ON THE DETECTION OF TRAFFIC CONGESTION AND VENTILATION CONTROL

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ABSTRACT

Traffic congestion has a fundamental impact on ventilation operation in case of unidirectional traffic, particularly if a longitudinal ventilation system is used. Existing technologies for congestion detection are generally based on CCTV, inductive loops in the pavement or other kinds of counting devices. New radar-based technologies recently became available on the market. In the framework of ventilation design for Zürich's Northern Bypass, a specific experimental campaign for comparing and assessing three potentially viable technologies (traffic counting sensors, CCTV and newest-generation radar sensors) was carried out in the 3.3 km long Gubrist tunnel. Based on the results, the relative advantages and drawbacks of the different technologies could be assessed under real-life conditions. Both CCTV and radar sensors proved to be viable technologies for this specific application. Based on the results, it was decided to implement a radar-based solution in the short Katzensee tunnel (0.58 m) and a CCTV-based solution in the three tubes of the Gubrist tunnel (3.3 km).

Keywords: Traffic congestion, ventilation control

1. INTRODUCTION

Traffic congestion plays a fundamental role for ventilation control in case of fire incidents in road tunnels with unidirectional traffic. Strategies devised for fluid unidirectional traffic are generally straightforward and very effective. Conversely, compromises are called for in case of congestion, with vehicles at rest downstream of the fire location. Under these conditions, strategies developed for fluid traffic directly endanger part of the persons in the tunnel and are not allowable. These drawbacks are particularly significant whenever ventilation systems without smoke extraction are used. Proper congestion detection is needed for implementing the most appropriate and effective ventilation strategy at any time.

Existing technologies for congestion detection are generally based on CCTV, inductive loops for vehicle-detection and counting devices. Recently, new radar-based technologies became available on the market, but have so far hardly been implemented for detecting traffic congestion in road tunnels.

In the framework of ventilation design for the 3.3 km long Gubrist Tunnel (Zürich, Switzerland, with two existing tubes to be renovated and a third one under construction), existing technologies were initially assessed in a qualitative manner. The open literature was investigated and several carriers of expert knowledge were consulted. The findings pointed out many open issues with a high level of relevance for ventilation design and operation. For this reason, an experimental campaign for comparing and assessing three potentially viable technologies was carried out between June 2015 and February 2016 in the first tube of the Gubrist tunnel (direction Bern-St. Gall) over a length of 1.4 km. The following systems were tested: traffic counting (Tri-Tech sensors), CCTV and newest-generation radar sensors.

2. TRAFFIC CONGESTION AND VENTILATION CONTROL

The most appropriate ventilation concept for tunnels up to 2-3 km length with one-way traffic is generally longitudinal ventilation. Only tunnels with bi-directional traffic or longer tunnels (prescriptions vary between different countries) are equipped with a smoke-extraction system.

Emergency-ventilation control in longitudinally ventilated tunnels is quite simple in case of fluid traffic. Vehicles between the fire location and exit portal can leave the tunnel unhindered and do not need to be considered. Vehicles and persons between the entrance portal and the fire location are trapped and need to be protected by the ventilation system through full smoke control. The ventilation control system shall achieve the critical velocity in driving direction.

In case of traffic congestion, the situation is much more complicated. Vehicles and persons are blocked on both sides of the fire location. The common ventilation strategy in such a case is to establish a moderate ventilation velocity, typically 1 to 1.5 m/s, for preventing loss of smoke stratification. This ventilation-control strategy should maintain as long as possible adequate self-rescue conditions for most persons.

Having these two widely different ventilation scenarios in mind, one fundamental prerequisite for optimum ventilation control is rapid detection of traffic congestion. At fire detection, information about the traffic situation is required. The allowable time delay for congestion detection should be smaller than the one for fire detection. This is usually in the range of one minute.

It should be noted that specific ventilation strategies for traffic congestion are generally required also for semi-transverse ventilation systems with smoke extraction. The consequences of using less appropriate ventilation strategies are however in most cases significantly less severe.

