A SYSTEMATIC APROACH TO THE SUPERVISION OF ROAD NETWORKS AND ITS APPLICATION TO TUNNEL VENTILATION

Pierre Schneider, République et Canton de Neuchâtel, CH-2208 Les Hauts-Geneveys
Rune Brandt, HBI Haerter Ltd, Consulting engineers, Tunnel Ventilation, CH-8002 Zurich
Alain Gilibert, Cegelec Entreprise Centre Est, F-01703 St Maurice de Beynost

ABSTRACT

Electromechanical equipment becomes increasingly advanced in order to cater for as many operational scenarios as possible. In the present paper, the functionality of the elements is specified using a scenario approach that incorporates a hierarchy of the actions to be taken.

The theory is applied to the control of the ventilation system that is generally assumed to be fully automatic. Nevertheless during an emergency, the operator must be able to modify a ventilation strategy, in which case the automatic system must ensure that the level of safety is not being compromised due to such actions.

Two examples of the ventilation of road tunnels with bi-directional traffic (Tunnel de la Vue-des-Alpes) and unidirectional traffic (Tunnel de Gorgier) illustrate the strength of the proposed approach. Both tunnels are equipped with axial smoke-extraction fans, remote controlled smoke-extraction dampers and jet fans. Furthermore, the location and quality of the measurements of the tunnel air quality and its velocity play key roles in the detailed control plans. Also the automatic alarming of the emergency services and tunnel closures depend on the reliability of the measurement in order to minimise the drawbacks of false alarms.

1 THEORY

1.1 The necessity of structuring the monitoring system for a road network

In the last few years, the conception of road network supervision has generally been the domain of integrators and is based on the management of equipment in the electromagnetic domain (signals, ventilation, lighting, etc.). This approach meets production requirements, as well as those for the physical breakdown of the system, but does not satisfy the normal operating conditions for such a network. Moreover, there are no standard regulatory documents giving a satisfactory solution to this problem.

The objective was to operate and maintain in a centralised manner a dense, mainly urban and fairly local network that includes numerous elements of work. Consequently, the Highways Department of Canton Neuchâtel ('Service des ponts et chausses du Canton de Neuchâtel') felt the need to develop new ideas for the supervisory system. This requirement is a result of the wish to provide simple warning tools, rapidly supplying useful information, available to the operators so that they can deal with any event.

Many factors have an influence on the security of a road network, for example:
- Its level of equipment and the intelligence of command and control procedures implemented
- The maintenance and upkeep of equipment of ever-increasing complex design
- The human factor of users and operators notably during critical events.

Therefore, the structure of such a system and its man-machine interface (MMI) play a major role in the management of a road network. An automatic response in real-time is only possible when operators are capable of verifying the automatic process. Furthermore, they must be in the position to take rapid decisions in order to adapt the system's response to the particular situation in hand. Hence, the conception of the supervisory system must meet following three objectives:
- Automatic responds to variations in the incoming data (auto-pilot)
- Inform the operator of the system status in order to verify its functioning
- Authorise complete take-over by the operator (manual control).

It is also important to realise that, in general, a road network supervision system is confronted with two types of distinct events:
- Firstly, alerts i.e. a warning due to a perturbation in the system
- Secondly, failures or malfunctions in the equipment itself.

It should be noted that the first type of event (alert) is part of system operation, whilst the second (fault) falls under the maintenance and upkeep of the system components. In Canton Neuchâtel automatic plausibility tests are in place, in order to detect faulty instruments. Furthermore when the quality of a measurement is vital to the operation, another plausibility test of the accuracy of the measurement is conducted prior to using the measurement for the dedicated routine. This applies e.g. to flow measurements when they are used in order to control the longitudinal velocity during a fire. Nevertheless to limit the scope of this paper, the remaining text deals exclusively with the first type of event.

To satisfy the objectives required, a new supervisory system structure and the development of an innovative MMI was developed. Their principal characteristics and initial practical applications are outlined in the chapters that follow.

1.2 **The notion of trip devices (measurements), strategies and scenarios**

Within the structure proposed, all controlling events are managed by means of a functional breakdown, involving three fundamental notions:
- The strategy; defined as the art of co-ordinating actions and skilfully responding in order to achieve an objective
- The scenario or plan; corresponding to the programmed implementation of a response to an action
- The trigger or measurement; a quantitative value - serving as the basic unit of evaluation.

