Evacuation Simulation for Road Tunnels – Findings from the use of microscopic methodology for escape route analyses

K. Botschek[1], B. Kohl[1],and M. Steiner[2]

When designing complex buildings and tunnels featuring special characteristics, it is necessary to study the evacuation scenario in case of an incident in addition to the empirical figures gained from practice and expertise, in order to optimise the respective structures.

1. Evacuation Simulation for Bindermichl Tunnel

1.1. Enclosure and Lowering of A7 Motorway in the Bindermichl Area in Linz

The requirements set by the inner city location necessitated a complex design with a challenging arrangement of lanes and ascending and descending ramps inside the tunnel. The resulting, continuously changing tunnel cross-sections and the multitude of tunnel portals adversely affected the performance of the designed longitudinal ventilation system.
Every day up to 100,000 vehicles are using this motorway section.

Figure 1: System Sketch of Motorway Section

As the complexity of such a tunnel system can not fully be covered by the existing guidelines on safety installations, a detailed investigation of escape routes and escape times in case of a fire was performed.

[1]ILF Consulting Engineers
[2]Asfinag

1.2. General Project Data

The project comprises the following works:

- » Twin-tube motorway tunnel in the Bindermichl area with a length of 1,084 m
- » Twin-tube motorway enclosure in the Niedernhart area with a length of 508 m
- » Conversion of Muldenstrasse junction into a traffic circle with a total of 6 access and exit lanes entering and leaving the tunnel respectively

The northern part of the Bindermichl tunnel has a longitudinal gradient of approx. 4 %, while the ramps to the Muldenstrasse traffic circle have longitudinal gradients of up to 5 %. These considerable gradients create especially difficult ventilation conditions in case of a fire (chimney effect).
Due to the high traffic volume and the complex tunnel situation, the cross-passages and the emergency staircases are envisaged to be provided at maximum distances of 130 m (operation phase with one-way traffic), but during the construction phase (completion of the western tube), in which the eastern tube is operated in a two-way mode and the second tube has not yet been completed, the cross-passages may not yet be used as escape routes and the distance between the emergency exits comes to 500 m.

1.3. Decisive Simulation Elements

Simulation Software

The „buildingExodus V4.0" simulation software [1] is a valuable tool for a dynamic simulation of evacuation processes. It focuses on the computation and simulation of large streams of people in pre-defined geometric structures.

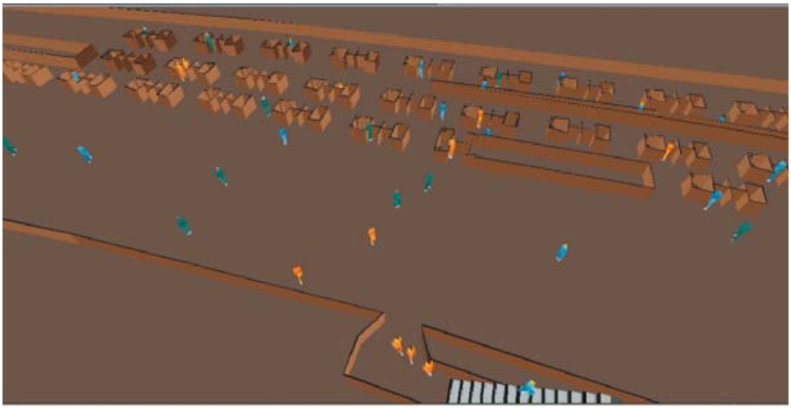

Figure 2: Tunnel users during evacuation simulation with buildingExodus

The following figure illustrates the individual process steps to be taken for an evacuation simulation:

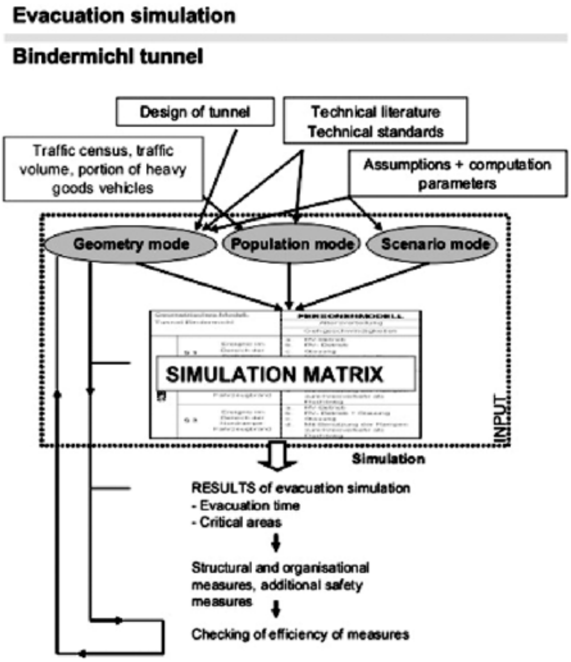

Figure 3: Simulation sequence and interaction of input data

Microscopic methodology

In order to calculate the evacuation time, the program covers the people-people, the people-structure and the people-environment interaction. For this computation, every person is seen as an individual, whose behaviour and movement is determined by heuristic rules. The respective rules are allocated to 5 different submodels (occupant, behaviour, movement, toxicity, hazard). These submodels work on the basis of a defined grid, which maps out the geometry of the structure under investigation. This uniform 2-dimensional grid is made up of nodes, to which individuals may be assigned. Between the nodes, arcs are defined, allowing individuals to travel from node to node. The movement trajectories of the individuals are largely determined by a potential map, which is developed depending on the distance to the nearest exit. Apart from the potential for the distance to the exit, additional attributes (type, concentration of smoke, etc.) are assigned to every node. These characteristics further influence the behaviour and movement of people seeking to escape a potentially hazardous situation.