In the case of Zürich’s Northern Bypass, with high congestion frequency, the situation is as follows:

- Tunnel Gubrist (3.3 km, ventilation system with smoke extraction): Information on traffic congestion is relevant but not vital.
- Tunnel Katzensee (0.58 km, longitudinal ventilation): Information on traffic congestion is essential since mechanical ventilation is used only in case of fluid traffic (Bettelini and Rigert, 2014).

From the point of view of ventilation control, there are two types of congested traffic:

- Type 1: Traffic or vehicles at speed below about 10 km/h (in case of fire, faster vehicles can generally leave the tunnel without being overtaken by the smoke).
- Type 2: One or several vehicles stopped in the tunnel.

From the point of view of ventilation control, congestion is only relevant if it is located between fire location and exit portal.

3. DETECTION METHODS

Today’s standard device for the detection of congestion, or traffic monitoring in general, are inductive loops. They are installed in the pavement and allow detecting vehicles, which pass or stop over the loop. Inductive loops allow for local ("point") measurements and are very reliable.

Traffic-counting devices, installed above a traffic lane, offer a similar functionality. They also allow for local ("point") measurements of vehicles passing or stopping directly under the devices. The big advantage against inductive loops is that they are not installed in the pavement and thus can be replaced without construction works and in short time.

CCTV allows full monitoring of traffic conditions in a tunnel. CCTV usually offers a comprehensive incident detection, including in general the detection of stopped vehicles, congestion, wrong-way driver and more. CCTV allows for area observation. Incidents are detected up to distances of roughly 80 m or even 150 m if the visibility conditions are favorable.

Its reliability is a steady concern. Optical effects (reflections, unfavorable light conditions) or bad visibility can cause false detections or prevent detections. Incident detection is thus not consequently used in tunnels for automatic incident detection.

New long-range radars also allow for area observations of traffic patterns, such as stopped vehicles or congestion. According to manufacturers, vehicles can be detected up to a distance of about 500 m. A major advantage compared to CCTV is certainly that optical conditions (light, fog, smoke) have no influence on detection capabilities. Since it is a new measurement method, there is not much experience about the reliability of long-range radars in tunnels.

The three detection methods considered herein have partially large differences in their capabilities to detect congestion or stopped vehicles. Traffic-counting systems can only survey the tunnel cross-section at the location where they are installed. Radar and CCTV cover a more or less extended area. The entire tunnel (or test section of the experimental campaign respectively) can be monitored. Thus, there are no fundamental limitations for detection of congestion because of the length or location of the congestion.

Table 1: Preliminary assessment of capability to detect different types of congestion

Detection method	Stopped vehicles	Short congestion	Congestion over entire tube
Radars	**Yes**	**Yes**	**Yes**
CCTV	**Yes**	**Yes**	**Yes**
Traffic counting	**No**	**No**	**Yes**

Due to the fundamentally different measurement principle, data from the traffic-counting system are not entirely comparable to the two measurement methods with area coverage. Careful comparison of data is possible with the observation sections of CCTV and radar in which the measurement cross section of the traffic counting system is located.

4. TEST CAMPAIGN

4.1. Sensor description

The goal of the experimental campaign was to compare and assess three potentially viable technologies. The experimental campaign was carried out between June 2015 and February 2016 in tube 1 (driving direction towards St. Gall) of the Gubrist tunnel (highway A1, Switzerland). The tunnel is well known for its high traffic volumes and daily congestion.

The following systems were accounted for: Traffic counting (Tri-Tech sensors, using a combination of doppler radar, ultrasound and passive infrared technologies in a single unit), CCTV and newest-generation radar sensors type ClearWay developed by Navtech. Two radar sensors were rented and installed in the tunnel just for the experimental campaign. For congestion detection with CCTV, the already installed cameras (type analogue) were used to get images from the tunnel. A new system for incident detection (using the existing cameras) and storage of images was installed for the duration of the experimental campaign. The traffic counting system is currently used by the ventilation control system for congestion detection. The raw data were used and analyzed by a slightly adapted evaluation routine to match the congestion criteria used for CCTV and radar.

