APPENDIX 5 – referring to chapter 5 "*Examples of interesting findings from real incident information*"

5.1. EVALUATION OF QUESTIONNAIRES ON REAL TUNNEL INCIDENTS – SURVEY OF 32 REAL TUNNEL INCIDENTS

Example 1: Car fire
Short description of incident: Self-ignition of a car stopped in lay-by

MAINS CONCLUSIONS	
Human behaviour	Driver + accompanying person leave their car - they do not know how to behave They moved on walkway away from lay-by Some cars stopped in right lane next to them Cars did not respect red light at tunnel portal for quite some time Dangerous movements of vehicles in front of portal have been observed (U-turn etc.) Finally the 2 people left the tube through an emergency exit
Emergency Services	-
Tunnel Equipment & Operation	Smoke coming out of tunnel portal is sucked into non incident tube (ventilation mode: fans blowing into tunnel from both sides to produce overpressure) → It is intended to change the ventilation mode in non-affected tube (in both tubes the airflow should be in the same direction)

Relevant illustrations:

Example 2: Rear end collision with fire as a consequence

Short description of incident:
- Unexpected stop of HGV; Second & Third HGVs crash into it. 8 lorries involved, partly crashed.
- Fire started immediately - estimated fire size: 15-20MW
- Dense traffic

MAINS CONCLUSIONS	
Human behaviour	One driver ran in direction of air flow Some stayed in cabins Some vehicles drove backwards No vehicles passed fire site Drivers respected red light almost immediately (no barriers) Only 2 drivers used emergency exits (only when they felt threatened by smoke, even though an emergency exit was very close). The evacuation of other drivers (the ones that remained in their vehicles at first) was organized by one active driver.
Emergency Services	Emergency services had difficulties to approach the incident due to congestion up to tunnel portals
Tunnel Equipment & Operation	After 3 minutes, piston effect decayed: longitudinal airflow stopped and turned to be negative Longitudinal ventilation was only activated after 12 minutes (3m/s) There was clear stratification of smoke almost all the time → Algorithm for emergency ventilation will be changed as a consequence of the event

Relevant illustrations:

Example 3: Self ignition of combi-vehicle stopped in tunnel
Short description of incident: Combi-vehicle stopped and started burning 730 m after portal

MAINS CONCLUSIONS	
Human behaviour	All cars passed by. One car stopped and helped to extinguish without success. Red light was respected quickly.
Emergency Services	Operator started ventilation as soon as he noticed back layering. Fire brigade extinguished fire quickly. Approach was easy ("*emergency-access-lane*" was respected)
Tunnel Equipment & Operation	Radio systems of police & emergency services are not compatible

Relevant illustrations:

Example 4: Breakdown followed by a collision

Short description of incident: During rush hour, in an urban motorway tunnel (3 lanes per tube), a vehicle came to a stop near the tunnel exit, due to lack of gasoline.

Via the CCTV system the police observed the incident and began to regulate the traffic by setting red crosses corresponding to the affected lane & by pulling down a stop barrier outside the tunnel corresponding to the affected lane.

Approximately 1 minute after the breakdown occurred, the stopped vehicle was hit from behind by another vehicle. As a consequence, it was pushed forward and turned around several times (horizontally).

The incident looked very serious. Therefore, once the incident occurred, the police totally closed the affected tunnel tube (not only one lane).

MAINS CONCLUSIONS	
Human behaviour	Driver of the stopped vehicle stayed in car, and called emergency number (112) with cell phone. Collision occurred due to lack of respect of the red cross signals (closed lane). After the collision, driver of stopped vehicle left the vehicle by crawling out of the front door window (without stopping talking in the cell phone), crossed the road and stopped next to the tunnel sidewall. Driver of the second vehicle walked also to the sidewall near the driver of the first vehicle. They stayed there together until the rescue services arrived. Several vehicles passed the collision site without stopping. Due to a decline in driver's behaviour over the years, maintenance operations are organised by tunnel manager when the concerned tunnel tube can be closed to traffic.
Emergency Services	-
Tunnel Equipment & Operation	-

Example 5: Collision

Short description of incident: In the same urban tunnel as for example case #4, a vehicle (veh. 1) hit into the side of another vehicle (veh. 2) when changing lane at high speed.
Veh. 1 ended up in a cable duct.
Veh. 2 flew about two meters up the tunnel sidewall, then turned around and landed on the roof about 300m ahead.
Thankfully, no one was seriously injured.

MAINS CONCLUSIONS	
Human behaviour	A lot of vehicles stopped and talked to drivers People tend to pass the barriers up to the last second, without respecting the flashing stop lights.
Emergency Services	Emergency services drove against the normal traffic direction to avoid the traffic queue behind the stop barriers → this process revealed as being very satisfactory: it took only 6 minutes for the rescue vehicle to arrive
Tunnel Equipment & Operation	-

Example 6: Collision followed by a fire (wrong way vehicle)

Short description of incident: A Sunday morning, in a 2 tubes urban tunnel, during a period with very low traffic, a car (vehichle 1) drove into one of the tunnel tubes in the wrong direction, and caused a collision (head-on collision) with another car (vehichle 2).
Both cars caught fire.
Driver of vehicle 2 did not manage to get out of the car and was a victim of the fire following the collision.

MAINS CONCLUSIONS	
Human behaviour	-
Emergency Services	Fire fighters got inaccurate information about fire location, & the intervention plan was not easy to follow. As a consequence, a simplification of the emergency response plan has been considered, with only 4 variants (original 18 variants).
Tunnel Equipment & Operation	Modified procedures have been implemented after the accident: in case of fire, both tubes shall be immediately closed (it was not the case during the incident: before arrival of firefighting rescue teams, only the affected tube had been closed). A low audibility & endurance of the walkie-talkies has been experienced during the intervention. Therefore it has been decided to improve communications after the case.

Example 7: Collision with several cars involved

Short description of incident: n a motorway tunnel, during winter, ice on road & over speeding led to a collision with 7 cars involved.
Thankfully, no injuries, & all drivers left the tunnel with their vehicles.

MAINS CONCLUSIONS	
Human behaviour	Drivers did not respect the red crosses traffic signs. Problems with foreign language were experienced with a driver.
Emergency Services	-
Tunnel Equipment & Operation	-

Example 8: Bus fire

Short description of incident: During the day on a motorway with normal traffic conditions, a bus caught fire due to a technical fault.
More than 20 persons were involved. No injury.
The incident was detected by the control centre via visibility meter alarm and a loop in lay by.
Both tubes were closed to traffic immediately after the detection.