These notions are organised into a system and their interaction are locked together, as shown in Figure 1

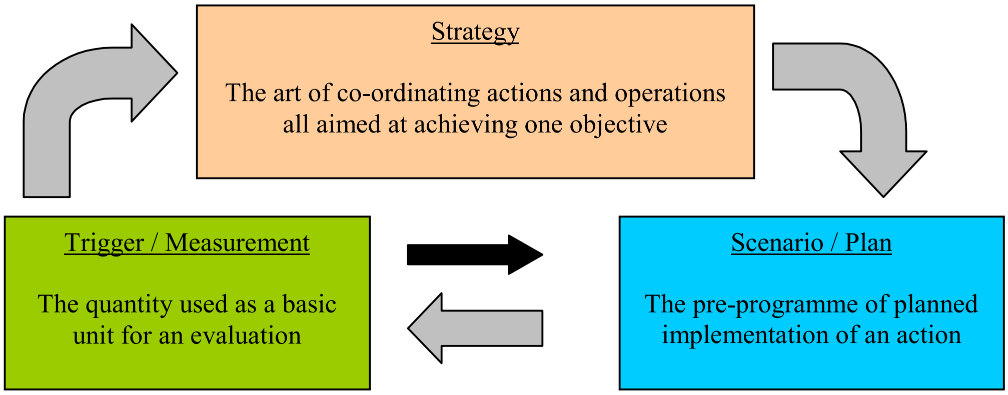

Figure 1: Fundamental notions

The system's functions obey the following rules:

- Generically speaking, each measurement has four thresholds (very low, low, high and very high). Once these thresholds are set for readings taken by the various security sensors (e.g. smoke or heat detectors), the exceeding of one of the extreme thresholds (i.e. “very high”) will trip an alarm;
- Once the alarm has been confirmed (automatically or by the operator), a corresponding strategy is applied. As more than one trigger may be set off, the strategies are classified in order of priority and a management system decides upon the strategy to implement;
- As a result of readings of measurements taken inside the tunnel, a scenario (or plan) is implemented by transmitting orders to various actuators. If the situation changes, a change in the plan can be implemented during the event itself, whilst the active strategy remains the same.
- The implementation of a strategy and corresponding scenarios (or plans) is aimed at returning the reading having tripped an alarm to a level below its critical level. Then the system is enabled to implement a new, lower-priority strategy. The strategy with the lowest priority is normal (incident-free) operating conditions.

The system control loops fulfil the systematic principles by enabling it to adapt to variations in external parameters and thereby return the system to a stable condition i.e. the normal and incident-free operating conditions.

1.3 System hierarchy

The supervision of a road network presupposes that the complete system runs under a coherent architecture. All functional aspects are treated according to the same philosophy without exceptions.

The system architecture used for the Canton of Neuchâtel is shown in Figure 2.

This architecture includes the notions of strategies, scenarios and plans that are covered by one single 'strategic' unit. This unit is an elementary building block of the system. It must be capable of functioning autonomously also with absence of information and orders from superior units. The superior units are responsible for functions covering several closely located strategic units (operational assembly), or even the whole network.