4.2. Setup

The test setup in the tunnel is presented in Figure 3.

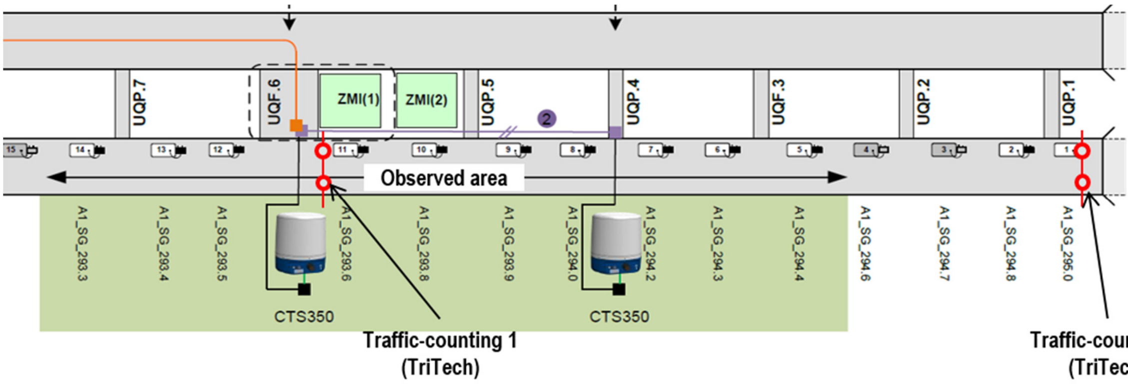

Figure 1: Test setup

The three detection systems cover different areas:

- The traffic counting system is a point measurement. Congestion is only detected if it occurs at the location of the sensors
- CCTV monitors an area of the tunnel. Each camera can detect congestion within a range of up to roughly 80 to 150 m. The cameras are installed in an interval of 150 m. Consequently, observation sections of 150 m length are defined, where each section is evaluated individually.
- Radar monitors an area of the tunnel. According to the manufacturer, each radar covers a range with a radius of 500 m. The evaluation software allows splitting this range into observation sections of any desired length. Observation sections with 100 m length were chosen, corresponding to for fire detection sections used in Swiss road tunnels.

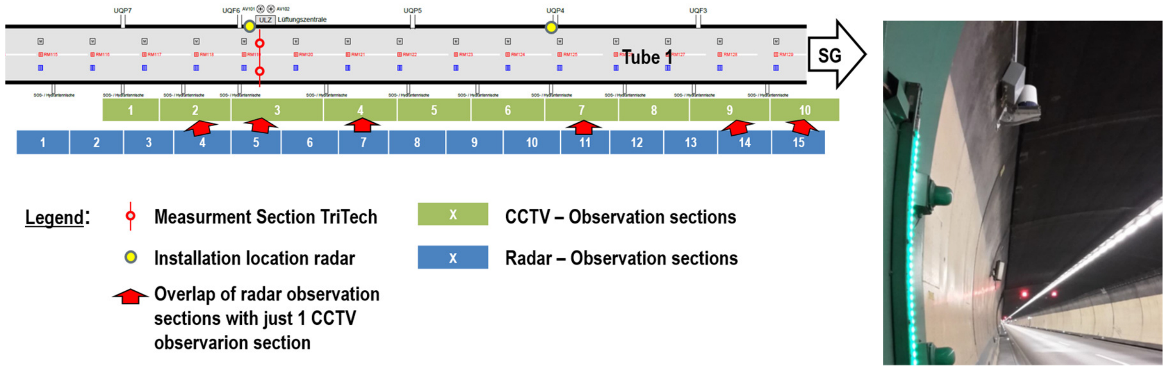

Figure 2: Coverage of radar and CCTV and measurement points of traffic counting system

As illustrated in Figure 4, there are in total 15 observation sections for radar, 10 observation sections for CCTV and 1 measurement cross-section for the traffic counting system. The observed tunnel section covered by the detection systems has no curves and accounts for approximately half of the tunnel, from the center to the exit portal (length of about 1.4 km).

