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FIRE IN ROAD TUNNELS AND LIFE SAFETY: LESSONS TO BE LEARNT FROM MINOR ACCIDENTS

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ABSTRACT

In the aftermath of the accidental fire disasters in several road tunnels at the turn of the century, fire safety in road tunnels was largely addressed through analysis of information drawn from major accidents; i.e. those resulting in significant casualties. This paper demonstrates that minor fire accidents in road tunnels, that is those resulting in no casualties, are also able to provide substantial and useful information relating to fire safety in tunnels. Many of these, fairly frequent, minor incidents had the potential to become major incidents, but a mixture of luck and appropriate actions, taken both by tunnel users and professional rescuers, helped prevent tragedy. Generally, information on minor incidents is limited to short dispatches or small 'news' articles issued for the wider public. This often scarce and scattered material is also marked by a cultural imprint which reveals the courage and initiative of people involved in the incidents, but also blurs and sometimes hides some aspects of the incidents which, perhaps, should have been highlighted. Through an analysis of a few recent examples of minor accidents, from all over the world, this paper shows why such information, despite often being of limited quality, should be systematically collected, integrated into existing databases and processed in order to better understand these incidents and, ultimately, prevent minor tunnel fire incidents escalating into major disasters.

INTRODUCTION

Since the severe fire in the Mont-Blanc tunnel, in March 1999, and the other tunnel fire disasters in Austria and Switzerland which occurred soon after, the attention of the fire safety community, with regard to runnel fires, has focussed mainly on major accidents. This interest in big catastrophes is also consistent with the various concerns marking our 'post September 11th' age. Also it is understandable within the general context of road tunnels themselves :

- Safety standards and regulations were viewed as needing revision without delay in the light of these 'worst case' scenarios which, for example, led the countries of the European Union to start a process of updating a number of regulations and guidelines for fire safe design of road tunnels [1].
- Scientifically sound investigation of realistic fires, by means of experiments or computer modelling, is easier to perform in the case of large fires than in the case of small fires. Large fires may be more liable to lead to deterministic histories, compared to more randomly evolving small fires, consequently they are naturally favoured in analyses by modellers and experimenters. This observation was clearly illustrated in a recent symposium [2].

Minor accidents due to fire in traffic tunnels are, however, fairly frequent; fortunately more frequent than major ones. These are labelled 'minor' because they resulted in no (or only minor) casualties and no major damage to runnel facilities, and for these reasons are generally only briefly reported in the media; in stark contrast to the 'big' accidents which generally generate comprehensive analyses by stakeholders at all levels.

More and more of these minor accidents have been mentioned in surveys in the last few years, where they

often play the role of underlining the relatively small number of severe accidents among a quantity of incidents resulting in a 'happy ending' (i.e. "it caused more fright than real harm") [3]. However, they also give an opportunity to study the sequence of events that resulted in a 'minor' outcome and consider which factors (including, for example, human behaviour) prevented the incident escalating to far more serious consequences [4].

This paper reviews some recent and, perhaps, significant 'minor' accidents involving fires in road tunnels, and identifies, through a deeper look at the characteristic aspects of such events, several aspects likely to lead to better management of the daily risks that may be reduced, but never eliminated, by fire safe design in road tunnels, however excellent the latter may prove in the future.