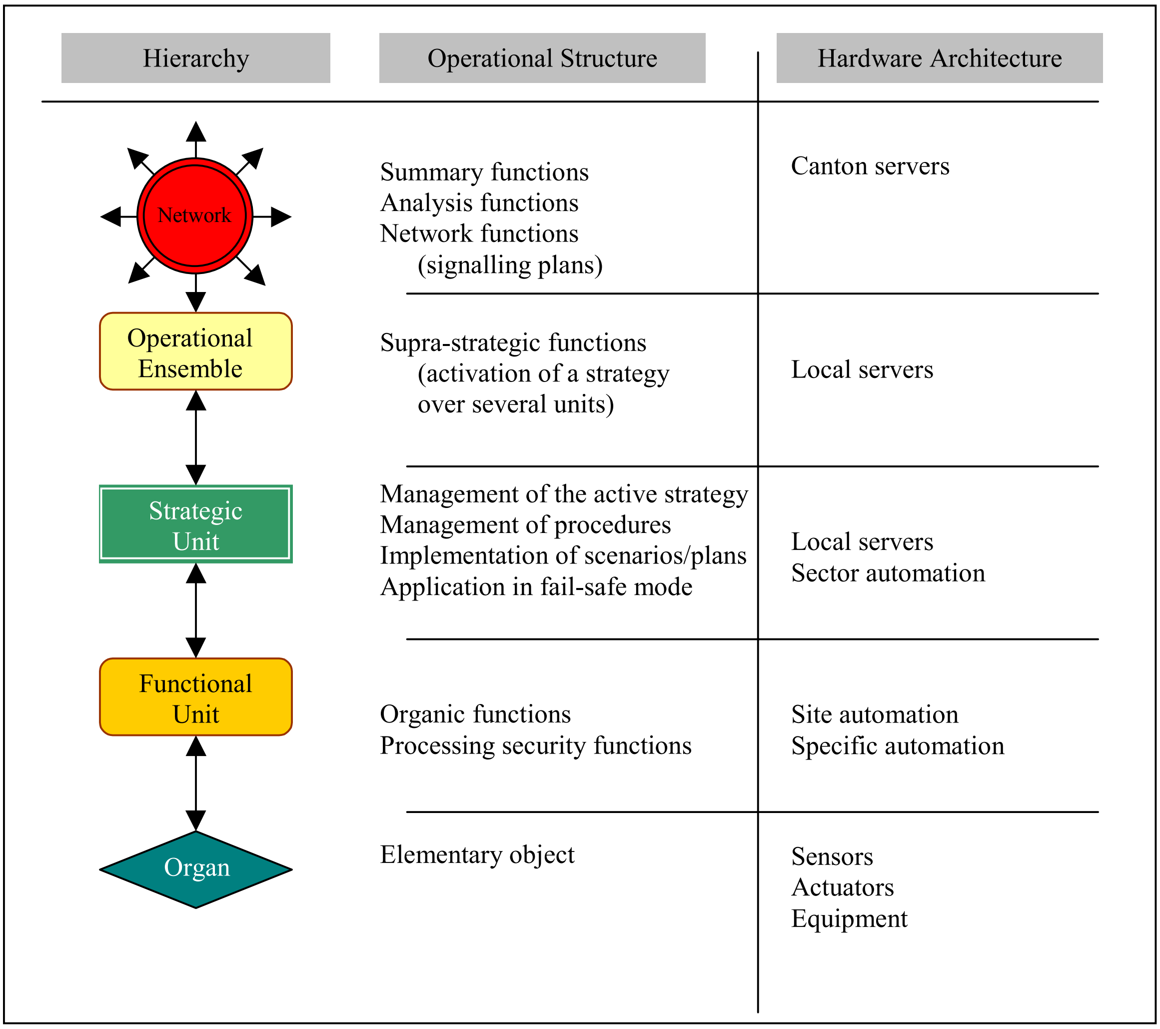

Figure 2: System architecture

2 PRACTICAL APPLICATION TO THE TUNNEL VENTILATION

2.1 Pollution or fire in a tunnel

Between 1999 and 2001, the Canton of Neuchâtel has completely renovated the ventilation systems installed in the Vue-des-Alpes tunnel. This operation, which was completed in stages, notably had an effect on hardware, by:

- The replacing the slots within the exhaust ducts by remotely controlled dampers that are situated every 50 metres in the false ceiling over the entire length of the tunnels
- The removal of the partition that separated the exhaust duct in the middle. This enabled smoke extraction from both portals concurrently
- The installation of eight air-jet fans with a rated shaft power of 12.4 kW inside the traffic space

Nevertheless, the principal innovation remains the updating of the supervisory system (SCADA) for new equipment and their associated functions. Events affecting the ventilation installations were organised according to the theoretical framework listed above. More importantly, the strategies and their priorities were elaborated, see Figure 3.

