FIRE SAFETY OF THE RAILWAY SYSTEMS

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ABSTRACT

Consequent to the arson fire in an underground train vehicle while travelling under the harbour, a paper "Preventive and Response Measures for Emergency Incidents" was discussed by the Legislative Council of the Hong Kong Special Administrative Region. Fire safety aspects in that paper will be discussed in this article. The total fire safety concept of implementing software fire safety management to control hardware provision, both passive construction design and active protection systems, is suggested to be considered.

1. INTRODUCTION

An arson fire happened recently [e.g. 1] in an underground train vehicle of the Mass Transit Railway MTR in the Hong Kong Special Administrative Region (HKSAR), while travelling from Tsim Sha Tsui Station to Admiralty Station under the harbour on 5 January, 2004. The fire was deliberately set by an arsonist using newspapers, a lighter and one of the five bottles suspected to be containing gasoline in the front compartment adjacent to the driver's cabin. Small LPG canisters were believed to be ignited. Fortunately, it did not grow up and very little damages were resulted. The consequence was not so serious in comparing with a similar arson fire in Daegu, South Korea in 2003 [2]. Perhaps, the emergency operation schemes of the local underground railway are more well-planned with appropriate actions taken at the right time; or the fire extinguished by itself, say due to insufficient air, not much combustibles to burn or appropriate actions taken by other passengers. A good point for the local train vehicles is that the walls are required to be 'non-combustibles', thus giving a very low 'fixed' fire load density.

However, that arson fire has raised public concern on the fire safety provisions in public transport. As reviewed before on the ventilation hazard in MTR trains several years ago [3], many citizens travel on the several railway lines everyday and might stay in the train compartment for up to an hour. The traffic loading for the local railway lines is very heavy. One of them has to accommodate up to 3,000 passengers in each train during rush hours. Some of the railway lines are built underground and some through tunnels.

Even though that MTR arson fire had not led to disasters as in the Daegu train fire, the two railway companies were instructed by the SAR government to review their emergency actions and preventive measures. Note that there had been small accidental fires in the local railway line [e.g. 4] before; and the number of non-accidental train fires appeared to be increasing [1,2,5]. A paper on "Preventive and Response Measures for Emergency Incidents" was discussed [6] by the SAR Legislative Council (LegCo). The fire safety provisions in trains were briefly discussed. This should only be the first step of studying how adequate safety can be provided in the railway lines.

In this article, comments on the fire safety aspects discussed in that LegCo paper [6] will be made. The necessity [7-10] of upgrading the current fire safety in the railway lines, both in the train compartments and railway terminals, by more researches and investigations as in the Korean railway [11-15] and others [16-20] is pointed out. This will take time to determine the appropriate hardware fire safety provisions on passive construction design and active fire protection systems; and even longer time to install those hardware provisions. An immediate action is to consider the total fire safety concept [21] by working out appropriate software fire safety management [22-25] to control hardware fire safety provisions [e.g. 26]. In fact, there had been some preliminary studies on train and bus fires in Hong Kong [7-10,27-32], more support is needed to provide better safety in the public transport systems.

2. THE ARSON FIRE AS REPORTED

An arson fire happened in an MTR train vehicle [1] while travelling under the harbour at 9:12 am on 5 January, 2004. As reported in that LegCo paper [6], a time line [10] of the events can be drawn as in Fig. 1 to describe the incident. The fire lasted for at least 2 minutes, with something still burning up to 4 minutes. The time line [9,10] for the

Daegu train fire in South Korea occurred on 18, February 2003 is also drawn in Fig. 2 based on the reports appeared in the recent literature [e.g. 11-13]. This indicated that 5 minutes would lead to a disaster [11-15].

The MTR arson fire did not grow big [1] as in the South Korean train fire [2], though the arson fire started in a similar way from four bottles of liquid fuels, which appeared to have similar combustion behaviour. Anyway, the train was instructed to move into the station 2 minutes later. Doors were opened and passengers were evacuated. The fire appeared to be under control within 4 minutes. Only 16 passengers and 1 staff were injured.