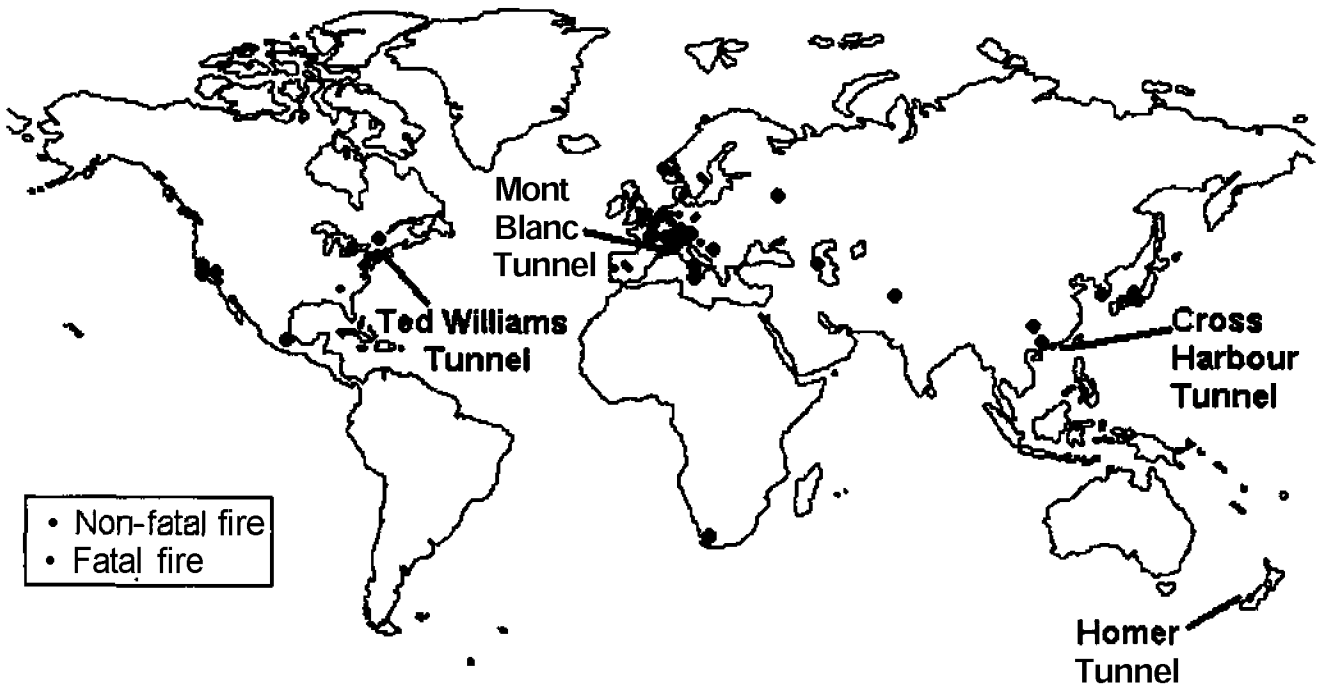
BRIEF DESCRIPTION OF SIX MINOR ACCIDENTS

Minor accidents involving fire in road tunnels occur regularly in each of the 'four corners' of our planet. In order to illustrate the preceding considerations, four incidents have been selected as being of particular interest, each from a different continent, all having taken place at the beginning of this century:

- A car fire in a tunnel in Asia (the Cross Harbour Tunnel, Hong-Kong, 29 May 2000) [5].
- A bus fire a tunnel in Oceania (the Homer Tunnel, New Zealand, 3 November 2002) [6].
- A bus fire in a tunnel in America (the Ted Williams Tunnel, Boston, USA, 19 May 2002) [7].
- An incident caused by smoke reportedly due to a "fondue" (melted cheese) cooked by firemen in the middle of a tunnel in Europe (the Mont-Blanc Tunnel, 25 September 2003) [8].

Two other European incidents are also briefly commented on.

Figure 1
The location of major and minor tunnel fire incidents
(reproduced from "The Handbook of Tunnel Fire Safety" [24], with permission)



Cross Harbour Tunnel (Asia)

Cross Harbour Tunnel (CHT) is one of the several toll motorway tunnels linking Hong-Kong Island to

Kowloon, "the Nine Dragons", i.e. the continent. Its two tubes of two lanes have a length of 1848 m, of which 1455 m are immersed. The major steps of the fire incident which happened on 29 May 2000 are as follows:

- Heavy smoke is detected at 1325 Hrs (= t*) in the Kowloon bound tube, generated by a private car fire ; fire emergency procedures are accordingly activated : a fire rescue team is dispatched to the incident scene, all vehicles are stopped at both tunnel entrances, the ventilation system is switched to 'fire mode', an emergency gate is opened to facilitate the access of fire engines.
- t* + 12' : The majority of the tunnel users are led to the other tube (the Hong Kong bound tube) through emergency cross passages.
- t* + 19' : The fire is declared under control.
- t* + 31 ' : The fire is suppressed, the evacuation operation is completed (a total of 500 people).
- t* + 45' : The HK bound tube is re-opened to traffic.
- t* + 55' : The Kowloon bound tube is re-opened to traffic.