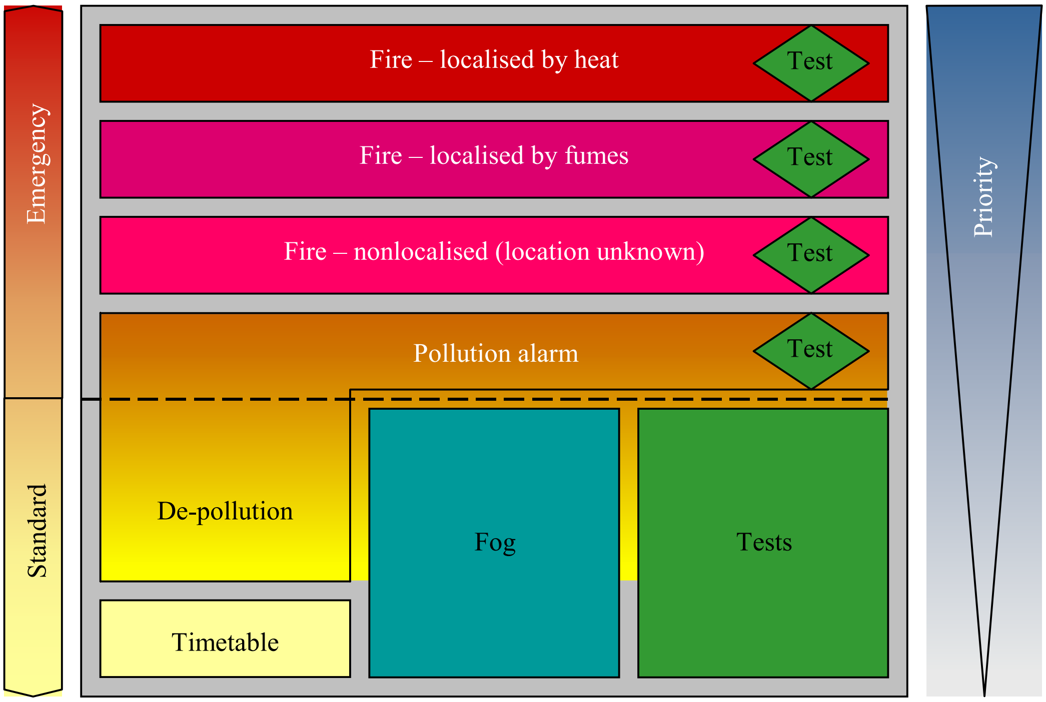

Figure 3: Pollution and Fire strategies

An initial division separates the strategies into two main categories:

- Those corresponding to normal (standard) operations, for which the equipment is protected by suitable hardware security measures
- Those known as emergencies, for which another treatment of the hardware security measures is implemented in order to avoid system close down due to false alarms.

Normally the lowest level of strategy (timetable) leads to the application of a ventilation scenario that operates according to fixed timetables during hours with peak traffic. Nevertheless, if preset thresholds of opacity or CO are superseded, another strategy (known as de-pollution) is activated. This strategy contains several progressive scenarios according to pre-defined levels of pollution. Consequently, this is another example of regulation using thresholds.

During normal operating condition, the operator can decide to replace the automatically implemented strategy by an anti-fog strategy or with a test strategy analysing the effect of a new scenario. The anti-fog strategy contains several scenarios depending on the location of the fog: positions inside the tunnel, outside one portal or outside both portals.

The first (lowest) emergency level is applied when a critical pollution level is detected within the tunnel. Concurrent with the application of a ventilation scenario, which depends on the location of the pollution peak, a plan aimed at closing down the tunnel is offered to the operator.

The three highest priority emergency strategies concern the dangers of fire. Their activation is solely dependant on the detail (quality) of information received with respect to the location of the fire:

- If neither the operator nor the system itself is in the position to determine the location of the fire, the non-localised fire strategy is activated. This strategy involves a scenario, where all the smoke fire dampers are slightly opened.
- If the fire has been localised by its smoke using the opacity-meters or video surveillance devices, the strategy implemented opens the fire dampers over a 600 metre long zone that is centred the position of the measurement that triggered the event.
- Finally, when the heat produced by the fire triggers the linear heat sensor, the strategy is to reduce the length of the zone with smoke extraction to 300 metres that is centred at the detected heat point.

The system automatically switches to a strategy with a higher priority as soon as the higher quality information is available. For the two scenarios with highest priority, the scenario depends on the location of the fire. Furthermore, for these two strategies, the air velocity at the location of the fire is automatically balanced to zero using a particular control routine for the jet fans, see Figure 4.

