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Methodology for Determining the Estimated Values of Dangerous Fire Factors in Double-Deck Passenger Cars

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Abstract

Currently, given the high demand for railway transport services both in the world and throughout the Russian Federation, scientists are increasingly paying attention to research in the field of fire safety of passenger cars of railway rolling stock. These studies are, on the one hand, very important, and on the other hand, very complicated, since they require the simultaneous involvement of researchers involved in the fields of transport, security, and engineering sciences.

The main goal that all research in the field of transport safety seeks to achieve is to reduce the risks of people's loss of life in combination with optimal organizational and economic conditions for the functioning of railway transport. In the event of emergency incidents associated with fires in passenger cars, it will take a considerable time to completely stop the train and rescue people, which can negatively affect railway traffic and create additional risks for railway service.

In the present scientific article, the main indicators that contribute to the rapid development of fire in double-deck cars are simulated based on the statistical analysis of models for predicting the fire development dynamics. The authors consider three models of free fire development, namely, integral, zone, and field. The results of the obtained data are justified and used as a basis for developing a method to determine the estimated values of dangerous fire factors, which allows calculating the time of the evacuation of people from double-deck cars.

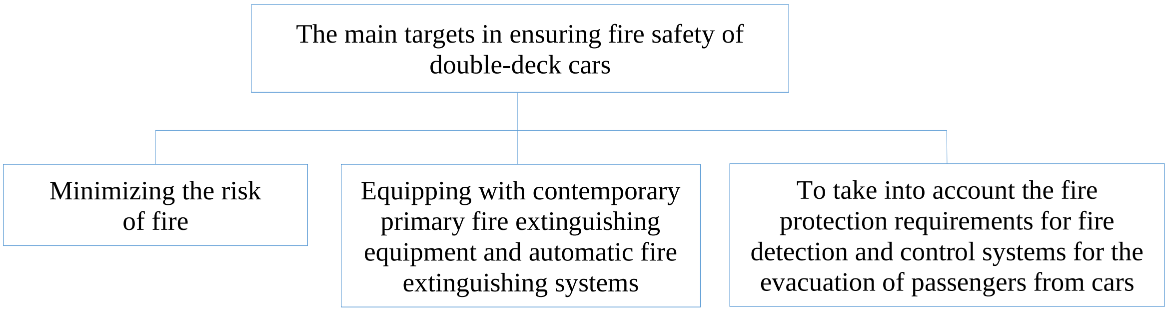
Key-words: Method of Determining Dangerous Fire Factors, Field Method, Fire Development, Dangerous Fire Factors Development Dynamics, Double-Deck Car.

1. Introduction

Monitoring compliance with fire safety requirements in new type double-deck passenger cars is crucial to ensure the safety of passengers [1].

The main tasks in ensuring fire safety of double-deck cars are presented in Fig. 1.

Figure 1. The main targets in ensuring fire safety of double-deck cars



Using some of the most popular software products (Firecat, Pyrosim, Pathfinder) will allow determining the estimated values of the dangerous fire factors (DFF) in double-deck cars [2] in various emergency incidents (EI) associated with fires [3]. Using software products for simulation, one can solve the main problems, namely, calculating the blocking of the escape routes as a result of the spread of the DFF. For fire modeling, several basic models are available, differing in the scope of application and the degree of detail of the process reproduction, namely, integral, zonal, and field models [3-5].

A mathematical model is a formalized description of a system in some abstract language, for example, in the form of a set of mathematical relations or an algorithm scheme, i.e., a mathematical description that provides an imitation of the operation of systems at a level sufficiently close to their real behavior obtained during field tests of these systems [6-7]. The model describes a real object, phenomenon, or process with a high accuracy approximation to reality. The type of mathematical model depends both on the nature of the real object and on the research objectives [8].

Using various mathematical models is more effective than performing experiments. Unfortunately, conducting full-scale tests on the DFF spread dynamics from double-deck cars, and the forced evacuation of passengers requires large economic costs, time, and also leads to the destruction of the cars used in the experiment. Moreover, a full-scale experiment is impossible in cases where people may suffer. The mathematical models developed to date [9] allow determining the DFF dynamics and the estimated time of blocking the escape routes [10, 11].