MAINS CONCLUSIONS	
Human behaviour	Very good behaviour of bus driver and tour guide: - Bus stopped in the nearest lay by - Bus passengers evacuated the bus to the next emergency exit - Use of fire alarm (push button repeater at emergency call cabin) - Use of fire extinguishers However, emergency call cabin were not used Approx. 80% of drivers passed by. The rest (approx. 20 vehicles) stopped in front of the accident and evacuated via the next emergency exits (after order via FM-broadcast). Barriers and red lights were respected.
Emergency Services	- very fast arrival of fire fighters at scene - Fire fighter in charge could not be recognized by tunnel users - Fire fighters forgot to ask the bus driver about the number of passengers in the bus - They used technical terms not understandable by tunnel users - Emergency service staff should be marked with name badges or something similar (in case of further inquiry) After this intervention, operative rules for fire fighters were adapted: they are now requested to interview tunnel users and especially bus drivers and tour guides if any.
Tunnel Equipment & Operation	To have a sufficient number of fire extinguishers was very helpful. Problems have been experienced due to different types of fire extinguishers with different release functions → Same types of fire extinguishers now. Push button repeater at emergency call cabin was very easy to recognize. Loud speaker announcements were not understandable due to high noise level in the tunnel (ventilation) → a new loudspeaker system has been installed. Due to the shadow of the bus there was difficulty in recognising the exit.

Relevant illustrations:

Example 9: HGV Collision

Short description of incident: HGV collision in a 2 tubes motorway tunnel, without any other vehicles involved.
No one injured (collision happened during the night, a period with very low traffic).
Due to inattention of the driver (micro sleep), the lorry hit an emergency call cabin and damaged the crash barriers in front of the tunnel.

MAINS CONCLUSIONS	
Human behaviour	All other vehicles already in the tube passed by After tunnel closure (the accident was detected in the control centre thanks to a message error of damaged tunnel equipment, and the tunnel has been closed immediately), no one entered the tunnel: barriers and red lights were respected. The lorry driver called the police via his cell phone.
Emergency Services	Quick arrival of emergency services at the scene. No problem reported.
Tunnel Equipment & Operation	Damage to CCTV camera / emergency call cabin → several error messages/alarms were generated in the tunnel control centre → very fast detection by the Operator. Vibration strips in the road surface should normally help to prevent this kind of accident. After the tunnel tube was reopened again one lane was closed for a longer period for repair works at the damaged tunnel equipment (Emergency call cabin).

Relevant illustrations:



Example 10: Fire

Short description of incident: Already on fire, a vehicle entered an urban motorway 2 tubes tunnel (driver had not realized the fire); then stopped inside the tunnel as the fire grew rapidly. The vehicle was followed by a patrol car of the operator, whose patroller tried ineffectively to alert the driver. The patrol car stopped at the entrance of the tunnel where patroller proceeded to block the entry of other vehicles into the tunnel (the traffic was deviated onto the adjacent motorway exit) while alerting the control centre.

MAINS CONCLUSIONS	
Human behaviour	The driver remained on site throughout the incident. Some other car drivers stopped to assist (use of emergency phone to alert the control centre & use of portable firefighting equipment: fire extinguishers & hoses). Red signs and physical closure by cones installed by the patroller were ignored by some drivers during the first phase of incident (some driving between the cones). Some drivers drove in reverse in order to get out. Some drivers occupied the emergency lane in front of tunnel entrance → Modifications of Traffic Regulations after the incident: more strict rules about the use of emergency lanes.
Emergency Services	Difficulties faced by the Emergency Services, due to the emergency lane being occupied upstream (was ignored & blocked by drivers), due to congestion in front of tunnel entrance.
Tunnel Equipment & Operation	The emergency stations into the tunnel were very well recognizable by the users. They made use of existing firefighting equipment (fire extinguishers and hoses) and of emergency telephone. Some difficulties were encountered in the initial phase of tunnel closure for implementation of blocking traffic vehicles (no barriers). In the absence of barriers, patrols are essential for quick tunnel closure in case of an accident → Procedures were adopted to secure the presence of patrols. Some modifications were adopted for equipment of the patrol personnel. Questions remain about legal obligation for personnel to proceed to firefighting before arrival of rescue services.

Relevant illustrations:

Example 11: Collision with DG vehicle involved – no DG release

Short description of incident: In a 2 tubes motorway tunnel, a light truck stopped inside the tunnel, in the right lane, probably due to mechanical breakdown. The operator detected the stopped vehicle through the CCTV network. He closed immediately the right lane by using the red crosses signs, and made use of orange flashing traffic lights (to inform drivers about a danger).

After a 3 minutes stop, the light truck started moving again at low speed (about 10 km/h) in right lane.

A semitrailer tanker (loaded with 25 T of gasoline and oil) that was on the closed right lane had a rear collision with the light truck. No fuel leakage, despite the impact on the tunnel sidewall.

Human consequences: one fatality (light truck driver), one lightly injured (tanker driver).

MAINS CONCLUSIONS	
Human behaviour	Tunnel is forbidden to DG vehicles, but some go through nevertheless. The driver of the tanker completely ignored the red crosses signs. During the first minutes, ongoing traffic was noted between the two immobilized trucks. Many drivers did not respect the traffic signs (VMS, LCS & red lights both at tunnel entrance & inside tunnel). Blocking of the tunnel was finally achieved when some professional drivers stopped at the portals, blocking the entrance → role of professional drivers seems to be critical (they can act as leaders). The vehicles trapped behind the immobilized vehicles escaped with a controlled turnover through the traffic cross passage to the other tube. Some drivers informed the Control Centre of the accident and of the smell of gasoline, accelerated the decision for tunnel closure.
Emergency Services	Fire brigade arrival time was long. Removal of the tanker was done very careful to avoid DG release.
Tunnel Equipment & Operation	The Control Centre at first did not have a clear perception of the situation because the accident took place in a blind part (not covered by CCTV network). The ventilation system was manually activated (for precaution reasons). Non-compliance of many drivers to the signals → physical closure seems to be more efficient (no barriers at the time of accident).

Relevant illustrations:

