algorithm of the analysis and evaluation of ERL in double-deck trains.

The ERL ($R_{ERL}^N$) value is valid if the condition is met:

$$R_{ERL} \leq R_{ERL}^N,$$

($R_{ERL}^N$ is as regulatory value ERL (in Russia $R_{ERL}^N = 10^{-6}$)).

The ERL value should be equal to the maximum ERL value of all possible fire scenarios in a double-decker train:
5. About the level of fire decker trains is made, a method for estimating the ERL in double
which means that the time required for evacuation increases.

The ERL value for i-th fire scenario \( R_{ERL,i} \) in double-deck train can be calculated by the formula:

\[
R_{ERL,i} = \max \{ R_{ERL,1}, ..., R_{ERL,i}, ..., R_{ERL,N} \}, \tag{2}
\]

\( R_{ERL,i} \) is as ERL value for i-th fire scenario;
\( N \) is as number of possible fire scenarios.

\( Q_{f,i} \) is as the frequency of a fire on a train in a year, calculated on the basis of statistical data for the
past period (in Russia \( Q_{f,i} = 0.84 \cdot 10^{-4} \) for passenger trains);
\( K_{a,i} \) is as coefficient of compliance of automatic fire extinguishing installations with the requirements
of regulatory documents. Value of coefficient \( K_{a,i} = 0.9 \), if at least one of the following conditions is met:

- each railway carriage is equipped with an automatic fire extinguishing installation that meets the
requirements of fire safety regulations;
- equipment of the railway carriage with an automatic fire extinguishing installation is not required
in accordance with the requirements of regulatory documents on fire safety.

In other cases \( K_{a,i} = 0 \).

\( P_{i,i} \) is as the possibility of the people presence in the railway carriage;
\( P_{ev,i} \) is as possibility of people evacuation from the train in the i-th fire scenario;
\( K_{p,i} \) is as the coefficient of compliance of the fire protection system, aimed at ensuring the safe
evacuation of people in the event of a fire on a train, to the requirements of fire safety regulations.

To estimate the ERL value in the carriages of double-decker trains, it is necessary to investigate
several factors:

- the presence of ignition sources in the train;
- the amount of fire load;
- limitation of the possibility of evacuation, the presence of low-mobility groups of people on the
train.

Additional fire safety measures may be provided to ensure that the calculated ERL values for double-
decker trains are in line with the regulatory value. For example, each carriage may have additional
evacuation routes to reduce the time it takes to evacuate people from the train in the case of a fire.

4. Conclusion
High-speed double-decker trains are becoming an increasingly popular means of transport
infrastructure. The problem of assessing the level of ERL during fires in double-deck trains has not been
practically studied in the scientific literature. Double-decker trains carry more people than regular trains,
which means that the time required for evacuation increases. This increases the danger to life in an
emergency.

In this article the first step towards the study of the problem of ensuring the fire safety of double-
decker trains is made, a method for estimating the ERL in double-decker trains in case of fire is
proposed. The studies in this article are essential for the safety of rail transport. Modeling the evacuation
process and ERL assessment using the methodology discussed in the article can provide information
about the level of fire safety, substantiate decisions to improve the safety of railway transport.

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