The purpose of the work is to develop a methodology for determining the estimated values of the DFF and the time of blocking evacuation routes in double-deck cars.

2. Methods

Fig. 2-5 describe in detail the existing models for predicting the fire dynamics in buildings and structures.

Figure 2. Characteristics of the integral model for predicting fire dynamics

Stage	Free development of fire
What allows	Evaluating the dynamics of the average volumetric values of DFF
Initial data	Dimensions of the room and openings, type and weight of the fire load
Advantages	Great simplicity, availability of analytical expressions
Disadvantiges	Limited accuracy and use of relatively small premises

Figure 3. Characteristics of the zone model for predicting fire dynamics

Stage	Free development of fire
What allows	To evaluate the dynamics of the DFF in the zones of the convective column, the smoke reservoir, and the rest of the space
Initial data	Dimensions of the room and openings, type and weight of the fire load
Advantages	Relative simplicity, availability of analytical expressions
Disadvantiges	Limited accuracy

Figure 4. Characteristics of the field model for predicting fire dynamics

Stage	Free development of fire
What allows	To evaluate the DFF dynamics at each point of the premises
Initial data	Dimensions of the room and openings, type and weight of the fire load
Advantages	High accuracy
Disadvantiges	The need for a special software and a trained programmer, the complexity in setting boundary conditions

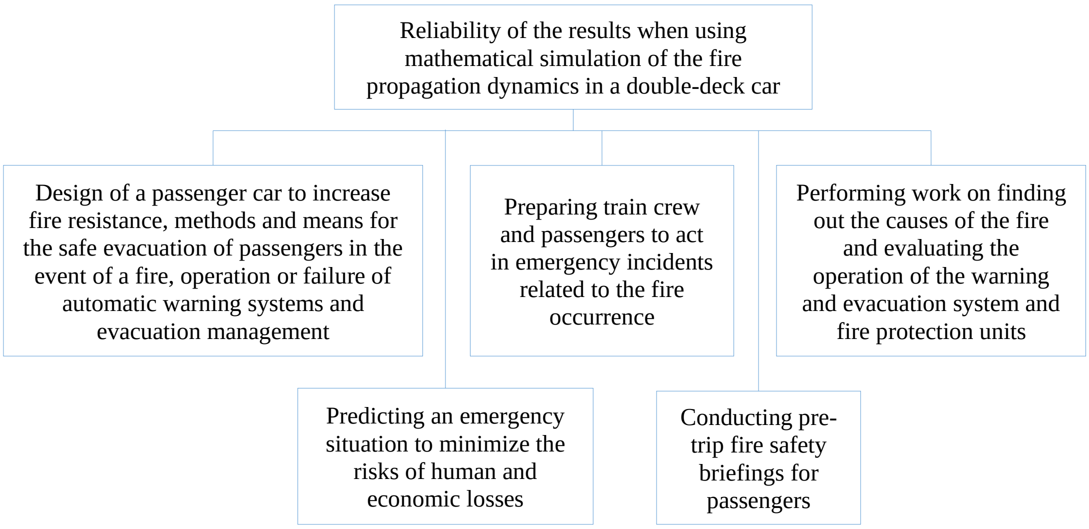
Figure 5. Characteristics of the fire-tactical model for predicting fire dynamics

Stage	Covers the entire period of the fire: from the beginning of the fire to the elimination of the fire
What allows	To assess the dynamics of the fire area, the extinguishing area, and the risk of destruction of structures from fire exposure; to determine the fire probability rank, as well as the sufficiency of the fire-fighting water line; to give an opinion on the involvement of the necessary fire protection forces and facilities, and recommendations of the manager of fire fighting operations and the facility administration
Initial data	Dimensions of buildings, structures, premises; categories by Departmental Fire Protection; limits of fire resistance of enclosing and supporting structures; type and location of fire load; general plan; water supply sources; electrical installations; technological process; extract from the schedule of fire and salvage unit emergency services
Advantages	Relative simplicity, clarity, availability of reference data and analytical expressions
Disadvantiges	Limited accuracy and consideration of just two DFF – fire area and fumigation area, subjectivism

In general, using mathematical simulation of the fire spread dynamics, and the impact of fire specifically on a double-deck car, as well as the behavior of people in the event of a fire, allows determining with greater accuracy the impact of the main DFF on people, and the time of blocking evacuation routes.