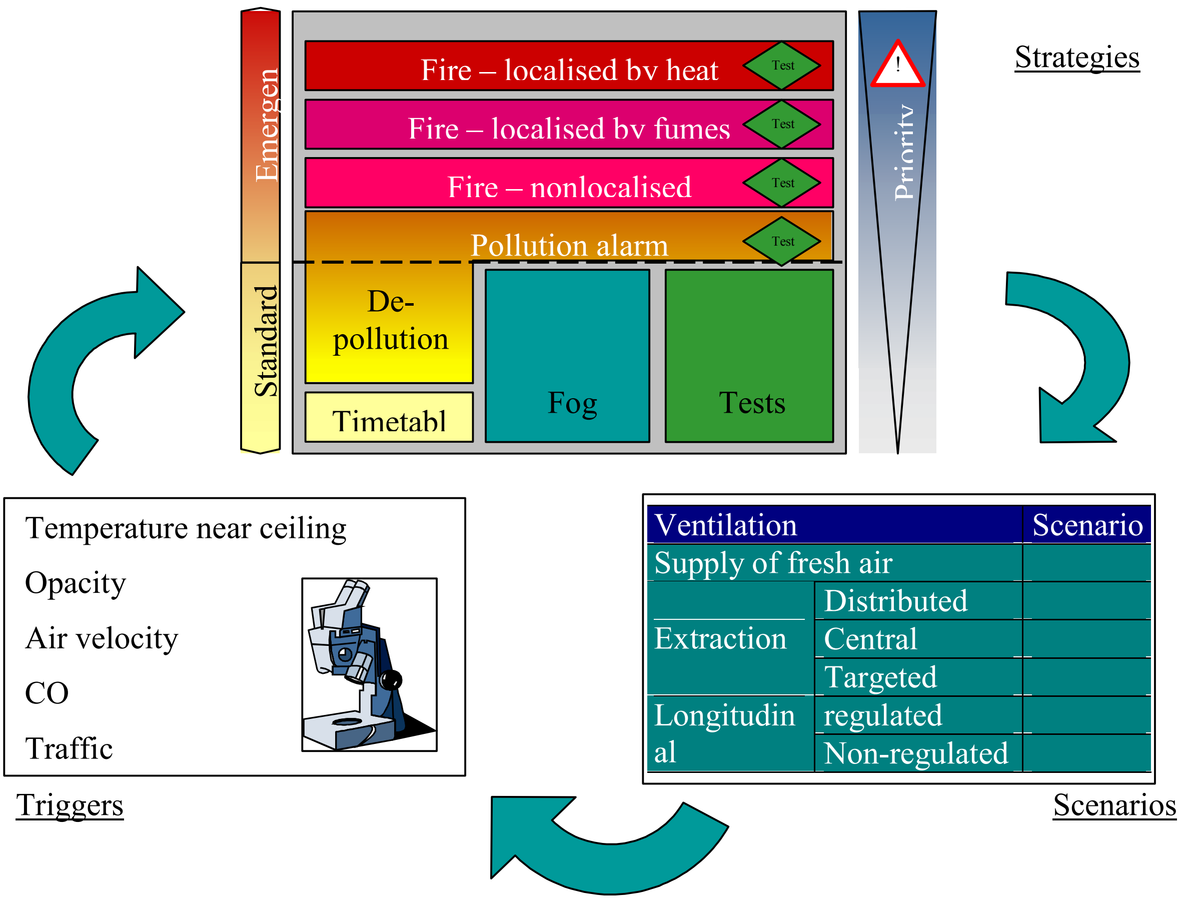

Figure 4: Triggers, strategies and scenarios

2.2 Treatment of the equipment monitoring

For normal operation, the fans are generally protected by hardware monitors. These devices are based on internal or external sensors and their readings are processes by dedicated automated equipment (PLC). The hardware monitors conduct e.g.:

- measurements of the temperature of bearings and windings of the motors,
- measurement of fan vibrations,
- detection of jet fan detachment.

The previously stated distinction between strategy types (standard or emergency) enables a differentiation to be made between the treatments of various data from the hardware monitors. Thus in the event of an emergency, it is important that:

- the fans run to the limits of their capacity (i.e. an equipment sacrifice philosophy),
- a machine is not stopped due to deceptive or non-existent faults.

In the Vue-des-Alpes and Gorgier tunnels, this differentiation guarantees the operator that all possible means are being implemented in order to match the seriousness of an event. Only the actual detachment of a jet fan cuts its power supply and renders it inoperable.