Example 12: Collision followed by a fire

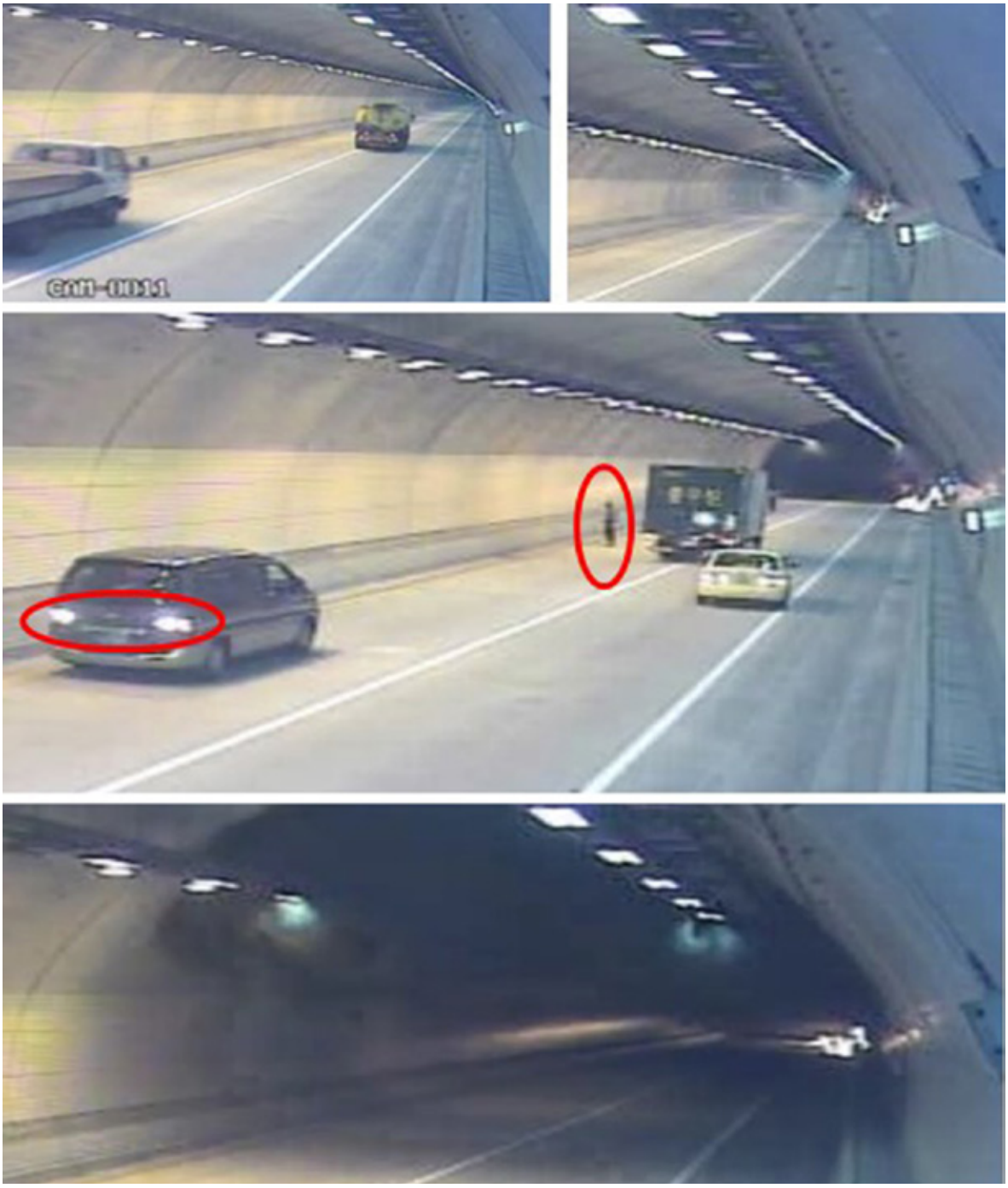
Short description of incident: In a 2 tubes motorway tunnel, a first light lorry drove from right lane to the left one, and then came back to the right lane. Consequently, a second light lorry carrying thinner (DG) that was behind on the left lane braked suddenly to avoid the first lorry: the driver lost control and crashed against the right side wall of the tunnel.

This collision immediately degenerated into a fire. The truck burnt completely, no casualty.

This accident happened in the entrance area of a 2 tubes motorway tunnel (140m from entrance: there was no emergency exit between upstream portal and accident place).

MAINS CONCLUSIONS	
Human behaviour	A few vehicles entered after the collision, then stopped behind the lorry on fire. One person went outside his vehicle. Another driver reversed back. Nobody approached to see if the driver of the vehicle on fire needed help. After a while, all the vehicles reversed out. Driver of the lorry in fire walked downstream (longest way to the exit).
Emergency Services	Fire brigade arrived in 15 minutes. They suffered from heat and toxic gas.
Tunnel Equipment & Operation	Due to the prompt and large size of fire, and because thinner fire spilled to the utility duct, the electricity cables were damaged which caused blackout and stopped all the facilities. After the fire, the tunnel authority took several measures such as: Add scenario and fire drill method for DG; Education for tunnel operator; Public relations to road users. Six jet fans were activated in less than 5 minutes by tunnel operator. VMS (Variable Message Sign), LCS (Lane Control System) and entrance shutting device were used. However, power supply system went down due to the damage of cables → Consequence on ventilation: backlayering was noted.

Relevant illustrations:



Example 13: DGV turbo compressor failure

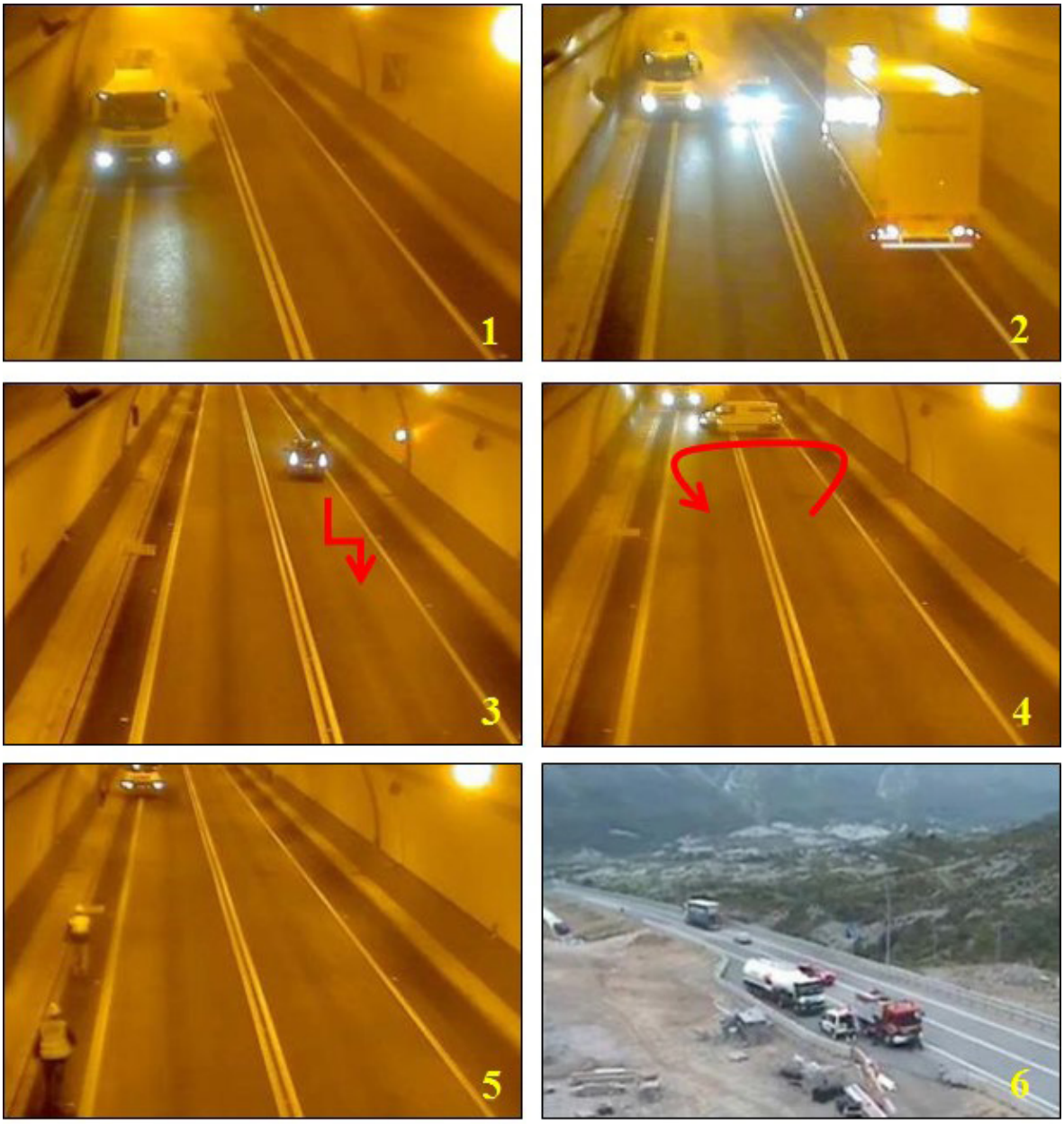
Short description of incident: The incident occurred in a one tube tunnel, 1500m long, with bidirectional traffic. There is a second parallel tube, closed to traffic for refurbishment. Both tubes are connected by means of three emergency galleries.