Fig. 6 shows the main parameters that were taken into account when mathematically simulating the fire propagation dynamics in a double-deck car.

Figure 6. Parameters for simulating the fire propagation dynamics in a double-deck car



According to the data analysis, currently, there is no methodological apparatus for determining the blocking time of double-deck railcars.

To use the developed model of a double-deck car when studying the DFF spread dynamics, as well as to determine the possible threat to passengers, it is necessary to consider the worst-case scenario of a fire and the corresponding simulation results.

The fire development dynamics based on an elevated temperature is determined by the formula:

$$t_{kr}^{T} = \left\{\frac{B}{A}\cdot\ln\left[1+\frac{70-t_0}{(273+t_0)\cdot z}\right]\right\}^{\frac{1}{n}} \tag{1}$$

The fire development dynamics based on loss of visibility in smoke is determined by the formula:

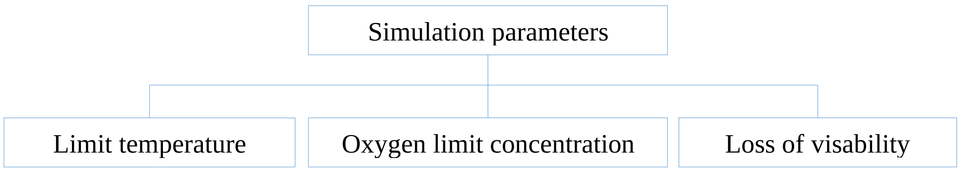
$$t_{kr}^{LV} = \left\{\frac{B}{A}\cdot\ln\left[1-\frac{V\cdot\ln(1{,}05\cdot\alpha\cdot E)}{l_{pr}\cdot B\cdot D_m\cdot z}\right]^{-1}\right\}^{\frac{1}{n}} \tag{2}$$

The fire development dynamics based on a reduced oxygen content is determined by the formula:

$$t_{kr}^{O_2} = \left\{\frac{B}{A}\cdot\ln\left[1-\frac{0{,}044}{\left(\frac{B\cdot L_{O_2}}{V}+0{,}27\right)\cdot z}\right]^{-1}\right\}^{\frac{1}{n}} \tag{3}$$

Layers (cross-sections) of temperature fields are recorded in the zones of burning and thermal impact. The estimated time taken as a basis when simulating these processes was 300 seconds. The simulation was carried out according to three main DFF parameters. The main simulation parameters are presented in Fig. 7.