2.3 The logic of the man-machine interface (MMI)

The man-machine interface (MMI) should not only correspond to the structure laid out in the preceding chapters but also enable rapid and efficient management of an incident identified by an alarm. As required, the operator must be in the position to intervene in the automated procedures, either by interrupting them (e.g. by false alarms), or to correct them if there is no efficient scenario set up for the trigger(s).

With these objectives in mind, the principles implemented for the Canton of Neuchâtel are as follows:

- The MMI is shown using three screens, see Figure 5. The right-hand screen is dedicated to alarms, the two others are used to present the operator with all the information and commands required in order to control the event with which he is faced;

Figure 5: Man-machine interface (MMI)

- The operator's principal tool is the list of alarms, see Figure 6. It enables to:
  - be aware of an event, and then automatically to obtain further information and useful commands using the two other screens,
  - confirm the procedure associated with an event, involving automated responses of equipment such as road signs, lighting and video surveillance,
  - cancel a procedure in the event of a false alarm.

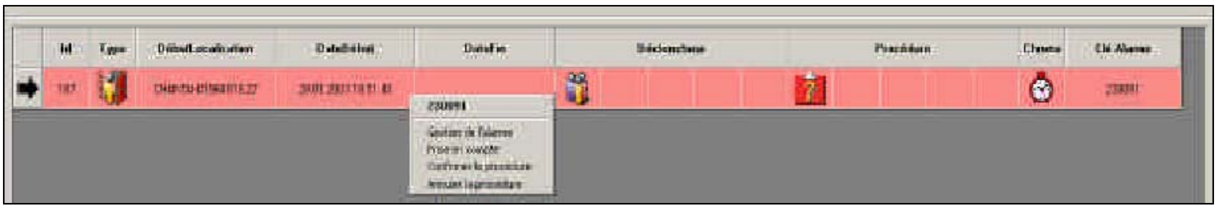

Figure 6: List of alarms

- The presentation of information and access to the various commands should be characterised by an ergonomic and user-friendly interface. These goals are difficult to achieve as there are no particular rules specifying the graphical presentation and the methodology to be used for the control of a road network.

The efficiency of a MMI is demonstrated by how it withstands critical situations and emergencies. At such moments, the operator is under extreme operating conditions. Therefore, he must have access to a tool which allows him to concentrate on the event itself and actions to be implemented, and not on how he should manipulate the tool itself to get the information that he needs.

2.4 Equipment tests

With the aim of ensuring that these theories are correct and have provided value for money in their implementation, the Canton of Neuchâtel has concluded that full-scale testing is the only viable method to confirm the procedures that are implemented and to determine any corrections to be made, see figure 7.

During traffic, a preliminary test level enables to verify the relationships between trigger, strategy and scenario. Among the functions perceived by the user (e.g. signalling and lighting), the procedures are implemented in their entirety. The objective of these tests is firstly to maintain the level of training of the operators and secondly to periodically verify the operation of the equipment. In this case, the fans remain protected by their monitoring equipment (see chapter 2.2).

A second level of tests consists of periodic exercises involving the emergency services and operators by simulating a major incident such as fires, leakage of hazardous materials, serious road traffic accidents, etc.

Figure 7: Fire test

3 CONCLUSIONS

The evolution of the safety of a road network, and in particular that of sensitive sites, is inevitably linked to the systematic comprehension of the phenomena involved. This methodology goes beyond the traditional approach, which divides the problem into electro-mechanical domains (such as ventilation, lighting or signalling). It involves new notions, event triggers, strategies and scenarios, all operating within a regulation system.

This new approach does not necessarily lead to the systematic increase in the level of equipment nor to enhanced complexity. It is rather an improved organisation of the processes involved, as well as the product of a well thought-out architecture, co-ordinating hardware and functions. Earlier Man-Machine Interfaces (MMI) showed plenty of scope for improvement. MMI has top priority in order to perform the integral systematic analysis. Its development is, however, occasionally hindered by the lack of specialists in this field and the absence of governing rules common to operators.

The Canton of Neuchâtel has demonstrated the potential of the presented systematic approach based on strategies, scenarios and triggers. It opens the way to numerous developments in order to meet current and future demands. Furthermore, the systematic approach to the management of a road network suggests the idea of a product that is divided into standardised functions and elementary strategy units.

The future challenge is to assemble operators that wish to participate in this new approach. The aim is to concentrate resources, accelerate developments and in the very near future to obtain equipment and tools that will cater for future challenges.