As reported in the LegCo paper [6], possible reasons are:

- The fire was started in the front part of the train without affecting most of the passengers.
- Though the fire happened within the rush hours, the train was not so crowded (with about 1000 passengers). This gave chance for the passengers in the front part of the train to move to the 'rear' part quickly. The evacuation time for leaving the train with platform screen doors PSD was short due to low passenger loading (only about 200) in the platform. Although the PSD were opened in time, this point should be reviewed further as pointed out recently on public safety in China [10] and in the discussion on railway fire in Beijing and the new links to 2008 Olympic Games Hall [7].
- Good, 'brave' and correct actions taken by a passenger to stop the arsonist from burning the fuel properly.
- Not much combustible luggage was placed nearby the fire.
- Correct actions taken by the MTR management at the critical moment.
- Good communication within the railway system. Note that communication problems had been identified in the Daegu train fires [2] in early 2003. Railway systems all over the world should have worked out acceptable communication systems.

3. ITEMS DISCUSSED IN THE PAPER

The SAR government is very concerned about that MTR arson train fire [1] ignited from some inflammable materials in the train vehicle [6]. While the incident did not result in serious injuries to passengers, both railway corporations were asked to examine whether their existing facilities, arrangements and procedures are adequate to prevent and handle railway incidents. Improvement areas should be identified.

