FIRST INFORMATION ABOUT THE SRDA PROEJCT: EXPERIMENTAL INVESTIGATION AND COMPUTER MODELLING OF AIRFLOW DURING ROAD TUNNEL FIRE

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ABSTRACT: The paper deals with the first information about the project supported by the Slovak Research and Development Agency SRDA-24-0429 entitled "Experimental investigation and computer modelling of airflow during road tunnel fire". The project began in autumn 2025. Researchers from the Institute of Informatics of the Slovak Academy of Sciences and the University of Žilina are collaborating on the project. The researchers will primarily deal with the interaction of emergency ventilation, meteorological factors and fire in a real tunnel, with the aim of creating a series of computer simulations of fires in two highway tunnels. The simulations will be verified by in situ measurements. They will also deal with the recording and evaluation of emergency events in road tunnels within Slovakia. One of the project outputs will be the design and implementation of modifications to the Tunnel Traffic & Operation Simulator in accordance with current legislation, which will strengthen its uniqueness in the Central European area and improve its use for research and educational purposes. We believe that the implementation of the project will enable the intensification and efficiency of research cooperation between project researchers, the creation of a strong partnership between research organizations with significant recipients of project results, and the effective use of the modern research infrastructure of participating workplaces to create innovative solutions to increase road tunnel safety.

1. INTRODUCTION

The project SRDA-24-0429 entitled "Experimental investigation and computer modelling of airflow during road tunnel fire" (hereinafter referred to as "the project") essentially follows on from the previous project SRDA-15-0340 entitled "Models of formation and spread of fire to increase safety of road tunnels", which was successfully solved between 2016 and 2019. This previous project dealt with the modelling of complex fire-related processes using CFD technology, the creation of a series of computer simulations of fire scenarios in two road tunnels and the investigation of a suitable method of parallelizing the simulation calculation in order to achieve a significant acceleration of the calculation without a negative impact on the accuracy of the calculation. Another goal was to investigate the effect of fire ventilation on smoke stratification in the tunnel tube and the realization of experiments in two road tunnels in situ. Important outputs were also The visualizations of smoke stratification during a fire in the virtual tunnel of the Tunnel Traffic & Operation Simulator created by computer simulation based on CFD models were important and significate outputs. A significant contribution to the simulation of fires in medium-length road tunnels were, among other things, the findings on the role of dynamic pressure variability at the tunnel portals on the flow velocity and on the spread of smoke in the tunnel. This finding became one of the basic goals for the creation and submission of a new project.

2. PILLARS OF THE PROJECT FROM THE PREVIOUS PERIOD

For a clearer explanation of the continuity and connections of the projects we are presenting some selected pillars on which the new project is based. For example, the Tunnel Traffic & Operation Simulator as an important part of the project.

2.1 TUNNEL TRAFFIC & OPERATION SIMULATOR

The Tunnel Traffic & Operation Simulator (hereinafter referred to as "the simulator") s one of the outputs of a project focused on applied research into new technologies to increase the safety of road tunnel operations. Concretely, it is an output of the project entitled "Centre of Research in Traffic" with ITMS code 26220220135 funded from the Operational Program Research and Development 2009 under the measure 2.2 Transfer of knowledge and technologies acquired through research and development into practice.

The simulator (Fig. 1) represents the Central Control System (CRS) of a virtual two-tube highway tunnel 1 km long, complemented by a simulation of traffic in the tunnel. There are two large-area LED panels, on the display wall, which showing an overview of the status of the most important technological equipment in the tunnel from adjacent intersections. The monitors below them imaging a virtual simulation of traffic in both tunnel tubes. The operator can choose to view any camera from all 42 cameras, which provide a perfect overview of the virtual traffic in the tunnel.

Figure 1: Tunnel Traffic & Operation Simulator at University of Žilina

The simulator is designed for control by two operators and its essential part is also the workplace of the simulation coordinator (Fig. 2).

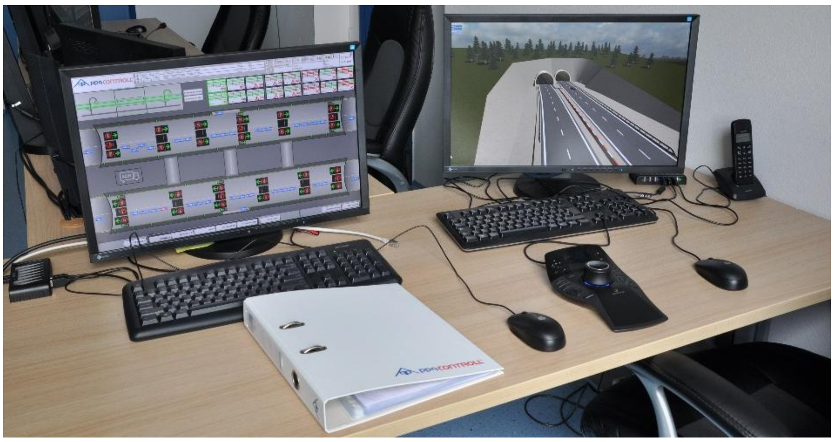

Figure 2: Workplace of simulation coordinator

From this position, the coordinator can initiate various simulations of emergency events (Fig. 3) in virtual tunnel traffic:

- a slow-moving vehicle that creates a column of vehicles in the tunnel tube,

- a stopped vehicle in the lane with the possibility of a subsequent traffic accident and fire,
- an animal (dog) in the tunnel with the possibility of a subsequent collision of the vehicle with the animal,
- a pedestrian in the tunnel with the possibility of a subsequent collision of the pedestrian with the vehicle,
- a stopped vehicle with ADR marking (a vehicle carrying dangerous goods) with the possibility of a subsequent leakage of a dangerous substance or a fire outbreak,
- a dropped object on the roadway with the possibility of a subsequent collision with the vehicle and/or a fire outbreak,
- a dropped object (barrel) and a chemical leakage,
- a demonstration of people in the tunnel,
- a threat of a terrorist attack,
- a vehicle in the opposite direction,
- an oversized vehicle blocking the entrance to the tunnel,
- a bus stopped in the lane and subsequent excessive movement of people in a tunnel,
- a traffic accident between two vehicles with the possibility of a subsequent fire outbreak.

Figure 3: Sample simulations of emergency events in the virtual tunnel of simulator

The coordinator's simulation capabilities are not limited to simulating extraordinary events in tunnel traffic, but allow to simulate various standard and non-standard phenomena, failures/malfunctions/losses of remote control of technological equipment, which can be influenced by the following changes:

- of physical values (opacity/visibility, CO levels, brightness, temperature, air flow velocity) with respect to current conditions,
- of traffic intensity (sporadic, normal, stop and go, traffic jams),
- of operational parameters (day, night, fog, smog),
- of video simulation development in the form of emergency and other calls (e.g. from the SOS cabin, with mechanics of tunnel maintenance, with branch of the integrated rescue system and other authorized persons),
- of the technological equipment status (malfunction or other error of cameras, sensors, traffic signs, power supply, etc.).

2.2 EXPERIMENTS IN SITU AND MEASURING DEVICES

Between 2017 and 2021, we managed to execute one network measurement of airflow in the Pol’ana tunnel during a simulated fire, three independent measurements of flow direction and velocity at the portals of the Poľana, Považský Chlmec and Ovčiarsko tunnels, and one measurement of airflow in the ventilation duct of the Branisko tunnel. The most extensive in situ experiment was the network measurement (Fig. 4) in the Poľana tunnel, in the tunnel with bidirectional traffic of approximately 900 m in length with a longitudinal ventilation system based on maintaining the maximum velocity (2.0 $m.s^{-1}$) of airflow in the tunnel during a fire.

Figure 4: Network measurement of airflow in Poľana tunnel

The experiment was focused on the monitoring/investigation of smoke stratification (cold smoke – aerosol, Fig. 5) and the influence of ventilation on stratification maintain and disruption. Disruption of smoke stratification was assumed (based on computer simulations) in the areas of emergency lay-bys, therefore we installed in these places two independent anemometers with potentiometric wind-vanes and three optical gates recording the occurrence of smoke at the level of the human respiratory system.

Figure 5: Experiment in situ (Poľana tunnel) with “cold smoke” – aerosol

The other mentioned independent measurements at the portals of the Poľana, Považský Chlmec and Ovčiarsko tunnels were focused on monitoring the influence of external climatic conditions on the airflow in the tunnel. Therefore, during selected ventilation tests, we placed an anemometer with potentiometric windvane at pre-specified locations (Fig. 6). Other climatic data were recorded by the weather stations of the relevant tunnels.

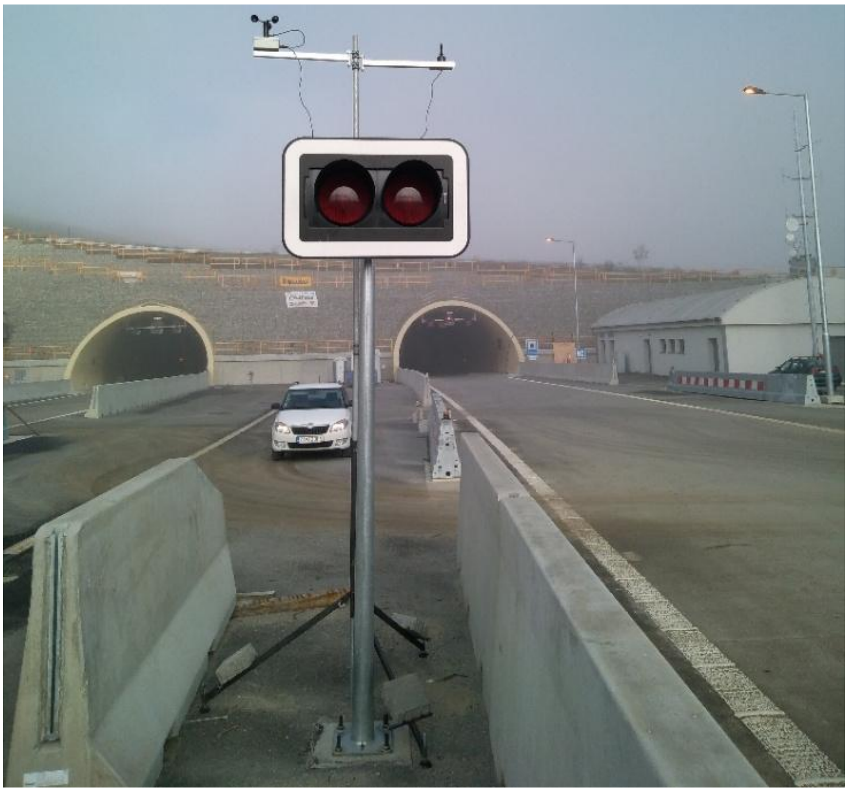

Figure 6: Anemometer with potentiometric wind-vane at the Ovčiarsko tunnel portal

No less important was the measurement of airflow in the ventilation duct of Branisko tunnel (Fig. 7), where we monitored the stability/decrease in airflow velocity during a fire with "cold smoke" as part of a tactical training of emergency rescue services and administrative authority.

Figure 7: Anemometer in the ventilation duct of Branisko tunnel

2.3 SMOKE SPREAD SIMULATIONS FOR THE VIRTUAL TUNNEL OF SIMULATOR

As part of the project, colleagues from The Institute of Informatics of the Slovak Academy of Sciences processed six simulations of smoke spread in three different locations of the tunnel. Two simulations were created for each location, the first of which was based on the principles of ventilation and smoke spread in the simulator's virtual tunnel, which uses a very simple algorithm for air flow in the tunnel. Each second simulation was based on new principles of tunnel ventilation coming out of the critical airflow velocity during a fire in a tunnel with bidirectional traffic. Five visualizations were created for each simulation (Fig. 8):

1. 3D visualization of smoke spread,
2. 2D visualization of temperature fields,
3. 2D visualization of velocity fields,
4. 2D visualization of visibility,
5. 2D visualization at the level of the human head.

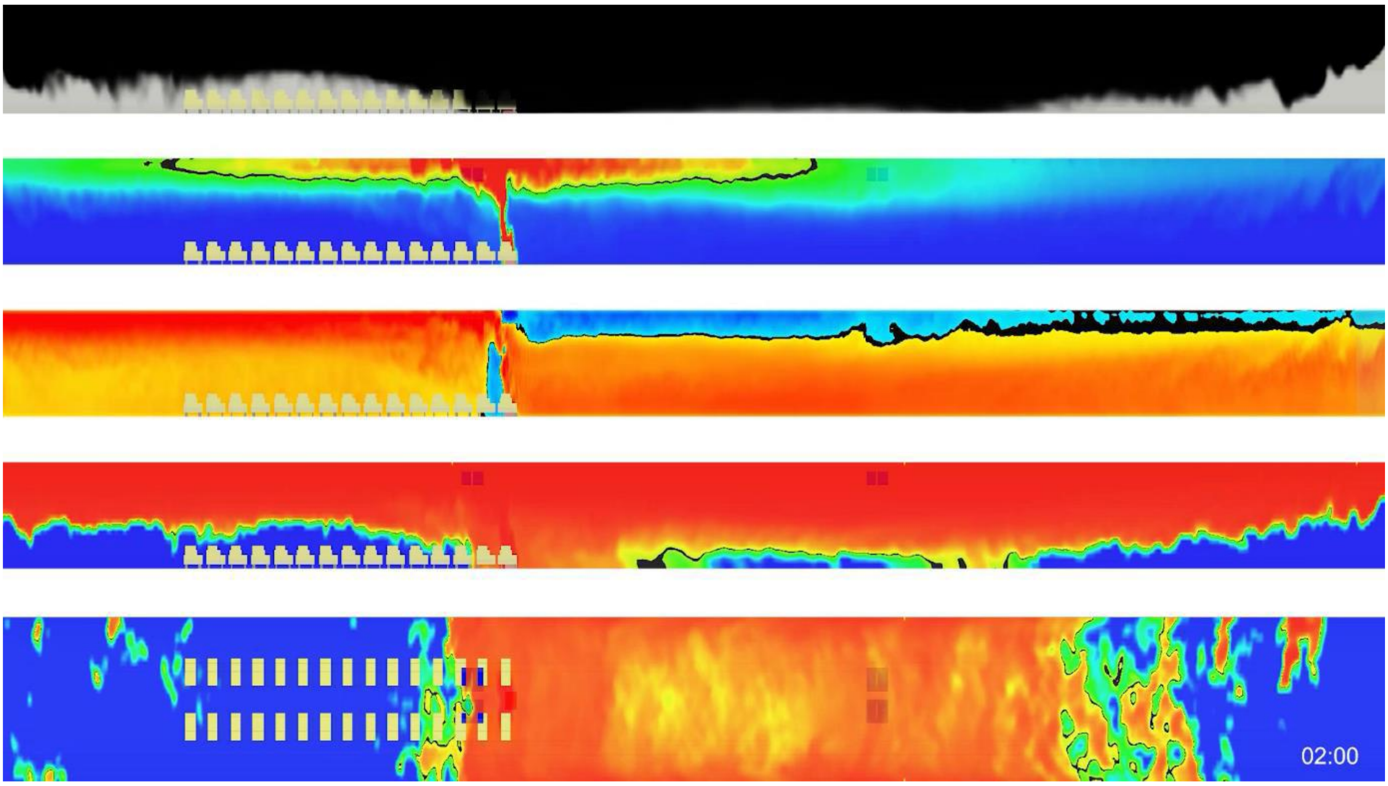

Figure 8: Visualizations of the smoke spread simulation in a fire with a critical ventilation rate under the first pair of fans of the virtual tunnel at the 120th second of the fire

3. FIRST INFORMATION ABOUT THE NEW PROJECT

The project SRDA-24-0429 "Experimental investigation and computer modeling of air flow during a fire in a road tunnel" is currently only at the beginning. The first negotiations between the project researchers and future recipients of the project results/outputs have taken place. The meetings were of a nature of planning, specification of requirements, preparation and testing of measuring devices, procurement of new necessary measuring instruments. Testing of measuring devices (anemometers and wind vanes) was carried out in a wind tunnel (Fig. 9) at the Department of Structural Mechanics and Applied Mathematics of the Faculty of Civil Engineering of the University of Žilina. The measured values were compared with a portable digital anemometer MASTECH MS6250. The test results were excellent. The measured values were comparable with an accurate portable digital anemometer.

Figure 9: Test of anemometers and potentiometric wind-vanes in wind tunnel

Then we used the measuring devices for an in situ experiment, which took place on December 1, 2025, during the smoke tests of the Višňové tunnel. We measured the speed and direction of the airflow at the tunnel portals as a potential influence on the air flow speed in the tunnel, and therefore the smoke spread. The measured values were sent for further processing. Unfortunately, currently we do not have other input data from the tunnel available and we are also currently unable to present any data, results and photos related to the Višňové tunnel due to GDPR.

However, the project goals are clear and we believe that we will be able to fulfill them through joint efforts:

- realization of in situ experiments in two highway tunnels with the aim of observing and monitoring the impact of emergency ventilation and meteorological factors on the airflow velocity and smoke spread in the tunnel,
- creation of computer simulations of tested scenarios (preparation of input data, parallelization design, creation of simulation on an HPC system, evaluation and visualization of simulation results and their validation using experimental data,
- modification/expansion of the simulator in accordance with the requirements of current legislation,
- evidence and evaluation of emergency events from Slovak tunnels,
- creation of visualizations of fire scenarios and their integration into the simulator.

4. CONCLUSION

Considering the long-term experience with experimental measurements, computer simulation and successful results of mutual cooperation of the project partners in the previous period, there is a strong assumption that the achievement of the set goals is realistic. It is expected that the project results will have a positive impact not only on solving serious problems related to tunnel fires, but also on fire prevention and on increasing the preparedness of tunnel operators, tunnel maintenance mechanics, firefighters and rescue workers involved in saving lives, values and property during an emergency situation, as well as on improving legislation.

5. ACKNOWLEDGEMENTS

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