Figure 7. Basic simulation parameters

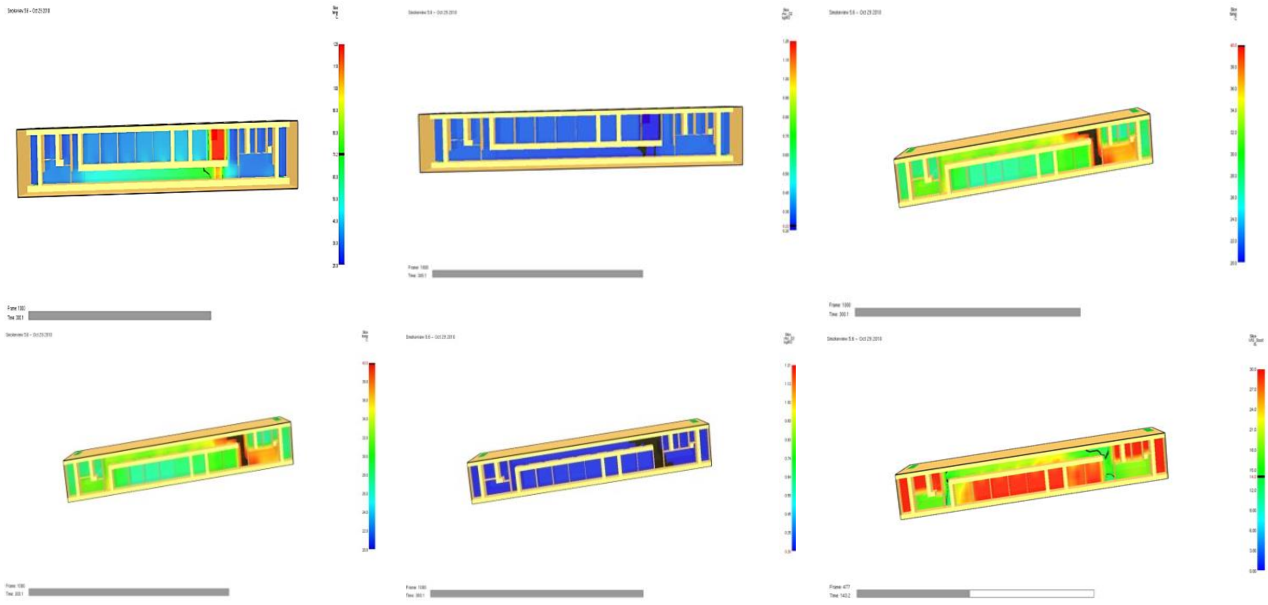


3. Results

The calculation was performed for the first and second decks of the railcar.

Fig. 8 clearly shows the results on the DFF spread dynamics on the first and second decks of a double-deck car.

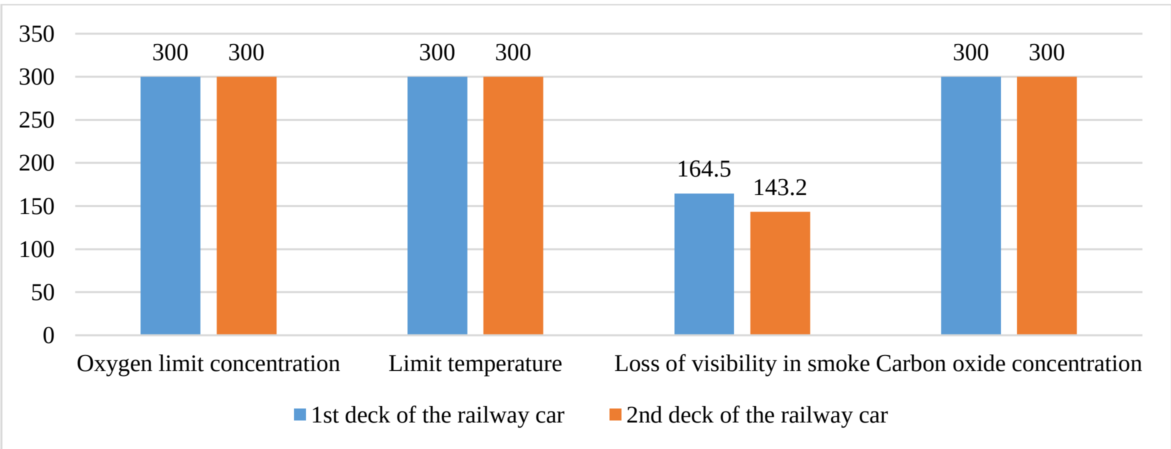
Figure 8. The DFF spread dynamics on the 2nd deck of the railway car according to the extreme temperature indicator



Fire hazards, according to the maximum permissible concentrations of CO_2, CO, and HCl, and heat flux do not reach the maximum permissible values but occur within a time exceeding the time of fire ignition (>300 seconds).

Fig. 9 shows data on the time of blocking the escape routes (at the level of 1.7 m from the floor mark).

Figure 9. Time of blocking the escape routes in the double-deck car



Thus, based on the DFF simulation for the 1st deck, the following can be stated: the indicator of the visibility loss shows that the smoke blocks the evacuation exits at 164.5 seconds, on the 2nd floor the evacuation exit is blocked at 143.2 seconds; the indicator of the oxygen limit concentration does not reach the maximum permissible values, the limit temperature does not reach the maximum permissible values during the simulation time > 300 seconds.

4. Conclusions

Summing up, one can draw the following conclusions:

- indicators of the DFF spread dynamics in double-deck cars allow solving problems of simulating and calculating the time of the evacuation of people from double-deck cars without using field experiments;
- simulation modeling provides an opportunity to consider a large number of alternatives, improve the quality of managerial decisions and the accuracy of forecasting indicators of the DFF spread dynamics;
- the obtained spread dynamics indicators allow solving the problems of predicting DFF and the time of the evacuation of people from double-deck cars.

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