A DGV carrying 20,000 litres of fuel suffered a turbo compressor failure while it was circulating through the tunnel, generating a large amount of white smoke inside the tunnel (picture-1). The vehicle moved forward for 500 meters, until it finally stopped.

No injury, although dangerous situations for the other vehicles involved.

MAINS CONCLUSIONS	
Human behaviour	The DGV driver did not stop when smoke began to escape from the truck: he tried to drive outside. When he finally stopped, he did not leave the tunnel, remaining close to the truck. After a few minutes (not immediately), he decided to contact the Control Centre through an emergency station. All the vehicles that were in the tunnel at that moment passed the truck and did not stop to assist. Furthermore, some of them made forbidden movements such as overtaking (picture-2), driving backwards (picture-3) or U- turns (picture-4). Nobody used the emergency exists.
Tunnel Operation	Operator of control center detected immediately the incident and launched the incident response plan. Some of the workers who were working in the parallel tunnel went to the incident place, so as to see what happened, and remained close to the truck (picture-5). As a consequence, the Emergency Response Plan has been modified after the incident in order to improve coordination between the Operator and the company responsible for the refurbishing works in the parallel tunnel.
Emergency Services	The firefighting services arrived 20 minutes after commencement of the incident. At that time, the problem has already been solved (picture-6).
Tunnel Equipment	The south portal barrier did not work due to a mechanical failure. As a consequence, after the incident, it has been decided to increase the maintenance frequency of the systems which are not used frequently (like the closing barriers).

Relevant illustrations:



Example 14: Collision caused by over speeding followed by a fire

Short description of incident: A speeding vehicle, driving 120 km/h in a 2 tubes urban tunnel (50 km/h allowed) hit another vehicle, resulting in shooting flames and burning of the 2 involved vehicles.

MAINS CONCLUSIONS	
Human behaviour	Two men immediately used fire hoses to extinguish the fire. A woman with a child fled in the same direction as the smoke and was caught up. Instead of continuing towards the near exit, she sat down with her child. Fortunately the smoke passed away rather quickly (due to the transversal ventilation). No one used the emergency exits (about 1 every 100 m), maybe because of difficult access: in order to reach them, it is necessary to climb up to a 1.1 meter high walking path, with a width of 0.7 meter.
Emergency Services	The fire was extinguished when the Fire brigade arrived, 8 min after the accident occurred.
Tunnel Equipment	Speeding cameras installed, which reduces the number of speeding cars, but not in their totality.

Example 15: Breakdowns & minor front-end collisions

Short description of incident: On average 150 breakdowns per year are recorded in this 1 km long twin tubes urban tunnel, where the number of breakdowns shows a decreasing trend.

Procedure in case of a breakdown: one lane is crossed red. A towing vehicle is ordered by the supervising operator. Often (estimate 30 to 40% of the cases) the vehicle is towed out by another car before the ordered professional towing vehicle arrives.

About 8 minor front-end collisions are recorded each year, of which one with minor injury.

Most collisions occur during peak-hours when driving is slow in heavy traffic.

The more serious collisions however occur in the quiet hours, when speeding is higher. One major collision has been recorded in 1999: accident with two deaths and two severe injured, caused by drunk driving at 120 km/h.

MAINS CONCLUSIONS	
Human behaviour	Drivers do respect the red lights in front of the tunnel. Most serious collisions are recorded in the quiet hours, mainly because of over speeding.
Tunnel Operation	Bi-directional traffic not allowed during maintenance.
Emergency Services	-
Tunnel Equipment	Addition of extra stop signs on several parts in the tunnel is under discussion. At the moment, traffic can only be stopped at the entrance in front of the tunnel. Speeding cameras installed, which was effective at reducing the number of speeding cars, but not totally stopping them.

Example 16: Fire/smoke from vehicle
Short description of incident: In a 6.7 km long 2 tubes tunnel on a provincial road, the driver of a broken down vehicle, using the emergency post, reported fire/smoke from the vehicle to the Operator.
The tunnel was then closed and evacuation process started.
By the time the Fire Brigade arrived the fire has gone out.

MAINS CONCLUSIONS	
Human behaviour	Driver of the affected vehicle used the emergency post in the tunnel. Other drivers followed the instructions given through loud speakers and message signs and evacuated the tunnel within two minutes. People stayed in the cross sections and got information from the Operator. In the end, people could return to their cars and the tunnel was reopened.
Tunnel Operation	Twitter was used to inform tunnel users of the closure of the tunnel, but having telephone communications and sending tweets at the same time revealed as being too much to handle for one employee. A reopening procedure was adapted after this incident. Procedures to operate very satisfactorily.
Emergency Services	The fire has gone out when the Fire Brigade arrived. Minor changes in communication lines of Emergency Services.
Tunnel Equipment	Worked as expected.

Example 17: HGV fire
Short description of incident: The engine of an empty HGV caught fire, and the HGV stopped in the middle of a 2 tubes urban tunnel, which is 3.8 km long. It happened at 2 pm and there was light that time. The tunnel was closed for 3.5 hours.

MAINS CONCLUSIONS	
Human behaviour	Other drivers observed the fire and called alarm central; then the alarm central called the traffic central (Operator). The HGV driver as well as a Road Assistant tried unsuccessfully to extinguish the fire using a handheld extinguisher. Another Road Assistant started evacuating trapped drivers. Some drove through the smoke and continued out of the tunnel. Others queued up behind the HGV and some tried to turn around the car and go back, but didn't succeed due to lack of space. Several people were standing outside their cars. Only few persons went to the fire exits following evacuation signs and messages. Two persons left their cars in the tunnel: one of them had a flight to catch, and the other one had to pick up children from kindergarten. Information in the tunnel, signs, pre-recorded messages and information from the control centre was a bit confusing according to the interviewed persons in the tunnel. When talking to the Operator, they were told not to evacuate but wait! (Procedures have been sharpened).
Tunnel Operation	The Operator observed the fire in the CCTV system after receiving the alarm from the Alarm Central. A report was written after the fire, including interviews of the parties involved and 4 car drivers. All comments that came up and all conclusions regarding the system ended up in an action list that was taken care of internally (no information whether the fire department has done any changes in their instructions).
Emergency Services	The fire brigade stopped outside a barrier and thought that the control centre would see them and open the barrier. According to procedures the control centre of the fire brigade should call the tunnel control centre and let them know which way they will arrive. Later, but not because of this event, a web-education has been developed, also dealing with this issue.
Tunnel Equipment	When the Operator starts the action plan for fire, the ventilation is lowered to a minimum until the Fire Brigade arrives and direct the Operator how to activate the Fire Ventilation. 3 out of 12 barriers didn't go down automatically. This meant that cars drove into the closed tunnel (software has later been changed). The automatic fire alarm did not activate until 9-10 minutes after the phone call to the Alarm Central (sensibility of the sensors has later been recalibrated).

