How to operate safely a tunnel: 
Definition of Minimum Operating Requirements

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ABSTRACT

Road tunnels are becoming more and more complex to operate, due to important increase of safety provisions in new or renewed tunnels in recent years: installation of Automatic Incident Detection systems based on video analysis, installation of complex ventilation systems operated with support of wind velocity measurements from anemometers, etc.

A state-of-the-art tunnel is assumed to be operated safely when all equipments / organisation is functioning as expected. However, what if:

• a breakdown/failure is observed on a given equipment: jet fan, terminal computer for supervision, emergency telephone(s), power supply(ies), etc.;
• an unexpected event occurs in organisation for maintenance, supervision or intervention in case of an emergency: an operator for supervision is missing, etc.

This paper presents reflections and practical experience in addressing the following question: under what conditions a given tunnel can be considered as safely operated?

KEYWORDS: tunnel safety, operation, failure of equipment, minimum operating requirements

OBJECTIVE

The Directive 2004/54/EC of the European Parliament and the Council of 29 April 2004 [1] specifies that the administrative authority is authorized "to suspend or restrict the operation of a tunnel if safety requirements are not met".

The French circular 2000-63 of August 25th 2000 [2] requestes a document describing "the cases of unavailability of equipments or operating staff in which the tunnel must be closed in the traffic because the safety of the users is not assured in a sufficient way" to be created.

The part 5 of the guide of the safety rapports of the CETU entitled "The Plan of Intervention and Safety (PIS)" [3] dedicates a chapter to the description of the Minimum Operating Requirements (MOR) and to their purpose.

The objective of the MOR is to define, for every technical and human means, thresholds of acceptable dysfunctions or not for the operation of the tunnel in safety. Every threshold of dysfunction justifies the implementation of compensatory measures of operation (when they exist) to maintain an acceptable level of safety of the tunnel, or the partial or total closure of the tunnel.
The definition of compensatory measures is not systematic, because it does not exist there inevitably of relevant to implement. Furthermore, the redundancy of certain equipments or the management of degraded modes (in the logic of ventilation in particular) can be such as it is not necessary to plan of additional compensatory measure.

METHODOLOGY

To reach the objective, the used methodology is based on the following 3 main elements:

- the situations of operation of the tunnel;
- the functions of safety to be satisfied and the technical and human means implemented to assure these functions;
- the dreaded failures of the technical and human means occurring in the functions of safety.

To the three incomes above, is also added the consideration of the regulations in force. The consideration of the regulations allows, indeed, for certain technical and human means, to define additional constraints on the operation.

The operation of a tunnel requires to assure certain number of functions of safety to limit the probability of case of the incidents and limit their consequences. The fact that one of it is not any more insured (or what it can be assured only in a way degraded in certain cases) has to lead to a preventive closure of the tunnel or to an adoption of particular measures of operation (compensatory measures), when it is possible or relevant.

The total or partial dysfunction of an equipment can lead to degrade, even to lose totally, a function of safety. Several equipments are redounded, one or several times, to assure a high availability of all the installations of the system. The degradation or the loss of a function will be in fact obtained only after dysfunction of a set of redundant equipments. Therefore, the conditions of closure are not generally affected on a simple loss of redundant.

Besides equipments, it is also advisable to consider the possible dysfunctions of the operation. It is also looked for in the elaboration of the MOR, if particular situations of traffic in the tunnel (i.e. ban on the heavy goods vehicles, the alternated traffic) exist, for which the conditions of closure (partial or total) are more quickly affected than in case of normal traffic.

Finally, it is to note that accidental situations bound to the traffic in the tunnel can require a closure of one or the both tubes. All these situations are defined in the Intervention and Safety Plan and the orders of operation.
The following figure schematizes the MOR elaboration methodology:

**Figure 1  MOR elaboration methodology**

**TECHNICAL AND HUMAN MEANS FAILURES DEFINITION**

The dysfunctions are mainly functional failure (loss of efficiency or performance of equipment). The detail of the possible technical failures of equipments allowing to end in the identified functional failure is not looked for.

For every technical and human means participating in the realization of the functions, several levels are identified:

- The nominal functioning of the means.
- The functioning in mode helped by the means. This state corresponds to a total availability of a system in spite of the failure of one of its redounded means.
- The failures of one or several equipments / human means according to several levels which correspond to intermediate states between the helped state and the loss of the level of performance pulling the closure of the tunnel.
  
  When a means is in a failure level, its function is not any more performed in the nominal. When it is necessary, and acceptable, compensatory measures are identified.
- The failure, alone or coupled with the failure of an other one equipment / human means leading to the closure of the tunnel (partial or total).

The gravity of a failure on the safety level of the tunnel depends on operating parameters, that is to say on situations in which is the tunnel.
The same function of safety is assured by several means. It is necessary to consider the fact that, if the individual loss of a given means does not lead inevitably to the closure of the tunnel, the loss combined of two or more of these means can lead to the achievement of the conditions of closure. The failures of several means are determined from the crossed matrix between the functions and the means by looking for, for every function, of failures' combinations which can lead to the closure of the tunnel.

**LINK WITH THE MAINTENANCE**

As soon as a means is not any more in its nominal state, an action of corrective maintenance is realized. The MOR approach allows to determine the emergency degrees of the actions of maintenances according to the impact of the dysfunction on the operation. An equipment's failure that leads to the closure of the tunnel (or imply an operation very degraded of the tunnel) must be fixed very quickly. On the other hand, a failure which will not degrade the operation of the tunnel (because of the redundancy of equipments or of the degraded modes integrated into their logic of functioning) can be fixed less quickly.

Furthermore, the equipments for which the failures can lead to the closure of the tunnel must be maintained in a regular and optimized way. This maintenance must limit the probability of case of achievement of the conditions of closure on failure.

**CONCLUSION**

The MOR's elaboration of a tunnel is based on a work of failures' analysis of the technical and human means of the tunnel.

The MOR's analysis is formalized in a document which is to evolving during the operation of the tunnel, during the modifications of the technical installations and in case of evolution of the organization. The operator is in charge of the update.

To be easily exploitable by the persons who operate the tunnel everyday, all the failures identified in the compensatory analysis and the associated measures (management of the degraded modes and the conditions of closure of the tunnel) must be resumed in a didactic document form, for example: "card reflex ", interactive document, etc.

**REFERENCES**