Homer Tunnel (Oceania)

The Homer Tunnel, located in a remote mountainous area of New Zealand, is on State Highway 94; the only road giving access from Te Anau, a town almost 2-hours travel away from the eastern end, to Milford Sound, a village 20 minutes from the western end [9]. The unlit, single tube tunnel is 1.27 km long on a steep 10 % gradient. The tunnel is bi-directional for cars but buses are generally only permitted in one direction at any given time.

The incident which occurred on 3 November 2002 involved a bus with 32 Singaporean tourists on a return trip from Milford Sound. At a distance of just 150 m from the eastern exit, the driver noticed flames coming from the rear of the bus ; he stopped immediately, got the passengers off the vehicle, made them link hands and walked them towards the nearest exit ; in the meantime, the burning bus rolled back 50-100 metres and went on burning, with a couple of explosions. Three of the escaped passengers were treated for smoke inhalation when the emergency services arrived from Te Anau. Two passengers who had walked the other way to the western portal were found some time later [10], presumably unscathed (see below). Damage to the tunnel itself was superficial and the tunnel re-opened to traffic on the following day [9].

Ted Williams Tunnel (America)

Named after Ted Williams, a famous baseball player from Boston, Massachusetts, this 2×2-lane toll motorway tunnel consisting primarily of a "binocular tube" [12] - which allows a partitioning of the two traffic ways - is a major component of the Boston Central Artery/Tunnel project (also known as "the Big Dig") [11]. The TWT leads over 2.5 kilometres from the South Boston waterfront to Logan International Airport in East Boston, under Boston Third Harbour for 1.2 kilometres, and was originally called the "Third Harbor Tunnel".

The incident on 19 May 2002 happened in the following sequence [7,11] :

- The second of two convoying buses, carrying the Seattle baseball team to Logan Airport, caught fire in the runnel; both buses pulled over near the end of the tunnel.
- The fire was not detected by the installed linear heat detector system but by a carbon monoxide (CO) alarm (ceiling detector); at 1724 Hrs a camera focusing on the smoking bus then allowed highway operators to record the incident ; the cause of the fire was probably an electrical malfunction in the battery compartment at the rear of the bus.
- As soon as possible all the passengers from the 2nd bus escaped it and boarded the 1st bus, which continued to the airport, stopping shortly after leaving the tunnel in order to let everyone get some fresh air. Everybody was checked before the plane took off; the driver of the bus that caught fire suffered smoke inhalation, some other passengers were given oxygen too, but all people eventually recovered (however, the bus driver did not recover until the following day).

- Both sides of the TWT were closed to traffic until the blaze was extinguished by fire-fighters, at 1820 Hrs, i.e. about one hour after detection ; in the meantime, the other motorists had abandoned their cars and run to the fire exits (one door every 305 m). Tunnel traffic eastbound (to the airport) was then re-opened and tunnel traffic westbound (to downtown) was re-opened a little later (1900 Hrs).

Mont-Blanc Tunnel (Europe)

This well-known tunnel (a single tube 11.6 km long) linking France and Italy through the Alps, a few years ago the seat of one of the biggest ever tunnel fire catastrophes (39 dead in March 1999 following a truck fire), has very recently been the scene of a strange incident resulting in the closure of the tunnel for 2 hours on Thursday 25 September 2003.

The safety provisions initiated after the 1999 catastrophe include a permanent watch of the tunnel by firemen at three locations: at both tunnel portals and a new fire control room in the middle of the tunnel. Late in the evening that Thursday, three firemen present in the fire control room, a 'confined' space of about 60 m^2, were reportedly [8] indisposed by pollution due to "carbone oxide" (meaning CO or CO_2) or "carbone dioxide" (CO_2), reports vary. All reports [8] agree, however, that the pollution was due to the cooking of a "fondue savoyarde" (a meal from the Savoie region of France, basically a mixture of melted cheese with white wine). Some of these reports stated that the "carbone dioxide rate" (sic) increased rapidly, within a few minutes, up to an "alert threshold" of 25 (with no unit specification), then 50 ("evacuation threshold"), ultimately reaching a peak value of 52. The three firemen were evacuated, and the tunnel was closed for a couple of hours, the delay needed to replace them with a new security team.