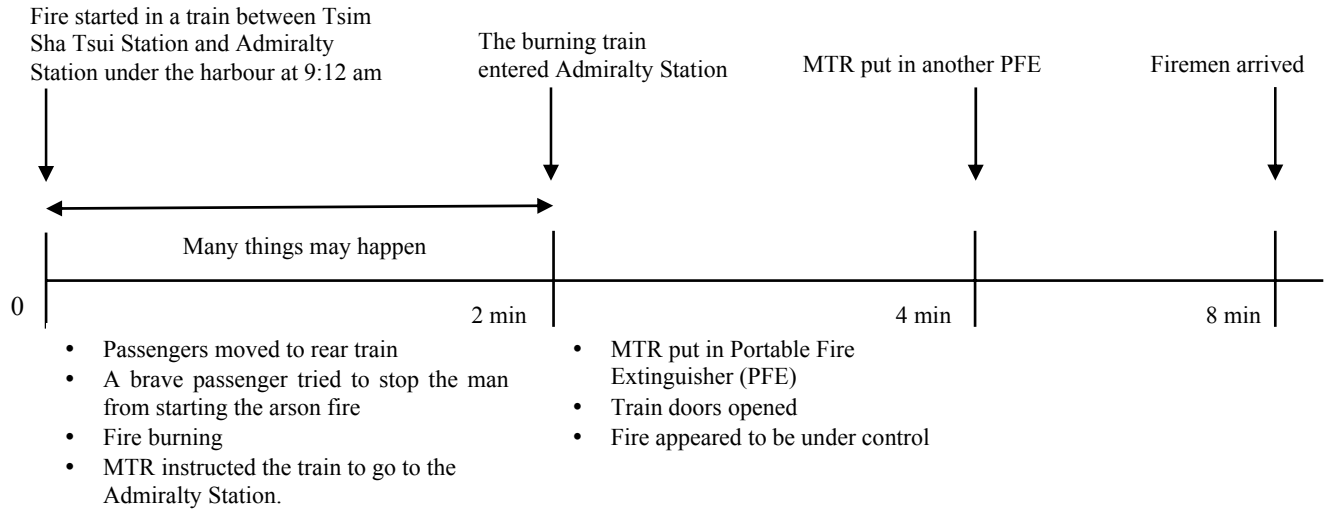

Fig. 1: Time line of the events in the MTR train fire

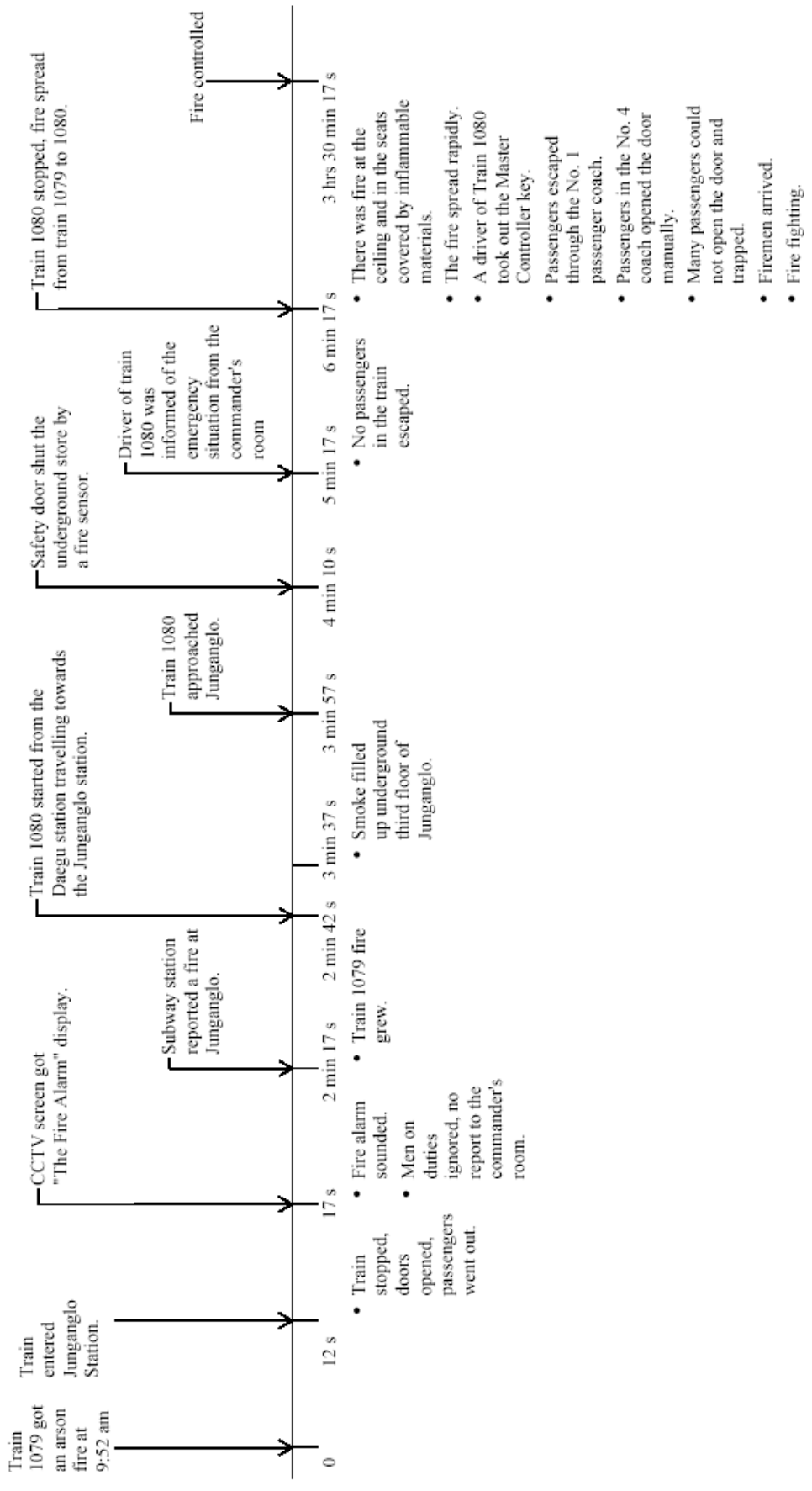

Fig. 2: Arson fire on 18 February, 2003, Daegu, South Korea

A review has been conducted by both railway corporations as shown in the Appendices of that LegCo paper [6]. However, reviewing the current fire safety provisions is only a preliminary step. Note that the report [6] was published in March, 2004, within a short time of about 3 months after the incident in January, 2004. There should not be sufficient time to work out scientific aspects supported by in-depth research such as full-scale burning tests. Note that the fire investigation reports [11-15] in South Korea are clearly demonstrated by research produced from longer-term studies for over one year. In fact, more in-depth studies with experiments are still ongoing as discussed recently in a fire symposium in March, 2004.

Though not yet demonstrated to be supported by scientific studies, the existing railway facilities, arrangements and procedures appeared to be adequate to prevent and handle such railway incidents. There were proposed improvement measures.

The existing safety standards of the two railway networks fall in the following two main areas as stated in the LegCo paper [6].

(i) Area 1 on safety features in the design of railway premises and trains:

- All train carriages are constructed with fire retardant materials and equipped with fire extinguishers. However, the materials are not yet tested under flashover.
- There are safety devices on trains including ventilation windows, audio communication system with train drivers, public announcement system within stations and trains, emergency doors; and fire alarm and fire fighting systems are available on platforms;

(ii) Area 2 on Fire Safety Management [22-25]:

- Comprehensive contingency plans and emergency manuals are in place to cater for different scenarios of railway incidents including fire incident handling and control, malicious acts and power supply system failures.
- Adequate staff training to ensure that staff members are trained and equipped to work safely and react to emergency incidents.
- Fire drills and exercises with relevant departments of the SAR government to develop an efficient joint response system.

Both railway corporations have also identified areas for further improvements, they are summarised in five key points:

- Stepping up of enforcement actions of the by-laws of respective corporations, in particular the provisions relating to prohibition of carriage of dangerous goods into railway premises.
- Taking further measures to enhance the design and effectiveness of train equipment such as easier-to-open ventilation windows, making the location of fire extinguishers easier to identify during fire incidents and consider providing Closed Circuit Televisions (CCTV) inside train compartments.
- Improving the procedures for handling incidents and the dissemination of information to passengers.
- Organising joint training programmes on railway accident investigation with the associated government departments.
- Stepping up public education programme to enhance public awareness of the regulations under the by-laws and emergency procedures for railway incidents. Both corporations are also considering the involvement of passengers in the drills and exercises.

A comprehensive and structured risk control system is adopted to identify any possible hazards in the system as well as to develop adequate measures to mitigate them. As such, the operational risk is reduced to a level as low as reasonably practicable.

But there is not yet detailed planning of fire safety management with scientific backup.

4. SPECIFIC VIEWS ON THE RECOMMENDATIONS IN THE LEGCO REPORT

It is obvious that railway safety is a concern as so many passengers travel by trains everyday, with a loading up to 3,000 persons per train during rush hours. The ventilation incident happened several years ago demonstrated that chaotic conditions could be resulted, and even electricity would be cut off. Several smaller incidents of similar train fires due to accidents further confirmed the importance of establishing good risk management systems. Obviously, more regular reviews and tighter control should be followed up by the Hong Kong Railway Inspectorate (HKRI).

The following are recommended to be considered:

- The railway systems appeared to be operating at high safety standard. It is correct that further improvement in taking appropriate actions under other possible fire scenarios should be well-planned. Technology (T), procedure (P) and behaviour (B) are the key aspects in safety engineering to achieve total safety.
- The MTR fire in fact lasted for at least 2 minutes, then it was put out or extinguished by staff (actions still not clearly reported) within 4 minutes. In comparing with the Daegu train fire in South Korea, allowing it to burn for 5 minutes can be very serious.
- It is disappointing that smoke toxicity on burning the materials under typical fire scenarios was not pointed out. This part was also identified in the South Korean railway fire.

There are comments on the MTR report:

- There are good communications in the railway system.
- The evacuation time required and the evacuation pattern of the train, especially where there were PSD [7,10], were not yet reported.
- Crowd control at the Admiralty Station platform and terminal should be watched.
- Thermal response of the saloon under other fires (not just this small 'controlled' arson fire), giving possible flashover, is not yet demonstrated to be safe by full-scale burning tests nor by fire models.

There are questions on:

- It took up to 13 minutes to evacuate 1,000 passengers in the train, and another 200 passengers in the station before closing the station, what will happen if the train is fully-loaded?
- The conclusion on appropriate saloon design and materials with fire retardants and non-flammable was demonstrated to work only under this scenario with such an arson fire. Note that appropriate actions had been taken by a 'brave' passenger. What will happen if the 'brave' action was not successful? Should railway police or even detectives be assigned if necessary?

5. FLASHOVER FIRE

As the train compartment is of a sealed structure with very little openings, the minimum heat release rate for flashover $\dot{Q}_{mf}$ is very low. $\dot{Q}_{mf}$ can be expressed in terms of the ventilation factor of the opening $A_o\sqrt{H_o}$, where A_o is the area and H_o is the height of the opening [e.g. 30-33]:

$$\dot{Q}_{mf} \propto A_o\sqrt{H_o} \quad (1)$$

Both bench-scale tests on materials with a cone calorimeter [34,35] and preliminary full-scale tests [36,37] for a retail shop under flashover indicated that the heat release rate of burning the materials will be very different under flashover condition. Testing the materials under small accidental fires will not give their behaviour under real-fire situations.

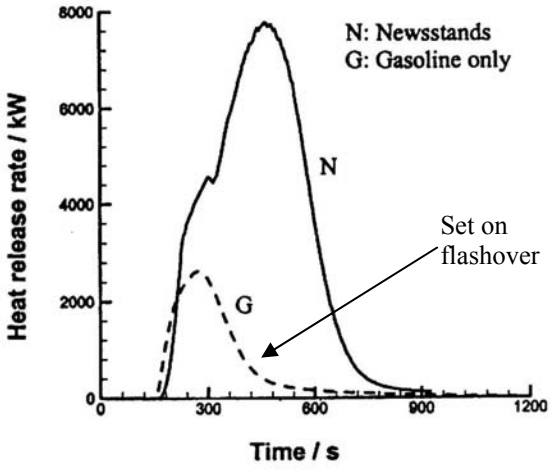

Fig. 3: Heat release rate

Smoke toxicity [38,39] is another issue. Plastic materials such as polyvinyl chloride (PVC) cannot be ignited under a normal flashover heat flux of 20 kWm^{-2}. But PVC will burn vigorously under 50 kWm^{-2} as reported recently. The emission of carbon monoxide is much higher to give more toxic smoke.

The heat release rate in burning a retail shop [37] under a flashover fire with limited openings can go up to 8 MW. Therefore, the possible heat release rate of a train upon burning should be measured under a flashover fire. In fact, the estimated fire size for the Korean railway fire was at least 20 MW as reported in the fire investigation [11-15]. Testing the materials under small accidental fires [e.g. 40,41] might not be sufficient to assess the behaviour of materials under a flashover fire [37].

6. TOTAL FIRE SAFETY CONCEPT

To ensure that all the hardware fire safety provisions on passive design and active fire protection systems work and people know what to do in a fire, there must be adequate software fire safety management schemes. Total fire safety [21] should be provided by passive fire protection [25,26,42-44], active fire systems [25,26,45] and fire safety management [22-26].

In implementing proper fire safety management [22-26], a fire safety plan including the following must be provided:

- Building maintenance plan
- Staff training plan
- Fire prevention plan
- Fire action plan

These schemes should be clearly laid down and include what should be done on the passive building design, active fire protection systems and control of fire risk factors. There should be two modes of operation:

- Normal mode
- Emergency mode

Fire safety management schemes expressed mathematically as matrix elements should be worked out carefully as for tunnels [24].

7. RESEARCH AND DEVELOPMENT DESIRED

As pointed out recently [7-10,46] in Hong Kong, Beijing, Tianjin and Hefei, the following are suggested to be considered in further in-depth investigations.

- A fire in the train vehicle and a fire in the railway terminal are not the same. In the train vehicle, the thermal response of the train system to an ignition source should be evaluated. That depends on the fixed fire load such as the flooring, ceiling, wall and advertisement panels. Tighter control should be implemented with the fire retardants tested under a flashover fire. Movable fire load is difficult to estimate. The luggage and baggage carried by the passengers on the East Rail to the China Mainland would be very different from those others for local transportation. Ignition resistance, smoke emission, fire spread and fire endurance are to be watched. A design fire for deciding the fire safety provisions in the railway station, especially in big stations, is another point. It might be due to burning a train or other combustibles. The design fire should be bigger than a certain value, say 20 MW as used for many tunnels. Otherwise, smoke would fill up the entire underground space as in the Daegu train fire incident [11-15].
- Materials with fire retardants should be tested under high radiative heat fluxes in a cone calorimeter [8]; and supported by some full-scale burning tests [37]. Smoke toxicity of materials [38,39] are to be watched. The materials used should be controlled by proper assessment tests. Testing under small accidental fires might not give a proper assessment on the fire behaviour of the materials [40,41].
- New active fire protection systems and new extinguishing concept should be provided.
- Crowd movement and control appeared to be not in good order as reported in the television. The presence of platform screen doors might affect the evacuation from the burning train.

Anyway, the total fire safety concept [21] has to be applied with fire safety management [22-26] worked out to control hardware fire safety provisions [25,26,42-45].

8. CONCLUSIONS

Although the recent MTR arson fire [1] started roughly with the same fire as the Daegu arson fire [2], the fire did not grow up as reported [6]. Note that the burning time was over 2 minutes and fixed fire services installation such as water mist fire suppression system was not yet installed.

As reported [6], that might be due to firstly, a ‘brave’ passenger stopped the man from starting the arson fire successfully. Secondly, the train was not fully-loaded while travelling towards the Central District after 9:00 am. This gave chances for the passengers to move to the other part of the train. Thirdly, the fire did not grow up though there was not yet active fire protection system installed in the train. The combustible content might be low, different from the train vehicles in another railway line travelling to China where passengers used to carry heavy luggage.

‘Brave’ passengers cannot always be relied upon. Further actions must be taken to provide adequate fire safety in the train vehicles. Otherwise, railway police or even detectives should be assigned in each train. This might be necessary if there are more arson fires.

REFERENCES

1. "14 injured in peak-hour MTR arson attack", Editorial, pp. A1, South China Morning Post, Hong Kong, 6 January (2004).
2. "Daegu's subway line has been beset by disaster", Main Section, p.10, South China Morning Post, Hong Kong, 19 February (2003).
3. W.K. Chow, "Ventilation of enclosed train compartments in Hong Kong", Applied Energy, Vol. 71, No. 1, pp. 161-170 (2002).
4. "KCRC attacked over power cut", South China Morning Post, Hong Kong, 13 June (1996).
5. "Suicide bomber kills 39 in packed Moscow train", Editorial, p. A1, South China Morning Post, Hong Kong, 7 February (2004).
6. "Preventive and response measures for emergency incidents", LegCo Panel on Transport - Subcommittee on matters relating to railways, Environment, Transport and Works Bureau, Legislative Council, LC Paper No. CB(1)1168/03-04(02), March (2004).
7. W.K. Chow, "Aspects on fire safety in railways with tunnels", Invited lecture to Beijing Municipal Institute of Labor Protection, Beijing Academy of Science and Technology, 25 March 2004, Beijing, China (2004).
8. W.K. Chow, "Fire safety in train vehicle: Design based on accidental fire or arson fire?", The Green Cross, March/April, 7 pages (2004).
9. W.K. Chow, Lecture notes for Continuing Professional Development Lecture, "Recent train fires and fire safety desired", 29 April 2004, Research Centre for Fire Engineering, The Hong Kong Polytechnic University, Hong Kong (2004).
10. W.K. Chow, "Arson train fires and safety research desired", Keynote speech appeared in Proceedings of the Subgroup 4 "Smoke movement and toxic harmful gases transfer in fire" of the Chinese National 973 project "Fire Dynamics and Fundamentals of Fire Safety", 26 May 2004, State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei, Anhui, China, pp. 1-7 (2004).
11. W.H. Hong, "The progress and controlling situation of Daegu subway fire disaster", 6th Asia-Oceania Symposium on Fire Science & Technology, Daegu, Korea, 17-20 March 2004, pp. 28-46 (2004).
12. H.J. Park, "An investigation into mysterious questions arising from the Daegu underground railway arson case through fire simulations & small-scale fire tests", 6th Asia-Oceania Symposium on Fire Science & Technology, Daegu, Korea, 17-20 March 2004, pp. 16-27 (2004).
13. T.H. Kim, J.C. Park, G.Y. Jeon and W.H. Hong, "The timetable and system for settlement resulted from the fire of subway in Daegu", 6th Asia-Oceania Symposium on Fire Science & Technology, Daegu, Korea, 17-20 March 2004, pp. 1071-1081 (2004).
14. R.S. Kew, "Urban railway safety system improvement plan", Session S Plenary lecture presented in the 6th Asia-Oceania Symposium on Fire Science & Technology, Daegu, Korea, 17-20 March 2004, pp. 11-15 (2004).
15. D.H. Lee, W.S. Jung, C.K. Lee, S.K. Roh, W.H. Kim and J.H. Kim, "Fire safety characteristics of interior materials of Korean railway vehicles", 6th Asia-Oceania Symposium on Fire Science & Technology, Daegu, Korea, 17-20 March 2004, pp. 735-741 (2004).
16. "UPTUN: Upgrading methods for fire safety in existing tunnels", Newsletter No. 15, The International Associations of Fire Safety Science, July (2003). http://www.iafss.org/html/ newsletter 04.htm#uptun
17. "CSIRO: Full-scale fire experiments on a passenger rail carriage", Newsletter No. 15, The International Associations of Fire Safety Science, July (2003). http://www.iafss.org/html/newsletter 04.htm#uptun
18. V.P. Dowling and N. White, "Fire sizes in railway passenger saloons", 6th Asia-Oceania Symposium on Fire Science & Technology, Daegu, Korea, 17-20 March 2004, pp. 602-611 (2004).
19. N. White and V.P. Dowling, "Conducting a full-scale experiment on a rail passenger car", 6th Asia-Oceania Symposium on Fire Science & Technology, Daegu, Korea, 17-20 March 2004, pp. 591-601 (2004).
20. H.B. Du, X.J. Li and Y.X. Qi, "Smoke flowing experiments in case of fire in running passenger train", 6th Asia-Oceania Symposium on Fire Science & Technology, Daegu, Korea, 17-20 March 2004, pp. 612-617 (2004).
21. W.K. Chow, "Proposed fire safety ranking system EB-FSRS for existing high-rise nonresidential buildings in Hong Kong", ASCE Journal of Architectural Engineering, Vol. 8, No. 4, pp. 116-124 (2002).
22. H.L. Malhotra, Fire safety in buildings, Building Research Establishment report, Department of the Environment, Building Research Establishment, Fire Research Station, Borehamwood, Herts, WD6 2BL, UK (1987).
23. W.K. Chow, "Instant responses – On the attack fire at World Trade Centre", International Journal on Engineering Performance-Based Fire Codes, Vol. 3, No. 3, pp. 128-129 (2001).
24. W.K. Chow, "General aspects of fire safety management for tunnels in Hong Kong", Journal of Applied Fire Science, Vol. 10, No. 2, pp. 179-190 (2001).
25. BS 7974, Application of fire safety engineering principles to the design of buildings - Code of practice, British Standards Institution, UK (2001).

26. BS 5588 Part 0-11, Fire precautions in the design, construction and use of buildings, British Standards Institute, UK (1990-99).

27. W.K. Chow, "Study on passenger train vehicle fires", Proceedings of the Institution of Mechanical Engineers Part F: Journal of Rail and Rapid Transit, Vol. 211, Part F, pp. 87-94 (1997).

28. W.K. Chow, "Preliminary notes on fire protection in buses", Journal of Applied Fire Science, Vol. 9, No. 1, pp. 79-89 (1999).

29. W.K. Chow, "Fire safety management using modeling technique", Journal of System Safety, Vol. 36, No. 3, pp. 17-24 (2000).

30. W.K. Chow, "Flashover for bus fires from empirical equations", Journal of Fire Sciences, Vol. 19, No. 1, pp. 81-93 (2001).

31. W.K. Chow, "Fire safety and maximum allowed heat release rate in a single-deck bus", Journal of Applied Fire Science, Vol. 10, No. 2, pp. 149-155 (2001).

32. W.K. Chow, "Observation on the two recent bus fires and preliminary recommendations to provide fire safety", International Journal on Engineering Performance-Based Fire Codes, Vol. 5, No. 1, pp. 1-5 (2003).

33. P.H. Thomas, "Testing products and materials for their contribution to flashover in rooms", Fire and Materials, Vol. 5, pp. 103-111 (1981).

34. V. Babrauskas and S.J. Grayson, Heat release in fires, Elsevier Applied Science, London (1992).

35. ISO 5660-1, Reaction-to-fire tests - Heat release, smoke production and mass loss rate - Part 1: Heat release rate (cone calorimeter method), 2nd edition (2002).

36. ISO 9705, Fire tests – Full-scale room test for surface products, International Standards Organisation (ISO), Geneva, Switzerland (1993).

37. W.K. Chow, G. Zou, H. Dong and Y. Gao, "Necessity of carrying out full-scale burning tests for post-flashover retail shop fires", International Journal on Engineering Performance-Based Fire Codes, Vol. 5, No. 1, pp. 20-27 (2003).

38. G.E. Hartzell, "Engineering analysis of hazards to life safety in fires: the fire effluent toxicity component", Safety Science, Vol. 38, No. 2, pp. 147-155 (2001).

39. C.L. Chow, W.K. Chow and Z.A. Lu, "Assessment of smoke toxicity of building materials", 6th Asia-Oceania Symposium on Fire Safety and Technology, AOSFST Symposium, Daegu, Korea, 17-20 March 2004, pp. 132-142 (2004).

40. FSD Circular letter 1/2000, "Flammability standards for polyurethane (PU) foam filled mattresses and upholstered furniture in licensed premises and public areas", Fire Services Department, Hong Kong (2000).

41. BS 7176, Specification for resistance to ignition of upholstered furniture for non-domestic seating by testing composites, British Standards Institution, London, UK (1995).

42. Code of Practice for Fire Resisting Construction, Buildings Department, Hong Kong (1996).

43. Code of Practice for Provisions of Means of Access for Firefighting and Rescue Purposes, Buildings Department, Hong Kong (1995).

44. Code of Practice for Provisions of Means of Escape in case of Fire and Allied Requirements, Buildings Department, Hong Kong (1996).

45. Code of Practice for Minimum Fire Service Installation and Equipment, Fire Services Department, Hong Kong (1998).

46. W.K. Chow, "Fire safety concerns in green and sustainable buildings", Keynote speech at 7th International Symposium on Building and Urban Environmental Engineering, 11-14 May 2004, Tianjin University, Tianjin, China (2004).