

## EXPERIENCES ON THE SPECIFICATION OF ALGORITHMS FOR FIRE AND SMOKE CONTROL IN ROAD TUNNELS

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### ABSTRACT

The main objective of ventilation systems in case of fire is the reduction of the possible consequences by achieving the best possible conditions for the evacuation of the users and the intervention of the emergency services. The required immediate transition, from normal to emergency functioning of the ventilation equipments, is being strengthened by the use of automatic and semi-automatic control systems, what reduces the response times through the help to the operators, and the use of pre-defined strategies. A further step consists on the use of closed-loop algorithms, which takes into account not only the initial conditions but their development (air velocity, traffic situation, etc), optimizing smoke control capacity.

*Key Words: Ventilation, fire safety, smoke control.*

### 1. INTRODUCTION

The transposition of the European Directive 2004/54/CE (1) to the Spanish regulation was finalized with the publication, in 2006, of the RD 635/2006 (2) on minimum safety requirements for road tunnels. One of the key aspects included in these two regulations is the necessity, in most of the tunnels, of automatic ventilation control systems, both in normal operation and fire case.

The main requirements to be achieved by the use of control systems are the reduction in the response time for ventilation activation and the implementation of predefined strategies both for manual and automatic response of fire safety facilities.

However, when trying to establish the criteria for the specification of predefined ventilation strategies, various aspects must be taken into account which depends on the type of ventilation system and traffic operation conditions previous to the incident development. Even, in some cases, an appropriate management of fire incidents requires complex multi-step strategies that must be predefined and implemented in the control systems.

### 2. BACKGROUND

During the last decades, a great amount of resources have employed for the study and development of ventilation control systems during normal operation, which included the use of closed loop algorithms and fuzzy logic for the optimization and improvement of the efficiency (CETU, ref. 3). However, during the last years, the reduction of the emission levels of the vehicles is reducing the efforts involved in the development of new technologies and methods for the control of the ventilation during normal operation.

On the opposite, ventilation control in case of fire is becoming of the utmost importance. Going to the past, the PIARC report on "Fire and Smoke control in Road tunnels" (ref. 4) in 1999 already reflected the importance, and lack of unique rules, on the use of active control systems for the operation of ventilation.

From then, several national guidelines have included recommendations on the operation of ventilation systems in incident cases: Austria (RVS 09.03.31) (ref. 5), Germany (RABT) (ref. 6), France (Circulaire Interministérielle 20-63 dated 20th August 2000) (ref. 7) or Switzerland (FEDRO) (ref. 8). One common aspect to all of these references is the distinction between the self evacuation phase and the fire fighting phase, and the importance of the longitudinal control of the air velocity in the tunnel, with no dependence on the type of mechanical ventilation system installed, to achieve the desired goals for smoke control.

Taking into account these criteria, different contributions can be found in the literature in what concern to practical application of automatic control system use in road tunnels: Pospisil et al (ref. 9), Wehner et al (ref. 10), Stroppa (ref. 11) or Bettelini et al. (ref. 12).

With the intention of describing some practical experiences in Spain, in the following, the authors describe in detail the criteria and algorithms developed and implemented for the automatic control of ventilation in road tunnels. It is important to note that the criteria and tools are mainly focused on the evacuation phase, even if some considerations are made on the general approach.

In addition, some results from the evaluation tests are presented as far as the authors consider that the whole process: design, implementation, test and adjustment is crucial to evaluate the reasonable performance of ventilation control system.

### 3. VENTILATION STRATEGIES IN CASE OF FIRE

Ventilation strategies to be used in case of fire are usually dependant to the operational configuration (unidirectional or bidirectional traffic) and the traffic conditions (free flow or standstill).

In case of tunnels with unidirectional traffic without congestion, a “high” velocity longitudinal ventilation strategy is the one most widely adopted, which consists in the generation of a longitudinal air flow in the vicinity of the fire, in the sense of the traffic flow, enough to avoid the back layering of the smoke.



Figure 1: Ventilation strategy for unidirectional free flow traffic

In case of unidirectional tubes with traffic congestion, a two-stages longitudinal ventilation strategy is commonly recommended which would consist in the generation of a “low” velocity longitudinal air flow until the vehicles stopped downstream the fire has left the tunnel. In a second stage, a “high” velocity longitudinal strategy would be desirable as far as no vehicles, or users, should be situated in the route invaded by the smoke (portal, intermediate exhaust point, etc).

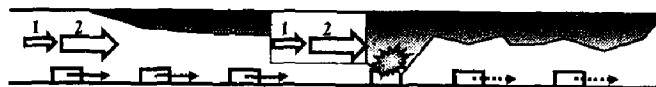


Figure 2: Two stages longitudinal strategy for unidirectional congested traffic

For bidirectional tunnels the two strategies explained before are not longer valid, as far as there will probably be vehicles at both sides of the fire location, what would recommend to adopt ventilation strategies focused on maintaining so long as possible the stratification conditions of the smoke, what is favored by the smoke extraction (if possible), the switch off of the fans that can cause turbulence, and the reduction of the air velocity inside the tunnel.



Figure 3: Stratification strategy for bidirectional traffic

#### 4. CHALLENGES FOR DESIGN OF VENTILATION CONTROL SYSTEMS

Consequently, it is of the outmost importance to handle the quick transition from normal operation to the emergency mode, which includes from the point of view of the ventilation system, the following steps:

1. Normal operation
2. Automatic incident detection
3. Ventilation safety response
4. Location and validation of the fire
5. Predefined ventilation response plan
6. Follow-up and correction (if necessary)
7. Emergency service strategy
8. Return to normal operation

All these stages must be implemented in accordance to the general emergency response plans so, coherence between the different equipments activation can be guaranteed.

