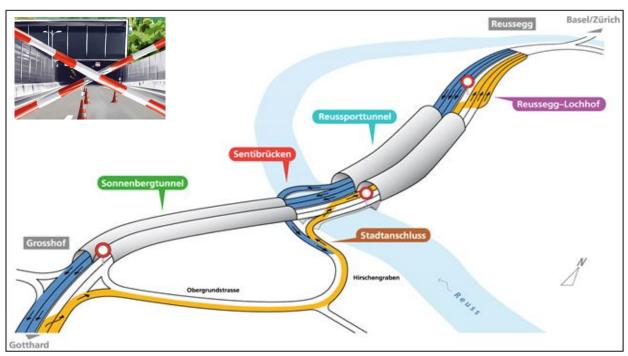# An innovative monitoring system for safe work and traffic management during tunnel renovation works

1.   Introduction

Nowadays in Europe many road tunnels have to be upgraded to comply with present technical and safety requirements concerning both structures and E&M equipment. The large amount of traffic poses in many cases a major challenge, because there are not any redundancies in the road network. Hence, the extensive tunnel renovation and renewal works have to be carried out during the nights and on some weekends, in order to minimize delays to traffic. The construction sites are installed every day in the evening and cleared up in the following morning.

Nightly traffic routing scheme example

If in the morning, after a whole working night, some E&M equipment, which is classified as "safety relevant", is not functional, the tunnel(s) could not be opened in time and the entire traffic must flow through secondary roads or through city centres.
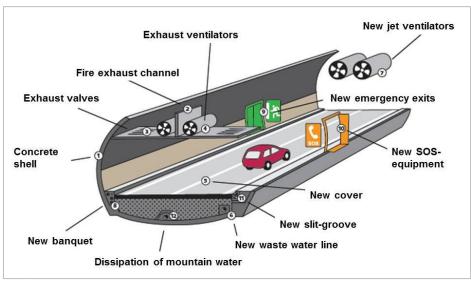In order to avoid potential traffic collapse caused by such events, a unique control system, called MonSys (Monitoring System), has been developed by Lombardi for
- planning the works and shifts in advance, including fine tuning in real time
- monitoring and controlling the progress of works at different construction sites
- tunnel closing and opening processes
- ensuring safety of workers and travellers during the renovation works

The main objective of the MonSys is to monitor all renovation and renewal works in real time and identify critical situations as early as possible. To our best knowledge, such monitoring system had never been implemented before. Thus, the development and implementation of such system was in many ways a pioneer work.

2. The Challenge

Most of the road tunnels in Western Europe were built in the 70s-80s. Heavy traffic has left its mark and the tunnels fail to fulfil the modern safety standards. Therefore they must be fully renovated and the operations and safety equipment have to be updated with the latest standards and technology.

Renewal examples of civil works and E&M equipment

In extensive renovation projects, many different stakeholders are involved and a large number of workers operates at the construction sites in shifts. This means that during the construction phase not always the same person is responsible and responsive. Hence, planning and coordination of works and workers must be done very precisely. During the renovation works, some E&M devices are working in a mixed way, i.e. with old, provisional and new devices and components. This fact alone makes safety and availability of the equipment extremely complex and error-prone.
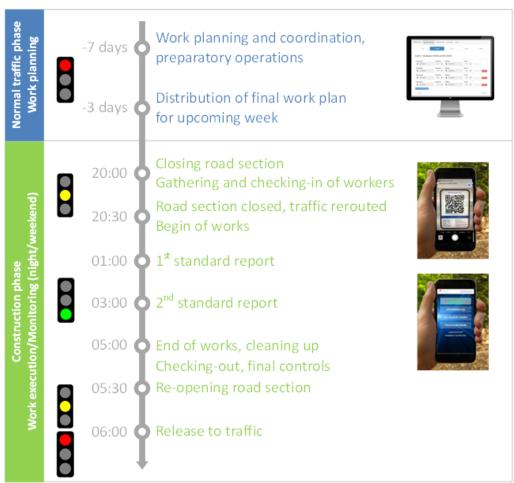
If a piece of equipment classified as "safety relevant" is no longer working in the following morning (or it does not reach a minimum level of availability), the tunnels could not be opened in time, so that the entire traffic flow must remain rerouted through secondary roads, cities or towns. This would lead to a complete collapse of the traffic in urban areas.

Since the safety of the construction workers as well as the safe opening of the tunnels for the traffic every morning are essential, a control system (MonSys) has been developed to collect information concerning both current status and forecast of the morning status for every main construction work and E&M equipment all over the construction sites throughout the night. This information allows the project management to make the decision whether the tunnels can be safely opened to the traffic in the morning.

3. Monitoring System (MonSys)

3.1 Standard Workflow

The standard workflow is cyclic as shown in the following flow chart.

Standard process flow chart: work planning and execution

3.2 Process "Work Planning"

The first step of the monitoring process is the work planning, which extends from an overall scheduling of activities and participants to the precise tuning of works and manpower, to be completed at the latest one week before the particular night closure. The data to be planned includes traffic routing schemes, closing times and durations, on-duty site supervisors, safety officers, etc.

All contractors involved in the project have to plan their works and workers (where, when, how long, what, who) a week in advance through a user-friendly online form in the MonSys. As soon as the work plan is filled out and submitted, MonSys send to the applicant an email containing all information provided and the authorization code for accessing the construction site at the required day/night.
Based on the work plans provided by all contractors, the site supervision coordinates all work schedules, optimizes the processes, avoids any inconsistencies or conflicts and make a fine tuning.
All these data are stored into MonSys and are thus available 24/7 for managing the entire monitoring process.
Specific reports – such as weekly plans and road traffic routing schemes – are printed out for the police and the street maintenance team, and are made available in tunnel operation rooms and assembly points as a backup.

3.3   Process "Work Execution/Monitoring"

During every work closure (night or weekend), the following workflow is repeated:

- 20:00-20:30: rerouting of traffic and closing
  Street maintenance team barricades the road section to the traffic.

- 20:00-20:30: check-in
  Workers and site supervisors gather at predefined time. Every team leader check in all his co-workers at the MonSys check-points

- at 20:30: start of works
  Street maintenance team has closed the road section and announces via MonSys the begin of works.

- at 01:00 and at 03:00: standard reports
  Every contractor team leader is reminded via SMS to enter into MonSys their "standard reports", i.e. a short report about both the current progress of his work and the prediction of the final status before the road reopening in the morning. A specific user-friendly smartphone application has been developed for this purpose.

- 05:00-05:30: end of works
  Works are finished and all construction sites are cleaning up from material and machines.

- at 05:30 (at the latest): check-out
  Every team leader checks out all his co-workers at the MonSys check-points

- 05:30-06:00: reopening to traffic
  If no abnormal situation has been stated in MonSys and every workflow step has been successfully completed, the section can be released to traffic at 06:00.

3.4   Standard and Spontaneous Reports

A standard report is required from the team leader of every main equipment and includes both the current status as well as a forecast of the final status before road reopening. For each report the team leader can select one of the following options:

🟩	**Normal status**	Everything is running normally
🟨	**Tolerable status**	Equipment has small, minor defects
🟧	**Undesirable status**	Equipment has defects, not affecting safety. Corrective actions are needed.
🟥	**Intolerable status**	Tunnel/sub-section cannot be opened for traffic because the safety is no longer guaranteed

The MonSys collects all reports from all team leaders of all construction sites all along the night and determines the worst case scenario, displaying the overall system color, from green to red. This information allows the project management to make the decision whether the tunnels can be safely opened to the traffic in the morning.
In case of an abnormal situation, i.e. when the overall system color is orange or red, the site supervisors in coordination with the safety officers take all the appropriate actions according to a predefined safety procedure.

In addition to the standard reports, a "spontaneous report" can be sent at any time through the MonSys application. The spontaneous report is used for changing at any time a system status or a prediction, or to generally share information, e.g. when the works have finished earlier than planned. Incidents and information can also be registered into the MonSys event log by calling the Alarm center at any time. MonSys automatically forwards the gathered information via SMS to the project management and safety officers. Others can access the information every time online and in real time.

Rigorous checks and alerts are moreover provided by the MonSys, in order to avoid human errors and machine failures and hence ensure a faultless and successful workflow.

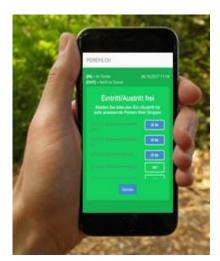## 3.5 Access Control (Check-In/Check-Out)

In order to manage the access of the people to the tunnel, the "Check-Points MonSys" are available in the main access locations. A check-point is a simple LED light box, which displays a poster with a QR-Code and further useful information for access control.

At the beginning and at the end of the works every worker or team has to announce their presence/departure by scanning the QR-Code with the scanner provided in the MonSys App. The MonSys will then verify according to the work plans whether or not the worker/team is enabled to access the tunnel and provide its feedback on the smartphone display. Unauthorized people cannot access the tunnel.

Example of a Check-Point MonSys at a tunnel portal

Example of simple check-in process for accessing the tunnel: scan of QR-Code with own smartphone (left) and confirmation which member of the team wants to enter/leave (right)

The MonSys updates in real-time the number and the list of all the people in the tunnel, including their contact details. The aim is to *"always know who is in the tunnel at all times"*.
Furthermore, a log of all entries and exits with check-in / check-out time is available.

In case of an emergency the blue light organisations (police, firemen, ambulance, …) can easily identify through the MonSys, who is still in the tunnel, so as to simplify the evacuation procedure. All the people can also be informed by SMS or by phone about an alarm or evacuation through the MonSys.

3.6 MonSys Technologies

MonSys communicates through internet using secure traffic encryption and electronic certificates (https). As standard web technologies are used, MonSys can be accessed from anywhere.

MonSys can be used by multiple users and on any client devices, such as PC's with large displays (e.g. for the work planning in offices or for printing specific outputs), laptops or tablets (e.g. for safety representatives and project managers when assessing the monitoring status) and smartphones (e.g. for contractors and site supervisors to be used at the construction sites).

MonSys application available for any devices

3.7 Other features: Control of Traffic Lights and Alarm System

MonSys can also be connected to both traffic signalisation and alarm devices at construction sites, in order to control them remotely and/or automatically.

Concerning traffic signalisation, during normal traffic in daytime, the MonSys cockpit as well as the physical traffic lights are set to red. During traffic rerouting process they are both set to yellow. During the construction and maintenance work they are both set to green, which indicates that the construction sites can be accessed safely by the workers.

MonSys can also be connected to the alarm system at the construction site (inside and outside the tunnel). Once ready, an authorised person can set off or disable a visual and acoustic alarm all over the tunnel, by simply sliding a button from a smartphone.

4. Conclusion

The MonSys has been successfully implemented in many recent tunnel renovation projects in Switzerland. The system have fully met the expectations of both Clients and users and thus represents – as Lombardi's latest innovation tool – a new way of conceiving safe traffic management during renovation works.