Example 18: HGV fire
Short description of incident: A HGV on fire (situated on the front axle of the HGV) entered & stopped into a 3.2 km long twin tubes motorway tunnel. Fire extended to the cabin.

MAINS CONCLUSIONS	
Human behaviour	HGV driver entered the tunnel whith axle already on fire (flames were noticed by many other drivers before the HGV entered the tunnel). Driver tried to fight the fire with a bucket he filled with the milk contained in his HGV tanker. Dangerous movements of vehicles upstream (U turn and drive backward) in order to get out. 3 vehicles stopped downstream in front of a by-pass. People in those 3 vehicles evacuated in the by-pass, then called the control centre using an emergency phone, and then came in the non-affected tube.
Tunnel Operation	Some interrogations arose after the incident about the automatic messages delivered in case of a fire. All drivers were asked (without distinction between drivers blocked upstream & drivers who can freely drive downstream the fire) to stop their vehicle and join a by-pass.
Emergency Services	The fire brigade stopped outside a barrier and thought that the control centre would see them and open the barrier. According to procedures the control centre of the fire brigade should call the tunnel control centre and let them know which way they will arrive. Later, but not because of this event, a web-education has been developed, also dealing with this issue.
Tunnel Equipment	Difficulties faced by Emergency Services to approach fire due to congestion in front of the tunnel (barriers have been closed by the Operator) together with a road works area upstream in the vicinity of the tunnel: Fire fighters had received no instructions about how to reach the tunnel taking into account the road works. After the incident, access conditions have been cleared.

Example 19: HGV fire
Short description of incident: In a 1.5 km long twin tubes motorway tunnel, a HGV caught fire & stopped due to technical problem (possible origin: turbo compressor failure).
A second HGV stopped close to the HGV on fire.

MAINS CONCLUSIONS	
Human behaviour	The driver of HGV on fire tried to fight fire with an extinguisher (the one in the cabin of the 2nd HGV), without success. After that, he called the control centre using an emergency telephone. Then he tried again to fight the fire with a fire extinguisher at disposal in the emergency station, again without success. He stopped trying to fight the fire when a tyre exploded. Then both drivers came in the HGV cabin of the 2nd HGV. They joined an emergency exit (by-pass) only when they were ordered to do so by the firemen (at their arrival on site). After having joined a by-pass, the driver of the HGV on fire came out of the by-pass twice to join the fire place, so that it had be necessary to ask him again and again to join and stay in the by-pass.
Tunnel Operation	Operation worked very well (delay to launch the fire sequence, ventilation, tunnel closure, etc.).
Emergency Services	Difficulties/lack of communication between the different intervention teams (firemen & police) → need for "*connection officers*". Language problems with HGV drivers (they spoke no English nor the language of the country where the fire took place). It has been identified the necessity to update the Emergency response plans (communication improvements, language issue).
Tunnel Equipment	It has been impossible to connect to the fire hydrant in the affected tunnel tube (the hose has been connected from a hydrant in the non-affected tube; therefore the doors of the by-pass remained opened during the intervention) → The maintenance program has been updated in order to check with a better periodicity the all the fire hydrants.

Relevant illustrations (19):

Example 20: HGV accident followed by spillage from diesel tank

Short description of incident: An accident occurred in a 0.8 km long 4 tubes motorway tunnel, which caused a leakage of the diesel tank. There was no fire and no injuries.
No other vehicles involved.
A traffic jam occurred upstream of the HGV until it has been removed from the tunnel.

MAINS CONCLUSIONS	
Human behaviour	-
Tunnel Operation	The accident was noticed by the tunnel operator, because the tunnel system reported that traffic had stopped. With the cameras, the operator could see the accident, but he could not see how much diesel had been spilled. The operator closed the affected tunnel tube, and traffic was diverted through the other tunnel tube in the same direction. Operators were not familiar with the use of the radio installation, the calamity-button and the quick-reference cards → This will be point of attention in the new training program.
Emergency Services	Emergency services did not follow the proper procedures and route to reach the tunnel and the incident location → Training of emergency services will be intensified.
Tunnel Equipment	The radio installation has been used to inform drivers; however this device only covers a few radio channels. Operator was not sure if all drivers heard the messages, but no problems or unwanted behaviour occurred. The position and technical possibilities of the cameras were not sufficient to get a good view of the accident and the size of the spill. However, replacement of cameras is not planned yet. Communication equipment of tunnel manager's employees did not function in the tunnel.

Example 21: Accident and car fire

Short description of incident: In a 0.5 km long twin bore motorway tunnel, a car hit the sidewall and caught fire. The accident happened late in the evening, traffic was light.

The accident was reported to police, and then Police contacted the tunnel operator.

The accident was also detected by tunnel system: the operator closed the tunnel. Tunnel was closed.

Other traffic could drive through and leave the tunnel.

Fire brigade arrived within 10 minutes after reporting of the accident. They were able to extinguish the fire very fast.

MAINS CONCLUSIONS	
Human behaviour	Traffic outside (in front of the tunnel) was stopped by traffic lights and barriers. No contact between driver and tunnel
Tunnel Operation	Tunnel operator followed the procedures correctly, except about the procedures evacuation messages, that should also be used. This was not done because the operator believed that no persons were present in the tunnel anymore, which was in fact true with the exception of the driver involved. It was concluded that even in such a case, the evacuation procedure should be followed, because there could have been some people to evacuate in the tunnel. After the incident, the basement of the tunnel has not been checked for contamination with extinguishing water → Such verification has to be incorporated in the standard procedure.
Emergency Services	Fire brigade did not follow the correct procedure. They entered the tunnel using the affected tube instead of using the adjacent tube, according to procedures. Emergency services did not participate in the post-incident evaluation process, whereas it is a legal obligation → Consequently, a new discussion occurred with the emergency services, and it was agreed that in future cases they will participate in the post-accident evaluation.
Tunnel Equipment	Initially one of the barriers in front in the tunnel did not close, but this could be solved by the operator.

Example 22: HGV Fire

Short description of incident: In a 11.4 km long bidirectional tunnel, a coach took fire and stopped approx. 3,5 km from the eastern tunnel portal. The driver initiated the necessary measures when he saw signs that something was wrong with the heavy goods vehicle, but he was unable to extinguish the fire using the 6 kg fire extinguisher from his own vehicle. 67 persons were trapped in the smoke in the tunnel and 28 persons sustained acute smoke injuries. The tunnel was longitudinally ventilated. The tunnel was opened in 1991 and was equipped according to the regulation at that time and is situated in an east – west direction. The AADT is 1000.