However, when accomplishing the design phase, even if all the steps are clearly defined into specifications documents, some practical details must be taking into account to reduce the incidence of mistakes. It has been considered interesting to describe some of them:

- Reception of multiple automatic alarms: once an incident occurs, the great amount of alarms that are received from the different equipments installed in the tunnel can interfere in the activities of the operator. For example, in the case of the AID (Automatic Incident Detection) system, the queue formation upwind the traffic stop point generates multiple alarms in areas far from the fire situation.
- Excessive demand of information from the operator: when designing the interface human-computer application, the excessive request of information must be avoided and, if totally necessary, priority criteria must be established.
- User failure protection: even if sometimes it is not possible to guarantee that the actions taken by the operator are correct, a great amount of mistakes can be avoided without complex means (for example, the use of 'double confirmation' messages for fire alarm cancellation as are used in standard applications)
- Exhaustive and permanent training: as far as, fortunately, fire situations are not common during the operation of the tunnel, it is necessary that the operators can receive permanent training in the management of the application, general concepts, expected behavior, practical cases, etc. In some tunnels, very good experiences are being obtained with the use of training 'simulators', where the use of the graphic interface screens for fire situation can be used reducing the 'surprise' of the operator to new situations.

It is important to note that the development of these applications require clear criteria, detailed specifications, considerable implementation efforts and rigorous test procedures, what in practice means time and economic provisions to be considered.

#### 5. PRACTICAL EXAMPLES

The tunnel of study has two independent unidirectional traffic tubes of about 2000 meters length. The proximity of an urban area produces a highly unbalanced traffic distribution what causes standstills in the morning and evening commuting times.

The ventilation system is longitudinal with jet fans uniformly distributed through the tunnel, although according to the new Spanish regulation in the close future the tunnel will be refurbished and the ventilation system modified.

For the detection phase, an automatic algorithm has been implemented which consider (through a weighting procedure) the signal coming from different types of sensors (fire detectors, quick changes in the measures of CO and turbidity sensors or alarms generated by the DAI) to propose the operator a “most probable fire location”. The result of the algorithm is to provide him, for each section a detection index, ranging from 0 (no alarms) to 100 (all alarms).

Depending on the detection index value for any of the sections, different predefined procedures can be activated (pre-alarm mode), i.e. stop of the ventilation in both tubes to avoid the de-stratification of the smoke during the early stages, starting of a pre-defined number of jets, etc.

In addition, a closed loop air velocity control algorithm has been implemented with the objective of maintaining the control on the longitudinal air flow what should facilitate the users evacuation.

The two main parameters taken into account by the algorithm are the air velocity inside the tunnel and the target air velocity. For the case study presented, the air velocity in the fire location is calculated as the average of the values given at every instant by some representative anemometers (not all the installed anemometers should be used because some of their measures can be influenced by the jet fans flow or the smoke layer around the fire).

The implemented algorithm follows a predictive - corrective logic, based on the average air velocity in the tunnel and the trend shown during the control intervals. Both magnitudes are evaluated at the end of each control periods by a linear adjustment to try to avoid the random temporal fluctuations (see red line in the decision figure). The algorithm estimates the value of the velocity expected ( $V_{est}$ ) to occur at the end of the time interval and the slope of the linear regression curve ( $m$ ).

Finally, from the values obtained for the control variables, the decision on the number of jet fans to be connected is taken based on pre-programmed charts with predetermine actuations (see next table) which depends on the velocity estimated comparison to the reference interval and the sign of the slope of the linear regression ( $m$ ).

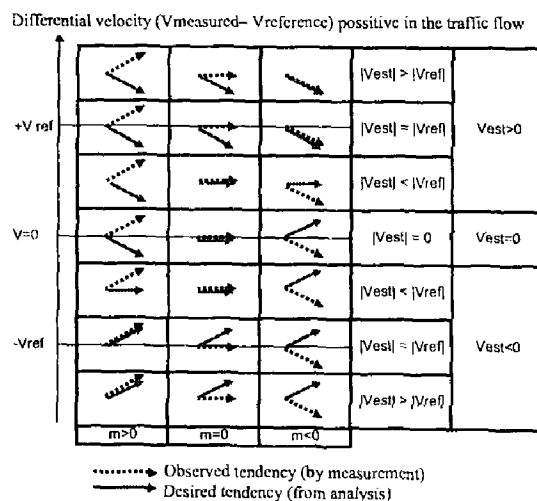


Figure 4: Scheme of the close-loop logic applied

An additional tool has been implemented in the control system to evaluate the traffic conditions in the downstream area based on the information gained from the AID system. Due to the reduced reliability of the information provided by the cameras in case of fire, it was decided that this system only provides a proposal to the operator about the traffic situation during the emergency which is responsible to modify the reference velocity for the activation of the automatic control system.

## 6. CONCLUSIONS

The research on ventilation control methodologies and algorithms, for application into road tunnels, is focusing more and more on fire situation instead of normal operation. This fact is being reflected in the national and international regulations and guidelines.

However additional research and development efforts seem to be necessary to improve the design, specification, implementation and testing of ventilation control systems.

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