The official public report of the incident written by the tunnel authorities [13] made no mention of any "fondue savoyarde" nor any "carbone monoxide/dioxide" peak, but just a sudden decrease of an "air quality index" (without further detail) which occurred only in the fire control room and not the tunnel tube itself. The three harmed firemen were taken to a hospital where they stayed for 6 hours before being discharged. Normal operation of the traffic in the tunnel was resumed overnight.

Two more minor incidents in 2004 : Kinkempois Trench (Belgium) and Dullin Tunnel (France)

When considering human effort to ensure fire safety in tunnels, the 'happy ending' of the last Mont Blanc Tunnel incident might be considered only of limited interest, which is not the case for two very recent incidents in other European tunnels; each resulting in no harm to anyone due to the appropriate behaviour of the key characters involved in the incidents. These also deserve to be briefly mentioned:

- *Kinkempois Trench :* On Tuesday 3 February 2004, in this 2-tube tunnel 735 m of length located in Belgium under Cointe Hill, a refrigerated lorry carrying mushrooms caught fire at rear axle level and stopped in an emergency side shelter some 30 m before reaching the exit portal [14-16,29]. The driver tried then to suppress the fire with his extinguisher, but he failed and had to move away. An emergency call was received at 1415 Hrs (= t*), 3 minutes later all safety procedures were activated including the closure of both tunnel portals. At t* + 15' the fire-fighters started to extinguish the fire, a task completed at t* + 30', and at 1600 Hrs vehicle traffic was resumed in the 2nd tube (the 1st tube remained closed for one week). Nobody was harmed, or even indisposed by smoke, and the motorists who had to stop behind the wrecked lorry and to walk to refuge in the other tunnel tube have all got their vehicles back undamaged.

- *Dullin Tunnel :* On Sunday 18 January 2004, in the middle of this 2 -tube tunnel 1543 m long located in France on A43 motorway linking Lyons and Chambéry, a coach carrying 37 British passengers suddenly caught fire at the back [17-20]. The French driver, a former fire-fighter, having noticed smoke spewing from the engine after the vehicle entered the tunnel, decided not to stop but rather to speed through the remaining 800 metres to the tunnel exit while urging all his passengers to move to the front of the bus. Once outside the tunnel he evacuated the bus and all passengers were later transferred, safely, aboard another bus to their destination. However, the driver failed to control the fire using the bus extinguishers,

and his bus was totally destroyed. The fire reportedly originated from a mechanical problem within the engine compartment.

FINDINGS AND LESSONS

By comparing and examining in detail the reports of the incidents described in this paper, as well as reports from other 'minor' tunnel fires not recorded here, a number of common themes in tunnel fire incidents have been identified. These are summarised in the sections below. It should be noted, however, that the available documents, in some cases only 'news' reports rather than 'official' reports, may not record all the important features of these incidents. Other, more 'official', documents may exist but are not publicly available, for various reasons.

1. The line separating minor accidents from potentially major disasters is not clear

The dividing line is clear with regard to the eventual consequences of an incident (no victims, no significant injuries, at most slight and temporary harm, instead of casualties or fatalities), but it is not clear from the incidents themselves :

- The driver and 30 passengers who walked to the nearest portal in the Homer Tunnel incident [6,9,10] had a narrow escape, as they had to walk towards the exit through 150 metres of a smoke filled, unlit tunnel. These poor conditions were due to the fact that the section of tunnel that they walked along was uphill of the fire (remember, the tunnel has a steep 10 % gradient). In addition to smoke, heat and a lack of visibility, the evacuees also had to contend with a hard walk uphill. The two passengers who walked the other way, i.e. downhill, had a more tenable environment for escape but were also endangered by the movement and subsequent explosions of the bus itself. The most injured of the evacuees at the eastern exit were not driven but flown [6] to a hospital in Invercargill (a city much farther away than Te Anau, the most southern city of New Zealand) which may indicate concerns about a serious potential for harm from the fumes they had breathed.
- The Seattle baseball players and those accompanying them who escaped the burning bus, are recorded as saying that they "were lucky to get off [7]. The largest element of 'luck' in this instance was that another bus was present at the time of the incident and was able to remove the passengers from the fire location very rapidly. This rapid and orderly evacuation was also undertaken by athletes, used to working as a team, in prime physical condition. Perhaps if the two buses had been carrying aged travellers instead the outcome would have been very different.
- Further investigation after the fire incident at Hong Kong Cross Harbour Tunnel [21] showed that the first rescue team dispatched to the incident scene (within the first three minutes) did not comply with the established safety procedures; specifically, instead of using fire extinguishers to control the fire (there are fire extinguishers at regular intervals in the CHT), they decided to leave the scene to assist evacuation. As a result, attempts to control the fire did not begin until the second rescue team arrived 5 minutes after the smoke was detected. In fire development, every minute counts; fortunately, in this instance, the fire did not grow too quickly and nobody was trapped by the fire, either inside or outside of the vehicle.
- The lorry driver in the Kinkempois tunnel was alerted to the fact that something was wrong with his vehicle by other motorists as they overtook him [16]. If this had not happened the fire might have grown to a much larger size before he became aware of it and the incident might have led to quite a different outcome. After it was stopped, several vehicles (including lorries) overtook the vehicle on fire and this continued until the tunnel was smoke logged. Once again, 'luck' played a role as no collisions occurred in the poor visibility and, hence, the fire did not get the chance to spread.
- Another crucial piece of 'luck' played a positive role for the survival of the British travellers nearly trapped in their coach fire. The fire involved the rear part of the coach [17] and not the front part of it, enabling the driver to continue driving and allowing the passengers to gather at the front of the bus, as far as possible from the developing blaze, before the bus came to a halt outside the tunnel. Reports differ on the attitude of the passengers within the coach, e.g. BBC news described their behaviour as "panic" rather than an ordered evacuation [20]. However, it is not clear how large the 'safety margin' was in this case. If the

fire had started a few minutes earlier or if the tunnel had been a kilometre longer would the bus have made it to the exit portal in time? Moments after the bus was evacuated (outside of the tunnel) it was fully ablaze, if this had happened inside the tunnel the result might have been catastrophic.

Most cases examined in this study had the following characteristic in common: *the route to safety was a comparatively short one;* either the vehicle on fire stopped close to a tunnel portal or another vehicle was on hand to assist in the immediate evacuation of people from the incident location, either by chance or purposely.

In summary, a **'happy ending'** may have concluded a history involving serious hazards for the people involved, which a further analysis should ideally confirm or invalidate.

In fact, during any fire accident in a road tunnel, given that the primary fire source is something which was passing through the tunnel and effectively **'unknown** to the **tunnel'** itself, there is a random aspect in the first minutes following the fire start, which may be minimised but can never be cancelled. A minor accident does not mean a minor fire nor a minor threat; consequently, considering that all minor accidents could have been the first steps of major ones is quite a reasonable approach, and considerable attention has therefore to be paid to them.

2. Major scenario details often remained unknown, or were intentionally hidden

- This was quite obvious in the Mont-Blanc tunnel incident, concerning the source of the problem itself: the effect of cooking a "fondue savoyarde" with electric plates (instead of just warming it [8]) on an increase of CO or CO_2 concentration is hardly believable. Likewise, the "sudden decrease" - without apparent cause - of an air quality index (and an equally sudden return to normal once the safety team was evacuated) [13]. Perhaps the fear of being perceived as having a poor fire safety record, despite the extensive refit following the 1999 disaster, led to some details being deliberately suppressed.
- Some uncertainties also remained in the scenario of HK CHT incident but, unlike the previous case, the authorities expressed a will to openly report information on them (for example, in the first stage of the investigation, it was revealed that the first rescue team did not tell the truth about their actions on arrival at the incident location [21]).
- In the case of the Homer Tunnel incident, no reference was made concerning other motorists that might also have been involved [6,9,10]. The daily traffic figures were nevertheless reported [9] to rise up to 1000 a day in summer, of which 200 are buses, which makes an average of more than one vehicle per minute (estimate on an approximately 12-hour operation basis).
- The interests of the mass media may also have hidden potentially useful information. For example, after the TWT incident the official broadcaster of the Seattle team declined to say which players were given oxygen [7], thus partially hiding the extent of the injuries. Conversely (and rather naturally), spotlights were directed on the baseball team - the first involved in the fire, indeed - but very little was reported about what happened to the other tunnel users, apart from a vague statement saying that they "abandoned their cars and ran for the exits" [7].

3. In these events human behaviour always played an important role

Solidarity, courage, intelligence and a spirit of initiative were among the chief qualities of those whose appropriate behaviour contributed in large measure to the **'happy ending'** in these incidents. This behaviour, whether instinctive or as the result of a conscious decision, often brought those individuals into greater danger in an attempt to save others:

- In the case of the Dullin tunnel incident [17-20], when the driver took the decision not to stop in the tunnel but to accelerate.
- In the case of the Kinkempois tunnel incident [14-16], when other drivers alerted the lorry driver of a smouldering fire concerning his engine.
- Also during the TWT incident [7], where the team manager left the 1st bus and did not hesitate to run into a

wall of smoke to provide help to the 2nd bus passengers.

- In the Homer Tunnel, when the bus driver, later given a 'highway hero' award [10], stopped his burning vehicle, got the passengers off it, ensured that all were safely off, made them form a human chain and led them to the exit.
- In the HK CHT [5,21] (despite the irregularities that were noted in a previous paragraph) the 1st rescue team was at the incident location a few minutes after the alarm. This is remarkable given the conditions in the hot, crowded and smoke filled tunnel at the time.

In summary, the weight of human factors taking part in these events was certainly more significant than in the case of, for example, the 1999 Mont Blanc fire (where a major fire occurred in the first few minutes, near the mid-point of single tube tunnel, much longer than those considered here). Human factors - not the easiest ones to be investigated - were critical in these instances, which is why they merit a particularly close examination; in order to determine, from case to case, which combination of factors led to the 'happy ending'. Here, the challenge is to address individual human behaviour in a very positive way, far from any "Pavlovian" reactions sometimes expected from people who are only seen as part of a crowd.

4. The event accounts were strongly marked with cultural imprint

A striking feature of the reports of tunnel fire events with 'happy endings' is the style in which they are generally written; these reports (often news articles) bear a strong imprint of cultural references from the region where they occurred, resulting in particular emphasis on certain aspects, while neglecting to mention other aspects which may be of more importance. The highlighted aspects are often presented as being critical in some way, while a closer examination may lead the reader to question the importance of these aspects. Some examples of this are:

- Some French reports on minor accidents appear to be overly brief when containing explanations of events; these appear to have been filtered and simplified by a "Jacobinic" authority with a view to reassuring the people. Thus they avoid giving too many details for fear of being questioned; this occurs in the context of a country whose ancestors were said to be afraid of "the sky falling on their heads". This is quite obvious in a series of reports [3] published from 2001 through 2003 about incidents in the Fourvière tunnel, a 2-tube motorway tunnel of almost 2 km in length located in the middle of the city of Lyon. Here is a sample of information given in some reports of tunnel fire incidents:
  - (12 September 2001) "A motorbike involved in an accident caught fire / traffic southbound was stopped for about one hour / order has been restored at 3:00 p.m."
  - (2 & 3 June 2002) "Dreadful fright in the tunnel / a car caught fire for an undetermined reason at 400 m away from the northern portal, resulting in thick smoke / Fortunately no victim was reported / The family which was aboard is safe / 300 people were evacuated / But the traffic northbound was stopped twice for technical checks / An accident questioning safety and tunnel access in case of problem during traffic peaks."
  - (5 June 2002) "More fright than real harm in the tunnel / Motorists moving northbound around 9:20 p.m. left their vehicles because of dense smoke emanating in the tunnel / All safety systems operated properly / The tunnel was immediately closed to traffic / Smoke did not come from a fire but from a lorry which could have broken a cylinder head gasket."
  - (13 August 2003) " More fright than real harm in the tunnel / At around 13:30 p.m. a dense smoke flowed in the northbound tube, resulting in panic of motorists / Fire-fighters arriving on stage only found a thick cloud of vapour they dispersed / This was probably due to the overheating of a radiator or a cylinder head gasket / Impossible to learn more because the vehicle involved went on its way towards Paris / At 14:30 p.m. the tunnel opened back to traffic."

  Another example of rather sketchy information was given in an official report already mentioned on a recent incident in the Mont-Blanc Tunnel [13].
- In a sparsely populated, "New World" country like New Zealand, where individuals are more likely to have to deal with dangerous events by themselves than in other, more densely populated, parts of the world, self bravery and a spirit of solidarity are high on the scale of values. During the Homer Tunnel

accident [6], the bravery of the bus driver played a crucial role (justly recognised by an award [10]), although one point remains questionable: before entering the tunnel, the bus had an oil warning light flashing on the dashboard, which could have indicated a major problem with the engine. The wise response in such a case would have been a thorough check of the engine, instead of just topping up the oil, which is what the driver did [10].

- Conversely, in a densely populated region like Hong Kong, people generally move - walking or aboard vehicles - in huge crowds. The sense of hierarchy is imprinted in Chinese culture and discipline is a cardinal value, consequently the failure to comply with strict obedience to established rules is more often punished than forgiven, and this has been demonstrated after the Cross Harbour Tunnel incident; the concern with discipline is particularly striking in the reports and comments that followed [5,21] and, as was mentioned above, the attitude of authorities may be considered rather severe against the two people of the first rescue team who had reacted promptly and compassionately, if perhaps not 100 % properly, in the difficult situation they found themselves in. Let us recall that, instead of trying to extinguish the fire (as specified in the emergency procedures) they helped evacuation, which was not necessarily a bad choice, given the failure often encountered in extinguishing vehicle fires with light equipment in that sort of context. The authorities, however, were upset as they had to deal with numerous complaints following the accident :
  - Slow detection of the fire by the tunnel staff (2 minutes, should have been ~ 0 min. !).
  - Slow arrival of the 1st rescue team (3 minutes, when the pledged response time was 2 min.)
  - The 1st rescue team did not wear masks, neither did they use a fire hose to extinguish the fire.
  - Their failure to hand over the operation to the fire officers on their arrival (2 min. later).
  - Confusing radio broadcasts due to another incident which occurred just before the fire incident.
  - Unsatisfactory evacuation (motorists and bus passengers feeling trapped for some time).

  Such complaints have to be considered within the context of the overcrowded and sometimes over-polluted atmosphere, where feelings of claustrophobia are likely to emerge very quickly after any incident occurs. Any misbehaviour is seen as having the potential to generate a catastrophe. Consequently, discipline is preferred to a spirit of initiative. Moreover, Hong Kong residents tend to be rather brisk and react promptly to unpleasant situations; as demonstrated by the comprehensive investigation that took place after the CHT incident. Nevertheless, despite many recommendations being made after the incident, it has been observed that none of them relate to the enforcement of a safety distance between vehicles in the tunnel.
- The way the TWT fire was reported [7] fits with the culture of a country characterised by its high level of technical development, along with a general concern with public image and with economic and legal consequences of any dysfunction occurring or likely to occur. The whole baseball team was reportedly checked on by fire-fighters before they took off after the incident, but, as noticed before, little detail was given about who among the players was affected or not. Technical (e.g. lack of response of linear detectors) and financial (e.g. damage, additional investment) consequences were extensively given.

In brief, there are cultural imprints marking the event accounts summarised above; these features demonstrate the close relationship between the actual conditions (that vary from one region to another) and the characteristics that each culture has developed, resulting in the location and culturally specific actions used in the control of unwanted situations.

SUGGESTIONS AND PROPOSALS

There is an important feature evident in all the reports of minor accidents discussed in this paper: the positive role - whether recognised by the authorities involved or not - played by individuals in the various instances presented. This leads us to reconsider the general concept of fire safety provisions in road tunnels, which should ideally include two types of goals/challenges :

→ goals/challenges concerning the tunnel designer and the tunnel operator, the fire authorities and perhaps also the local road authorities.

→ goals/challenges concerning the individuals temporarily involved in the life of the tunnel; as they move through the tunnel from one portal to the other as vehicle drivers or passengers.

Among the goals/challenges belonging to the 1st type, i.e. involving directly tunnel and road professionals, fire safety procedures and equipment, can be viewed in two ways:

→ *Stricto sensu,* which basically means: efficient equipment and management for detection, alarm, ventilation, suppression, evacuation of people.

→ *More generally,* by complementing the above with, for example:
- prevention of any potential risk due to the layout of roads and crossing (merging) zones as far as possible; a recent forum report [4] indicated that traffic free flow is often considered a more important goal than safety in Switzerland, which may result in complex lane merging inside tunnels,
- efficient control of the way motorists drive their vehicles while in the tunnel, e.g. with enforcement of minimum distances between vehicles,
- prevention (by technical means) of any use of mobile phones inside the tunnel, which remains a source of potential risk.

But the goals/challenges of the 2nd type above should involve both professionals and non-professionals:

- Since a bus or HGV (and LGV too) driver is clearly a professional who should be capable of relevant initiative in the case of an emergency due to fire/smoke. This is of immense importance as the actions of a bus driver in an accident scenario may influence the chances of survival of fifty or more people, a number greater than the total number of fatalities in any of the worst road tunnel fire incidents.
- Since runnel designers/operators and fire/road authorities have a good view of their sites and/or the phenomena related to fire, they are best placed to address the definition of relevant actions if a situation develops, aiming at stimulating an integration of such actions by individuals, e.g. through information, education and training. This is all the more important considering that many case-to-case recommendations still turn out to be controversial [4]. General information communicated to the people e.g. the new rules of use [27] of the Mont-Blanc tunnel (which re-opened recently) are valuable and necessary, but could not meet such a challenge since they promote a series of specific actions, useful in the specific case of the Mont Blanc Tunnel, but not generally applicable to all instances of fire in any road tunnel.

All the aforementioned goals, which can be considered as complementing one another, could be achieved by the setting-up of an extensive base of knowledge concerning the minor accidents which have occurred:

- Databases concerning accidents in road tunnels - as well as in other types of tunnel - do exist and gather valuable information on major and minor accidents, e.g. 'Database 5' available on the 'FIT' website [1,26,27]. An extensive database on tunnels in general, all over the world, has also been set up by Gunnar Lotsberg [23] and also includes data on fire accidents. An extensive list of many tunnel fire incidents will shortly be published in "The Handbook of Tunnel Fire Safety" with future incidents to be added to the website of the book in due course [24]. Such databases should be redeveloped or have some sections redesigned in order to host additional data on minor accidents, and hence to form the framework of a comprehensive base of knowledge. By a recent official circular [25], France enforced the reporting of all so-called 'significant' incidents in road tunnels belonging to the national highway network,. . It is hoped that this will become a world-wide trend and, hence, much more information on minor incidents will become available in the future.
- Information on minor accidents, at present generally scarce and scattered, should be gathered and fed systematically into such a base of knowledge, with a view to keeping it relevant and up-to-date. Without neglecting reports and dispatches issued for the general public and full of details that can be cross-referenced - for example, those referenced in this paper - they also should ideally incorporate data from professional reports and investigations; hopefully these will be published instead of remaining confidential, when they exist. An example of such valuable reports has been issued by the Norwegian Public Road Administration [28] after a minor accident (in the sense we defined in our paper) in the Seljestad Tunnel (Norway), which occurred on 14 July 2000.

- New elements of knowledge could also be drawn from such a database through statistical analyses, with emphasis on common aspects linking various minor accidents; insofar as there are common aspects which influenced the course of events, e.g. the fact presented above that the vehicles on fire were stopped by their drivers not too far from a tunnel portal. Other important criteria have also been identified from statistics; some observations to date include the disproportionately high instance of minor accidents in non-operational tunnels (i.e. during construction or refurbishment) and the significantly high number of minor incidents involving buses (which, again emphasises the crucial role that bus drivers play in tunnel safety).
- Conversely, exploring specific aspects of each minor accident, especially those concerning relevant actions undertaken by rescuers, could enrich the range of 'feasibilities' in that field. This could be complemented with some sort of 'sensitivity analysis', in order to imagine other courses of events that might have resulted from slight changes in the initial parameters or configurations involved in minor accidents which actually occurred, and consequently provide a better assessment of the actual actions that were undertaken in the event.

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