MAINS CONCLUSIONS	
Human behaviour	No information was given to the road users that immediate evacuation was necessary. Only those in the immediate vicinity of the fire scene or who realised what was happening at an early stage manage to evacuate before the tunnel filled with smoke. All the people that were involved in the tunnel fire were able to either walk out or drive out of the tunnel. Some of the people walked 6 – 7 km more or less in smoke. Road users with the most severe symptoms had the longest stay outside cars and the highest degree of physical exertion in the tunnel Young age and good health were probably contributing factors to the fact that no lives were lost in the fire
Tunnel Operation	As a result of the pre-defined strategy for fire extinguishing and rescue work that is set out in the emergency response plan, the Road Traffic Centre, immediately after the fire was reported, routinely starting the fire ventilation so that the smoke from the fire was ventilated 8,5 km in direction west. The smoke blocked the only possible evacuation route for the road users on the west side of the fire. According to the same plan the fire service should access the tunnel from the eastern portal. From that portal it was 3,5 km to the fire site. Before the fire was the natural direction of the tunnel air (and the ventilation) from west to east. After the fire the ventilation was reversed according to the emergency response plan to support the fire service accessing through the eastern portal of the tunnel.
Emergency Services	The tunnel was not equipped with any kind of monitoring or device for counting vehicles that could have provided continuous information about how many vehicles were in the tunnel. However, such devices are not mandatory equipment. The Road Traffic Centre and the fire service thereby did not have an overview of how many people were inside of the fire towards which the smoke was ventilated. According to the emergency response plan, the fire service, that was situated close to the eastern portal of the tunnel had the responsibility to react. On the western side of the tunnel the nearest fire service was over one hour away. The fire service arrived at the fire site 30 minutes after the fire was reported. The fire was extinguished within 30 minutes.
Tunnel Equipment	The tunnel is equipped with totally 92 fans, divided into 6 groups. Due to continuous maintenance 5 – 10 fans are normally out of service. This fact does not influence the necessary capacity of fire ventilation according to the emergency response plan for the tunnel. There are 18 lay-bys in the tunnel, illumination according to standard regulation, 20 SOS telephones, 42 fire extinguishers and communication cable through the tunnel.

Relevant illustrations:

Example 23: Turbo compressor failure on a bus

Short description of incident: The incident occurred in a single tube tunnel with two lanes and bidirectional traffic. The tunnel length is 2600 meters. There is a second parallel tube, connected to it by means of emergency galleries every 300 meters. The second tube has no traffic (although circulation of emergency vehicles is possible) and it is only used in case of emergency and/or evacuation.
The circulated tunnel is equipped with a longitudinal ventilation system, and provided with some very specific safety equipment: infrared TV cameras, barriers immediately after lay-bys, etc. It is monitored permanently from a local control centre. A main control centre has been built in the region, from where this tunnel is monitored as well (only surveillance; sending commands is not possible). In the future, it is intended that the continuous surveillance will be carried out only from the main control centre (several kilometres away from the tunnel).

The day of the incident, a convoy of four buses entered the tunnel with about 150 passengers (most of them children). Due to an engine failure concerning one of the buses, a large amount of white smoke was suddenly generated. However, the bus did not stop, and continued moving along the tunnel until it arrived at a point where the barrier was down. As a result, three of the buses stopped in lay-bys, while the fourth one left the tunnel without problems. A vehicle which was moving in the opposite direction didn´t respect the signs and continued moving towards the place where the buses were stopped. When it arrived to the place of the incident, it passed by the broken bus and got into the smoke. As the visibility level was extremely low, the driver turned round and stopped near the broken bus.

The evacuation of people from the buses and the vehicle was guided by a member of the operation staff who was working in the tunnel. Emergency services arrived 20 minutes after the incident. They experienced difficulties to communicate with the local control centre. The smoke exhaust started when emergency services took control of the situation. No injuries. The tunnel was closed for 3 hours.

MAINS CONCLUSIONS	
Human behaviour	The driver of the bus that generated heavy smokes did not stop until it arrived in front of a barrier close to a lay-by. Then most of the people remained in the bus or close to the bus. Some of the bus passengers started to walk along the tunnel road, instead of going towards the nearest emergency exit. Moreover, a vehicle driver did not respect the stop signals of the tunnel. As a result, this driver has also been involved in the incident. People involved in this event did not know how to behave after the incident: the evacuation process began only when a staff member arrived and guided people. The importance of the presence of this staff member during the evacuation was noted. The necessary personnel that must be present at the local control centre in the future is now a question under study.
Tunnel Operation	Tunnel operation during the incident went according to the emergency procedures. Anyway, some mandatory calls from the local control centre of the tunnel to the main control centre of the region could have caused a delay when alerting emergency services.
Emergency Services	Emergency services arrived 20 minutes after the incident. The firefighting services that arrived to the West portal had no radio or phone signal so that they had some communication problems. As a result, some operative rules regarding emergency services have been changed after the incident: Now, in cases of an incident in the tunnel, emergency services arriving at the West entrance have to visit the control centre, prior to any action in the tunnel.
Tunnel Equipment	All the systems worked as expected. IR cameras were really useful to follow the evacuation process, whereas classic cameras have been disabled because of the smoke. Barriers inside the tunnel revealed to be a good device to stop the traffic. Barrier at east portal was damaged by the emergency services. Therefore, its visibility has been improved after the incident. Once the emergency services took control of the situation, they activated the 2nd stage of the ventilation system (smoke exhaust stage). It now under study if such decision could be taken directly by the operator under specific circumstances.

Example 24: Motorcycle collision followed by a fire

Short description of incident: The incident occurred in a twin tubes 1900m long tunnel (2 lanes per tube) situated on motorway in an urban area.
An over-speeding motor cycle skidded, touched a handrail, stumbled and burned. There is no report of casualties.

MAINS CONCLUSIONS	
Human behaviour	Over speeding
Tunnel Operation	The collision was detected from the traffic control room through a CCTV camera. Sprinklers were in operation immediately and lasted for 7 minutes. 2 bottles of portable fire extinguisher have been used by patrollers (bottles loaded on patrol car). No change in operation rules was found necessary.
Emergency Services	Water fire extinguisher has been used for 16 minutes and lasted for 5 minutes by firemen.
Tunnel Equipment	Equipment performed as expected; fire extinguisher and sprinkler worked well.

Example 25: Collision followed by a fire

Short description of incident: The incident occurred in a twin tubes 780m long tunnel (2 lanes per tube) situated on motorway in an urban area.
A vehicle collided against a handrail due to mishandling. After the vehicle stopped, a fire started from the front of the vehicle that burnt partially.
The driver was slightly injured.

MAINS CONCLUSIONS	
Human behaviour	Driving mistake
Tunnel Operation	The collision was detected from the traffic control room through a CCTV camera. 2 bottles of portable fire extinguisher were used by the police. A foam fire extinguisher device was used by patrollers after 4 minutes. No change in operation rules was found necessary.
Emergency Services	Water fire extinguisher was used after 25 minutes by firemen.
Tunnel Equipment	Equipment performed as expected; fire extinguisher worked well.