4.3. Measurement campaign

The measurement campaign started with the installation of the additional equipment in June 2015 and the duration was limited to one year. Calibration of the different systems was initially a major issue. CCTV and radar are originally trimmed to detect dense traffic situations for traffic management. Their usual parameters for incident detection filter unimportant events, which are not relevant for tunnel operators (e.g. stop-and-go situations). This allows reducing the number of alarms issued to the traffic control center, but leads to a considerable delay of alarms of the order of 1 minute (depending on system calibration). Conversely, using automatic congestion detection for fire ventilation, the number of alarms is not important since the system will treat them automatically, but the detection of a congestion event should happen as rapidly as possible. A large effort was carried out initially for calibrating CCTV and radar as consistently as possible. Since these two systems use entirely different parameters, this task was complex.

5. RESULT EVALUATION

5.1. Methodology

Each congestion event detected by one or more of the three systems was recorded in a file with time stamp. The CCTV system additionally recorded images over the entire measurement period allowing for a visual verification of the correctness of congestion detection.

In a first step, the recorded congestion events were assessed on correctness. Wrong detections (congestion events recorded although not present in the tunnel, congestion events not recorded although present in the tunnel) were separated from correct detections applying the following rules:

- A congestion event detected from two different systems at the same time and at the same location was qualified as correct detection, congestion was present in the tunnel.
- A congestion event detected only by one system represented possibly a wrong detection.

In case of doubts about the validity of a recorded congestion event, the camera images were used for validation. However, due to the high number of detected events, this time-consuming approach could not be followed is a systematic manner.

5.2. Number and duration of congestion events

A high number of short events extending over just one observation section were found. For both systems, radar and CCTV, a minimum duration for congestion events was defined to reduce the number of events whenever the traffic (velocity, density) was fluctuating around the congestion criteria. Congestion events with just the minimum duration correspond to stop-and-go events, with low relevance for comparison of the two systems. The probability is high, that these events are detected by just one of the detection systems (radar or CCTV). The traffic counting system will have anyway almost no chance to detect such events. Of importance for comparison are the congestion events, which have a longer duration and an extension over several observation sectors. A minimum duration of 8 minutes was defined for relevant congestion events.

The ClearWay radar detected more events than CCTV (see Table 2). The only exception was radar's observation sector 15, where the corresponding CCTV's observation section 10 detected around 15% events which were not detected by radar. This is due to the limited range of the radar discussed in section 5.3.

The higher number of events detected by radar is due to its independency from adverse meteorological situations or visibility conditions in the tunnel. In case of heavy rain outside the tunnel, a lot of humidity is transported into the tunnel and disturbs the functionality of CCTV routines. CCTV does often not correctly detect congestion in such situations.

Table 2: Comparison of number of detected congestion events for observation sections

CCTV observation section	2	3	4	7	9	10
Radar observation section	4	5	7	11	14	15
Events detected only by radar	18%	32%	9%	7%	10%	5%
Events detected only by CCTV	0%	0%	2%	0%	3%	15%
Events detected simultaneous	83%	68%	88%	93%	86%	80%

5.3. Detection range of radar

Comparing the number of congestion events recorded by CCTV and radar, Figure 3, the radar shows well-defined peaks along the tunnel axis. The events detected by CCTV are more evenly distributed over the different observation sections. The peaks are located around the location of the two radar positions (observation sections 5 and 10/11, see Figure 2). Most of these additionally detected events are stop-and-go events, with a very short duration. These events could be declared as wrong detections. However, they occur only in case of very dense traffic situations, when the probability for a real congestion is high.

If the two peaks are not considered, the number of events detected by radar and CCTV is similar. There are only two important exceptions:

- The radar observation section 15 (located around tunnel km 294.4) detects only around 60% of the events detected by CCTV.
- The radar observation sections 1 to 3 (located between tunnel km 292.8 and 293.2) detect only between 20% and 60% of the events detected by CCTV in the same area.

It can be concluded that the observation range of the radar is more limited than originally believed and dependent on the driving direction of vehicles. This leads to a very important conclusion concerning the range of the radar sensors for congestion detection in tunnels:

- Range in driving direction: 400 m
- Range against driving direction: 100 m.

The reason for this large difference is probably related to the aerodynamic shape of the vehicles. The front side of cars creates less or weaker reflections of radar waves than the backside.

The above-mentioned limitations of the measurement range were observed under intense traffic conditions. Better results could probably be achieved in case of lower traffic intensity.

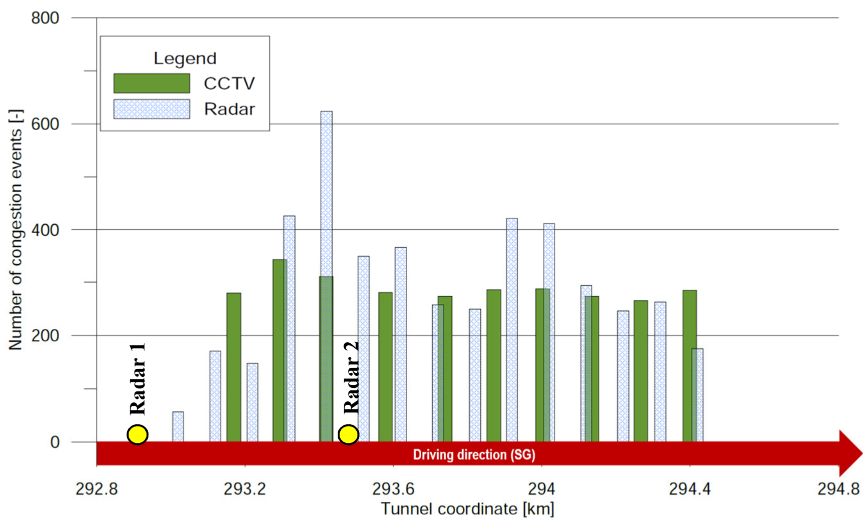

Figure 3: Number of congestion events

5.4. Detection time and temporal delay

Detection time or starting time of congestion events should be identical. Just the traffic counting system has clear drawbacks, as it is based on measurements in discrete cross-sections and congestion has first to develop to that measurement cross section to be detected. Thus, the focus of the evaluation of detection time is laid on radar and CCTV. In this section, only congestion events are considered, which were detected by both radar and CCTV.

The evaluation results lead to the following conclusions:

- Median delay of detection time between radar and CCTV was around 30 seconds, if all events are considered. Possible causes for the delay are the different perspective situations of radar and CCTV, as well as different algorithms for congestion detection. Especially in dense traffic situations, CCTV detects congestions only when it occurs close to the camera position (up to about 80 m).
- Delay is slightly reduced for larger congestion events developing over several observation sections. Congestion events extending over several observation sections are easier to detect than stop-and-go events which occur only for short time and in just one observation section.
- There were no explicit indications that one of the detection systems is faster than the other. The location of the first occurrence of the congestion seems to influence the delay. If it occurs close to the one of the radars, the faster detection comes from radar.
- The maximum delay is the consequence of special conditions with bad visibility or unusual traffic conditions affecting CCTV detection capabilities.

5.5. Influence of meteorological conditions

It was observed that in case of heavy rain the humidity level in the tunnel rises strongly. The high humidity reduces the image quality and affects the proper functionality of the CCTV system. Under these conditions the high humidity level reduces the quality of the images. It becomes blurred and the red breaking lights of the vehicles enlighten the whole image. This leads to very difficult conditions for analyzing the images through the CCTV system. The CCTV system often recorded "debris" (small objects on the road) instead of congestion in the log file during such conditions. Further investigations would be necessary for verifying, if this kind of detection could be interpreted as congestion by the ventilation control system.

No influence on the radar's detection quality through different meteorological conditions could be observed during the whole test campaign.

6. SUMMARY AND CONCLUSIONS

The presence of congestion has a significant impact on the selection of the most appropriate road-tunnel ventilation strategy. Three methods for detecting congestion in road tunnels have been extensively and systematically evaluated by means of an experimental campaign carried out in Swiss highway tunnel Gubrist. The following systems were investigated:

- Tri-tech vehicle-counting devices
- CCTV with image analysis
- New-generation radar sensors.

The traffic-counting system showed clear and distinct drawbacks against the other two systems. The two measurement cross-sections located at a distance of roughly 1.5 km were not adequate for detecting a similar number of congestion events as radar and CCTV, which both monitor the whole range. In case of fire, this technology could miss a significant number of congestion episodes or detect them too late (after fire detection), which would let the ventilation control start the ventilation scenario for fluid traffic. The situation could be improved by reducing the distance between measurement cross-sections.

New-generation radar systems proved to be well suited for congestion detection in road tunnels. The detection quality of radar and CCTV is basically comparable. Both systems detect the relevant congestion events with and acceptable time delay and accurate location. Deviations have been identified only for rather irrelevant congestion events. These are stop-and-go situations, where the criteria for congestion (primarily velocity limit) are fulfilled for a few seconds only. The detection of such events is dependent on the location of the congestion event in relation to the location of the detection device (radar or camera). The closer the location of the congestion event to the detection device, the higher the chance for detection. Not relevant congestion events have been recorded mainly by the radar system, in great number.

The observation range of the radar for detection of congestion in tunnels was shown to be smaller than declared. Reliable detection can be expected:

- up to distances of about 100 m from the installation location of the radar against the driving direction
- up to distances of about 350 m from the installation location of the radar in driving direction.

The difference is explained with the aerodynamic shape of cars. The aerodynamically shaped front side creates weaker radar reflections than the rather flat backside.

Congestion detection is of special importance in tunnels characterized by high traffic volumes and longitudinal ventilation. An activation of the ventilation system in the fluid-traffic-mode could lead to undesired consequences. The experimental campaign revealed, that common solutions for detection of congestion (traffic counting) are not always appropriate.

There are no normative or legislative prescriptions concerning the detection of traffic congestion. Systems with the capability to monitor the whole tunnel and not just a few cross-sections are recommended for tunnels with high congestion probability. Simple traffic-counting systems could detect congestions with an undesired high delay.

Radar systems have additional advantages in case of difficult visibility conditions (portals with illumination from outside of the tunnel, wet conditions in the tunnel). The high measurement range of radar is only an advantage in straight tunnels.

Radar and CCTV systems are commonly designed for application in traffic monitoring. The corresponding congestion criteria cannot be compared to those requested by the ventilation-control system. A system working for traffic monitoring is designed for preventing unnecessary alarms. An excessive number of alarms could not be handled by the operators working with the system. In the case of ventilation control, all congestion alarms received form radar or CCTV are treated automatically and the number of alarms is not an important factor. These different requirements have influence on the detection criteria and device calibration. Some parameters can be easily adapted, other ones cannot be adapted. For applications of radar or CCTV in tunnels for detection of congestion for ventilation control, the systems should be specifically designed and calibrated for exactly this application. Otherwise, the effort for parametrization of the system is huge.

Based on the results of this test campaign, it was decided to implement a radar-based solution in the Katzensee tunnel (0.58 m) and a CCTV-based solution in the three tubes of the Gubrist tunnel (3.3 km). The main reason is that adverse environmental conditions have a much larger impact on the short Katzensee tunnel, where congestion detection has a much more significant impact on ventilation control. The more conventional solution was deemed adequate for the Gubrist tunnel, which is significantly less demanding from this point of view.

7. AKNOWLEDGEMENTS

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8. REFERENCES

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