Total evacuation time

The total evacuation time is determined by the following components:

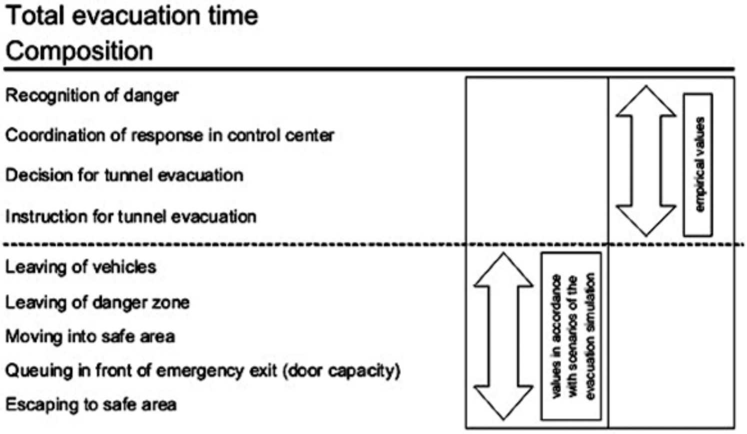

Figure 4: Simulation sequence and interaction of input data

1.4. Determination of Investigation Scenarios

The fire scenarios were designed in such a way that the event occurs immediately in front of one of the emergency exits, blocking this exit in question for tunnel evacuation and as a result creating a longer escape way.
In addition, several, rather adverse boundary conditions were chosen (peak traffic volume, high vehicle occupancy, reduced escape speed due to increased gradient, long detection time, long reaction time, etc.).

1.5. Consideration of Smoke Build-up

As, in case of a fire, smoke spreads inside the tunnel, the visibility is impaired as is the escape behaviour of the people heading to the emergency exits. The spreading of smoke leads to orientation and breathing problems. In the evacuation simulation these problems are considered by reducing the walking speed of the people seeking to escape the hazard scenario.

1.6. Sensitivity Analyses

Detailed Investigations for Construction Period

Numerous emergency exits will be leading into the adjacent tunnel tube, but are not available while constructing the Western tube from December 2004 to December 2005.

As a result, the spacing between the emergency exits increases to 506 m during construction. In the light of this scenario, investigations were performed to determine how the integration of operational facilities into a temporary escape route could help improve evacuation times.
Based on the simulation results, steps were taken to adjust the staircase in the operation centre in a way for it to be used as temporary emergency exit. This way, a tunnel evacuation within an adequate period of time will also be possible during construction.

Detailed Investigations for Western Tube

The Austrian design guidelines for ventilation systems in tunnels stipulate that in case of a fire the existing air flow of the ventilation system may not be changed. In the case of the western tube of the Bindermichl Tunnel, which is operated in a one-way mode, this stipulation leads to a longitudinal air flow in a southerly direction. Yet as a result of the unfavourable conditions encountered (longitudinal gradient, open ramps. meteorology, location of fire, etc.), this requirement can in some cases not be met. A strong thermal buoyancy may induce the smoke to change direction after a certain time, sweeping over the vehicles behind the source of fire.
It was the task of the evacuation simulation to investigate, whether the emergency exit situation in the western tube created conditions offering enough time to evacuate the tunnel before smoke would spread over the vehicles trapped inside the tunnel.

1.7. Findings

Despite the great variety of unfavourable assumptions, which are unlikely to occur in this combination, an evacuation of the tunnel in the required period of time is still possible.
The details of this computation allow significant conclusions to be drawn for the following tunnel design components:

» Decisive escape routes and escape route elements
» Additional safety measures
» Temporary escape route design during construction
» Impact of unfavourable boundary conditions on evacuation time
» Interfaces to alarm and rescue planning

2. General Applicability of Evacuation Simulation for Risk Analyses for Road Tunnels

In general there is a wide field of application for evacuation simulations in road tunnels; a simulation model may for example be used to assess the extent of damage in the framework of quantitative risk analyses. A risk is calculated considering the occurrence frequency of events of damage and the resulting extent of damage. As the extent of damage incurred by infrequent events, like a major vehicle fire, can not be assessed based upon statistics, the evacuation simulation is used to evaluate the extent of damage caused by effects of fire in varying tunnel configurations. The use of an evacuation simulation in combination with a ventilation model, which allows the development of the fire and the spreading of the smoke to be simulated in an integrated model, makes it possible to represent the time factor, which is of such significance for the rescue chances. With the help of the evacuation simulation model, the impact of heat, smoke and toxic gas can be considered with respect to both the speed of movement and the toxic effects exerted on individual persons [1]. For the modelling of various types of tunnels, the following influencing factors can be brought into play:

- » Size of fire
- » Spacing of emergency exits
- » Traffic volume
- » Type of ventilation
- » Traffic routing (one way or two-way tunnel)

By determining the evacuation times, the impact of toxic gas on individual persons can be concluded and as a result the extent of damage for defined scenarios may be assessed.

This method may be used for a good relative comparison and – if further data are added – it may also be applied for an absolute evaluation.

In order to develop a sufficiently accurate model, which illustrates the concentration and spreading of smoke inside a tunnel, a detailed ventilation computation, which considers the parameters which are of relevance for the flow patterns inside a tunnel, is to be performed. «

References

1. E.R. Galea, S. Gwynne, P.J. Lawrence, L. Filippidis, D. Blackshields: *buildingEXODUS, User Guide and Technical Manual*, Fire Safety Engineering Group, University of Greenwich, London (2004).