Example 26: Car fire

Short description of incident: The incident occurred in a twin tubes 1350m long tunnel (3 lanes per tube) situated on motorway in an urban area.
A vehicle ran over a chain block which was assumed to have previously dropped from a truck and then left on the roadway.
After the driver stopped the vehicle, a fire started from the lower part of the vehicle.

MAINS CONCLUSIONS	
Human behaviour	Driver of the damaged car reported the accident to the traffic control room using an emergency phone.
Tunnel Operation	Before the fire extinguisher was used (after 26 minutes), the sprinkler system was activated (after 13 minutes), but the water spray did not reach the car because the location was too close to a portal.
Emergency Services	Water fire extinguisher were used after 26 minutes.
Tunnel Equipment	Equipment performed as expected; fire extinguisher worked well.

Example 27: Car fire

Short description of incident: The incident occurred in a twin tubes 2170m long tunnel (3 lanes per tube) situated on motorway in an urban area.
A car that previously had a collision on an ordinary road entered the expressway.
After entering the tunnel, the left-front tyre of the vehicle caught fire. The cabin of the vehicle burned.
The driver was killed in the fire.

MAINS CONCLUSIONS	
Human behaviour	The incident was reported with support of an emergency phone to the traffic control room by a worker that was working on a repair work of the expressway close to the accident location.
Tunnel Operation	Sprinklers were in operation after 22 minutes. Foam fire extinguisher has been used by patrollers. No change in operation rules was found necessary.
Emergency Services	Water fire extinguisher has been used after 100 minutes.
Tunnel Equipment	Equipment performed as expected; fire extinguisher and sprinkler worked well.

Example 28: Engine Fire on a Taxi

Short description of incident: Just after entering the tunnel, a taxi in the very left (slow) lane caught fire. It was just after the morning peak in a heavy trafficked tunnel, which is a twin tubes tunnel with 3 lanes per tube and about 1.7 km long.

MAINS CONCLUSIONS	
Human behaviour	The taxi driver called the Police for help. As there are no barriers to stop vehicles from entering the tunnel when closed, some motorists were slowing down, others left the expressway upstream of the tunnel but also some motorists continued into the "*closed*" tunnel. It is necessary to educate motorists in how to behave in the event of a tunnel fire.
Tunnel Operation	The Operator closed the tunnel and activated the fire ventilation mode correctly. After that, the Operator proceeded to broadcast evacuation messages through radio and variable message signs. Based on the fire ventilation system design, certain time periods are available for clearing the downstream tunnel vehicles before the smoke descends to an unacceptable height. However, due to the piston effect from the cars passing the burning taxi in the initial phase, the smoke layer spread to other parts of the tunnel.
Emergency Services	Emergency services/agencies responded directly to the incident. Communication amongst agencies is essential in order to optimise the organisation of response. Once at the scene, they closed the tunnel physically. It was established that initial responders can make the assessment to close the tunnel and stop traffic from proceeding further.
Tunnel Equipment	Learning from the incident - enhanced features are progressively being rolled out. The system has been enhanced with a more intuitive "*No entry*" graphic to be displayed on the VMS when the tunnel is closed to improve motorists' compliance to tunnel closure instructions. Traffic lights will also be installed and switched to red when tunnel is closed. The fire ventilation worked as planned. No smoke back layering was observed. The rest of the equipment performed also as expected but due to aging equipment it was difficult to get a clear view on site through the CCTV system (the CCTV system has since been upgraded, in line with earlier plans prior to the incident).

Example 29: Car accident

Short description of incident: In the approach of a 3 km long one bore toll tunnel with 3 lanes, a drunk driver lost control of his vehicle. Vehicle speed was too high. Both the driver and passenger were injured and hospitalised.

MAINS CONCLUSIONS	
Human behaviour	Drivers of other cars passed by. They respected the red lights and evacuated when needed.
Tunnel Operation	Cashiers on payment lanes are instructed to forbid access to the tunnel to drunk drivers. Video surveillance helps to identify drivers behaving unsafely (over-speeding, hazardous driving, etc.) so that the operator's staff are able to give them recommendations to prevent collisions.
Emergency Services	-
Tunnel Equipment	-

Relevant illustrations:

Example 30: HGV collision and Fire

Short description of incident: On the approach of a 3 km long one bore toll tunnel with 3 lanes, a truck driver, driving too fast, did not see a lane reduction. Consequently, he lost control of his vehicle and hit a signal concrete base. Some diesel oil spilled and degenerated into a fire.

MAINS CONCLUSIONS	
Human behaviour	HGV driver driving too fast.
Tunnel Operation	Maintenance team used fire extinguishers
Emergency Services	When firefighters arrived at scene, they took over from the maintenance team to contain and extinguish the fire. When police arrived at scene, policemen helped to stop the traffic.
Tunnel Equipment	The signals have been modified after the incident, for a better understanding of how to behave when drivers are approaching the scene.

Relevant illustrations:

Example 31: Collision with 3 vehicles involved

Short description of incident: In a 3 km long one bore toll tunnel with 3 lanes, a speeding vehicle hit a car ahead (low speed vehicle due to a mechanical failure). A 3rd vehicle behind was not able to stop and hit the speeding vehicle, resulting in 3 vehicles being damaged and slightly injuring the people.

MAINS CONCLUSIONS	
Human behaviour	Drivers of the affected cars remained in their vehicles. Drivers of other cars stopped to assist; drivers respected the red lights.
Tunnel Operation	Video surveillance helps to identify drivers behaving unsafely (over-speeding, hazardous driving, etc.) so that operator's staff is able to give them recommendations to prevent accidents.
Emergency Services	-
Tunnel Equipment	-

Relevant illustrations:

Example 32: Coach fire

Short description of incident: In a 6.2 km long bidirectional single bore traffic and adjacent evacuation tunnel, a coach caught fire and stopped in the tunnel. The coach driver went to the front of the coach and made a call on SOS Phone. The fire was detected by Operators using CCTV and linear heat detection. On site, fire rescue teams were mobilised and in attendance in less than 6 minutes. Fire was extinguished before it reached its full potential. People were evacuated into the evacuation tunnel. There are no reported injured people as a result of the incident.

MAINS CONCLUSIONS	
Human behaviour	Many poorly maintained vehicles are in use, and many overloaded goods vehicles are seen. Road traffic violations are unfortunately very common.
Tunnel Operation	Tunnel is monitored 24 hours per day allowing a rapid response to an incident. In case of a fire, the operation mode is as follows: • Fire is detected from CCTV or from the rate of rise addressable linear heat detection system which shows the tunnel zone of the fire; • The operator selects the ventilation fire plan for that zone, and the system is configured to automatically control the air flow to achieve zero velocity in the zone of the fire; • The operator closes the tunnel portals and sets intermediate traffic lights inside the tunnel to prevent traffic approaching the fire zone; at the same time mobilises the onsite Fire Team and on site Rescue Team. • When the rescue team confirms to the Operator that one side of the fire is clear of people, the ventilation is put into longitudinal mode in the direction of the side of the fire cleared of tunnel users so as to assist firefighting operations; • After the incident, an onsite scene clearance team clears the tunnel of damaged vehicles and prepares the tunnel for reopening, whilst system and tunnel integrity is checked by tunnel engineers. After the incident, the tunnel Operator has refined procedures so as to achieve the fastest possible response to tunnel fires by the onsite fire team.
Emergency Services	Rapid mobilisation and response of the fire team is considered essential to deal with the fire before it reaches a developed stage. Training and communications are regularly practised to achieve this. However, this incident demonstrated that even though the response to tunnel incidents by an on site fire team is very quick (less than 6 minutes), the fire growth can be even quicker. Since this incident, continuous improvements have been made to provide response teams with up-to-date rescue equipment and personal protection including: • Routine use of Breathing Apparatus by the onsite fire team; • New full size fire appliance capable of higher pumping capacity and stowage of cab mounted Breathing Apparatus for rapid deployment; • Personal protective clothing for fire fighters; • Additional 100,000 litre water supply tank, to increase duration of water supplies in the tunnel.
Tunnel Equipment	A jet fan system is used for ventilation in a fire situation. The jet fan system is fully reversible and uses a control philosophy to create a zero velocity in tunnel zone where the fire is situated. The zero velocity theoretically enables maximum stratification of the smoke to allow tunnel users to escape via cross passage doors into the parallel evacuation tunnel. After the incident: • New illuminated evacuation signage has been provided in the main tunnel aNew illuminated evacuation signage has been provided in the main tunnel and evacuation tunnel, in order to improve effective evacuation of people; • CCTV surveillance and control room displays have been improved, with planned links to Provincial Police control room to improve the control & identification of traffic violations; • Improved SCADA and Traffic Management Control computers have been provided; • Further investment is planned to improve the efficiency of the tunnel ventilation system.

Relevant illustrations:

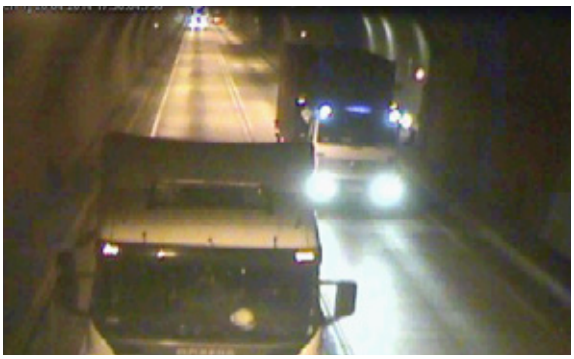
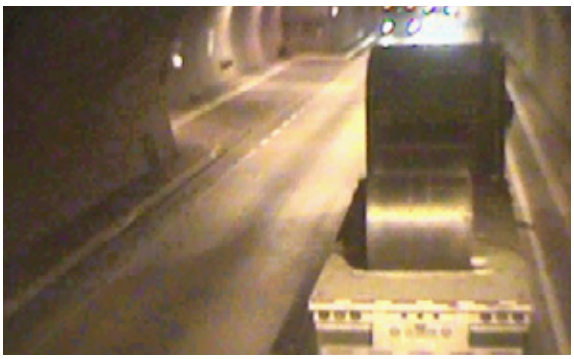
Example 33: Collision of 3 HGV

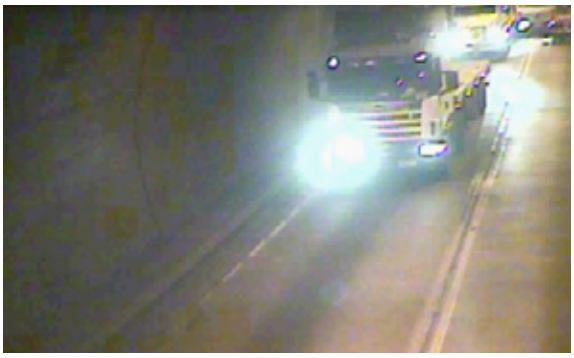
Short description of incident: A HGV driving fast on the road is detected through the Closed Circuit TV. The HGV is overtaking other vehicles on its way to the tunnel. The HGV enters the tunnel at high speed, without braking (due to brakes failure), and overtaking vehicles when possible. 1.8km after the tunnel entrance, this fast HGV collides with a second (unloaded) truck while overtaking it, causing a fuel release. A second collision occurs with another HGV coming from the opposite direction. The HGV that provoked the collisions eventually comes to standstill between the other twoh involved HGVs.

MAINS CONCLUSIONS	
Human behaviour	The driver of the HGV driving without brakes should have attempted to stop on an emergency lane before entering the tunnel (there are 5 emergency lanes along the 9km of road before the tunnel). There was no fire from the collisions. The driver of the HGV that caused the collision was the only person injured (not severely). The drivers of the vehicles in the tunnel, close to the incident, stopped to help.
Tunnel Operation	The tunnel operator detected the incident through the Automatic Incident Detection (AID) system, and sent staff on site. The operator in the control centre called the emergency services (ambulances, fire brigades and police), harbour terminals and the Control Centre of the Logistic Support Extended Area of the harbour, which is 10 km distance from the tunnel, in order to stop the HGV traffic. He also launched alerts about the incident through the Variable Message Signs on the road, and closed the tunnel. Serious traffic disturbances resulted from the incident.
Emergency Services	Fire brigades and health services arrived on site 10 minutes after the incident, and police arrived 60 minutes later.
Tunnel Equipment	No damages on tunnel structure nor to the equipment resulted from the incident. The tunnel was reopened 5 hours after the incident.

Relevant illustrations:





Example 34: U-turn of a HGV in a tunnel

Short description of incident: The driver of a HGV tried to make a U-turn in a single bore bidirectional tunnel. He finally got stuck on both sidewalls during the manoeuvre. During the manoeuvre of the HGV, the shock absorbers of the right back wheel were damaged.

MAINS CONCLUSIONS	
Human behaviour	Once the HGV got stuck, the driver went out from the HGV, and looked confused about what to do. Car drivers arriving on site made U-turns so as to look for alternative routes. HGV drivers arriving on site remained stopped in the tunnel.
Tunnel Operation	The Automatic Incident Detection (AID) system detected the HGV trying to do a U-turn. The operator advised the driver that this manoeuvre is forbidden through the Public Address System. Without taking any notice of the call from the operator, the driver continued the manoeuvre and got stuck between both sidewalls, blocking all lanes in the tunnel. The operator then closed the tunnel, turned the traffic lights to red, warned the other drivers using the Variable Message Signs on the open road and in the tunnel, and sent staff to the place of the incident in compliance with procedures. As the truck was loaded, the transport owner sent a tow truck to unlock the cabin and remove the container. This operation lasted 2:45 hours, with the assistance of the operator's road staff.
Emergency Services	The Police attend the incident and issued the offender with in fringement notice. No other emergency service was required. The tunnel operator telephoed the Control Centre of the Logistic Support Extended Area of the harbour, which is located 10 km from the tunnel, in order to stop the HGV traffic.
Tunnel Equipment	The tunnel equipment worked as expected: in particular, the Automatic Detection System warned the operator about the incident. There was no damage to the tunnel structure nor to the equipment resulting from the incident.

Relevant illustrations: