INTRODUCTION OF LARGER-SCALE COMMERCIAL SPACES INTO UNDERGROUND MASS RAPID TRANSIT STATIONS IN SINGAPORE

R. Wong[1], B.H. Chiam[2], A.J. Lovatt[1] and K.C. Lim[2]
[1] Arup Singapore Pte Ltd, 371 Beach Road, #03-01 Keypoint, Singapore 199597
[2] Land Transport Authority, 1 Hampshire Road, Singapore 219428

ABSTRACT

This paper presents a case study of an investigation into the introduction of larger-scale commercial spaces (i.e. retail tenancies) into three existing underground mass rapid transit (MRT) stations in Singapore. The design was based on the performance objectives of the current Standard for Fire Safety in Rapid Transit Systems (SFSRTS) 2005 which specifies both the prescriptive requirements and performance objectives for fire safety of such facilities in Singapore.

Historically, MRT stations in Singapore have been considered relatively sterile places, intended solely for transit purposes. This is reflected in the prescriptive requirements of the SFSRTS which limit the extent of commercial spaces within the underground station envelope to fire-separated individual commercial floors; or not more than one 15 m^2 kiosk and one 100 m^2 shop unit in the underground station concourse public areas. However, with increasing commercialization of rapid transit systems (RTS) operators, introduction of larger-scale commercial spaces into existing and future underground stations is inevitable.

This paper will detail the challenges, both technical and operational, on the design and implementation of an alterative solution into the three existing underground MRT stations. It will describe in detail the process of implementation, responsibilities of different parties (station owner, authority having jurisdiction, fire safety engineer, operators and other stakeholders), and the formation of a design guidelines document to guide similar designs in future underground stations as well as other existing ones.

KEYWORDS: Performance-based, fire safety, fire hazards, commercial spaces, MRT stations

INTRODUCTION

Before the opening of the first sector of the mass rapid transit (MRT) system in 1987, Singapore's public transport system had been reliant largely on buses. Although buses still enjoy an average daily ridership of about twice the number of passengers carried on both the MRT and light rail transit (LRT) systems (2.8 million passengers on buses in comparison to 1.4 million passengers on the MRT and LRT in the year 2006[1]), the Land Transport Authority (LTA) has plans to further expand the rail systems with the aims of developing a comprehensive rail network as the main backbone of the public transport system in Singapore.

The current MRT network consists of three main lines – the North South Line (NSL), the East West Line (EWL) and the North East Line (NEL) – which as their names refer, serve the four corners of Singapore. These three lines have a total length of 109.4 kilometres with 65 stations. The North-South and East-West lines are the oldest of the three lines, and were progressively opened in stages from 1987 to 1990. The newest of the three - the NEL - was completed and launched in 2003. The NSL and the EWL are run by SMRT Corporation, while the newer NEL's operator is SBS Transit.

All three existing lines were designed in accordance with the prevailing NFPA 130 "Standard for Fixed Guideway Transit and Passenger Rail Systems"[2] at the time of plans submission. Where

required to accommodate the design and local requirements, alternatives to NFPA 130 were incorporated on through consultations and waivers to the relevant authorities having jurisdiction.

Besides these three existing lines, a new line is currently under construction - the Circle Line (CCL). The CCL will be a fully underground orbital line linking all radial lines leading to the city and will interchange with the existing North-South, East-West and also North East lines. The line will be 33.3 kilometres long with 29 stations, and is slated for full completion in 2010. It will be run by SMRT Corporation. Unlike the existing three lines, the CCL has been designed in accordance with the prevailing Standard for Fire Safety in Rapid Transit Systems (SFSRTS) [3].

During the planning and construction of the earlier lines, fire safety requirements were formulated on the premise that an MRT station would be primarily used for transit purposes. Hence, provisions for means of escape, fire protection and other fire safety systems within the existing MRT station public areas can be considered relaxed in comparison with similar commercial buildings such as shopping malls.

However, increased commercialisation is inevitable to ensure continued commercial viability of RTS operators. In view of the high demand for more commercial spaces in MRT stations, a task force was formed in August 2004 to look into ways to address the arising fire safety concerns from such a proposal. The task force comprised representatives from the relevant authorities having jurisdiction, including the LTA and Singapore Civil Defence Force (SCDF). The task force concluded that the way forward was to carry out a performance-based fire safety study to investigate on the possibility of additional commercial spaces in three existing underground MRT stations (one integrated/interchange, one civil defence and one typical station), with the final aim of formulating a well-defined guide for undertaking similar performance-based fire safety design for commercial spaces in other existing and future MRT stations.

Stakeholders

One of the principal stakeholders in this study is the Land Transport Authority (LTA). The LTA is a statutory board under Singapore's Ministry of Transport and is the authority responsible for the planning, construction, management and development of land-based transport system, which includes road infrastructure and the rapid transit systems (RTS) network. While LTA is responsible for the planning and construction of the RTS network, it allocates operating concessions to private corporations, such as SMRT Corporation and SBS Transit.

Another principal stakeholder is the Fire Safety and Shelter Department (FSSD). The FSSD is the authority in fire safety regulations in Singapore, and their role involves formulating, implementing, regulating and enforcing fire safety policies and standards in accordance with the Fire Safety Act [4]. The FSSD forms part of the larger Singapore Civil Defence Force (SCDF), which also provides rescue and ambulance services, fire-fighting and civil defence. The SCDF itself is under the purview of the Singapore's Ministry of Home Affairs.

Prior to any fire safety works being carried out, either on existing or new premises, plan submission and approval are required from FSSD. This covers both code-compliant and performance-based fire safety design. Though typically such designs involve buildings under the scope of the Code of Practice for Fire Precautions in Buildings[5], which is the Singapore building fire code, rapid transit systems and their facilities are governed by a different standard - the SFSRTS - which is intended to accommodate the uniqueness of transit operations and infrastructures.

PERFORMANCE-BASED FIRE SAFETY DESIGN

On 1st July 2004, the performance-based fire safety code and regulatory system came into effect in Singapore. This permitted recognized and registered Fire Safety Engineers (FSE) to prepare and

submit alternative design solutions to the FSSD for approval, on the basis of achieving the performance objectives outlined within the fire code and supported by fire engineering analyses. The approach advocated within the performance-based regulatory system is largely similar to those within international guidance references, such as the "International Fire Engineering Guidelines" [6].

Under Clause 2.1.3.4 of the SFSRTS, commercial spaces are limited to one 15 m^2 kiosk and one 100 m^2 shop unit in the underground MRT station public areas except the platform. Whole commercial floors are permitted within stations, provided that such floors are located on another level and fire separated from the station platform and concourse.

The study undertaken was intended as part of the on-going effort to introduce additional commercial spaces into underground MRT stations beyond that permitted under the prescriptive SFSRTS. It is the final goal of this study to establish a fire safety strategy (performance-based solution) and approach for such additional commercial spaces, in order to meet the performance objectives of the SFSRTS.

Broadly, the fire safety performance objectives of the SFSRTS are to safeguard people from illness or injury due to a fire in a station; safeguard occupants from illness or injury while evacuating a station during a fire; facilitate the activities of emergency services personnel; and avoid the spread of fire between station and adjacent buildings or stations.

The performance-objectives are divided into root and sub-objectives which spell out the intent of the code and the conditions to fulfil the intent respectively. An example of one of the relevant root and sub-objectives of the SFSRTS 2005 are:

"*Root Objective 2.2.1 Occupants must be able to escape to a safe place, directly or through a protected exit, before untenable conditions are reached during a fire emergency.*

Sub-Objective 2.2.10 - Provisions for adequate time for occupant escape to a safe place."

THE THREE MRT STATIONS

The study covered three existing underground MRT stations, which were selected by LTA as being representative of the majority of rapid transit stations in Singapore – NEL Dhoby Ghaut (interchange station), Clarke Quay (civil defence station) and Tanjong Pagar (typical station). Of the three stations, two were part of the newer NEL (i.e. Dhoby Ghaut and Clarke Quay) and one was from the older EWL (i.e. Tanjong Pagar). All the stations selected were underground stations, as the prescriptive limits involving introduction of commercial spaces in aboveground stations were considered less restrictive due to the cross-ventilation design and readily available access to means of escape at grade that is typical of aboveground stations.

The NEL Dhoby Ghaut station is located at the eastern end of Orchard Road, linking the NSL with the NEL, as well as an aboveground shopping mall. In the future, the interchange station will expand to include the Dhoby Ghaut (CCL).

The Clarke Quay station is located along Eu Tong Sen Street and forms part of the NEL line. As part of the Civil Defence Shelter programme, the Clarke Quay station has been hardened in order to serve as a shelter in the event of national emergencies. This includes provision of additional services and structure that are not part of typical MRT station design.

The Tanjong Pagar station is located along Maxwell Road, Wallich Street and Choon Guan Street and forms part of the EWL.

Though the primary objective was to meet the performance requirements for fire and life safety, any proposal would also have to identify and consider existing constraints within the subject stations.

More importantly, the three subject stations are existing and operational. And as such, any design concept would have to take into account existing fire safety systems and the need to maintain the station operations. For example, a design solution involving major structural works, in particular for the Clarke Quay station, would be considered impractical as its outer structural shell had been hardened due to its dual use as a civil defence station.

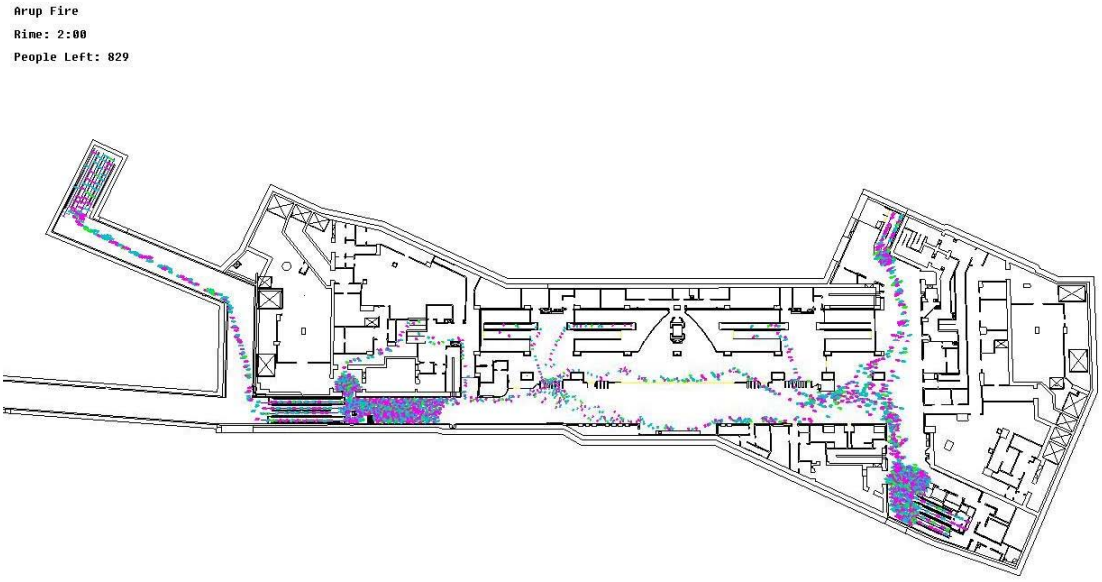
The location where the additional commercial spaces could be provided was also subject to scrutiny. While the RTS operators favoured maximizing the quantum of possible commercial spaces in both the paid and unpaid public areas for the three existing underground MRT stations, the LTA maintained certain guidelines to avoid impacting the level of service for passengers within the station, such as not permitting any commercial activities on platform level.

For all three subject stations, the general fire safety measures provided as part of the original design include automatic sprinkler protection in ancillary and commercial spaces, automatic fire detection (heat and smoke detection) in station public areas, smoke purging in the station concourse public areas and corridors of ancillary areas, dry riser systems for fire brigade use and fire compartmentation between the public areas and commercial spaces; and public areas and corridors of ancillary areas.

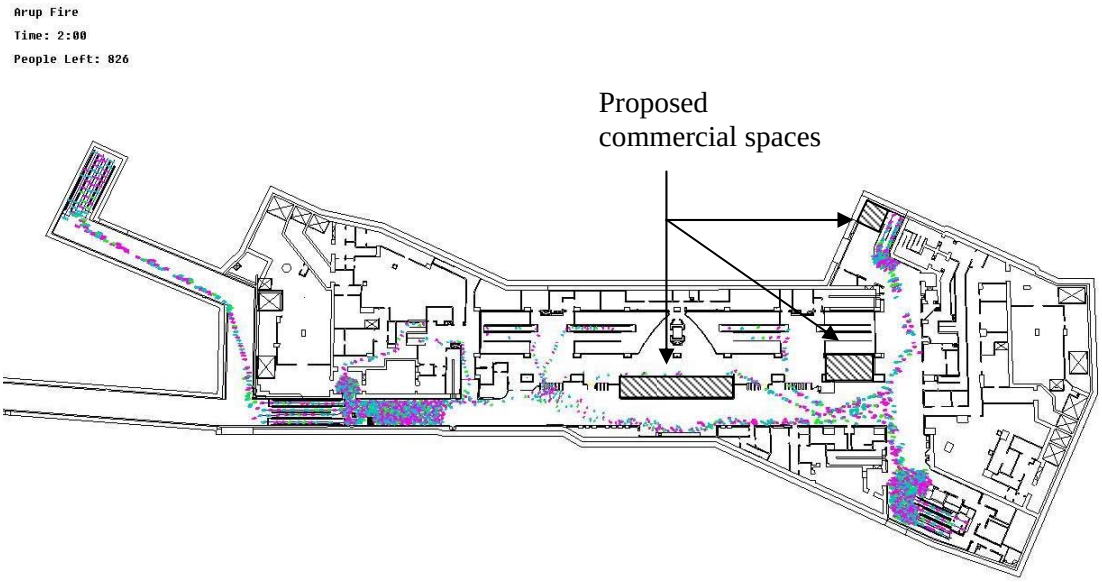
ANALYSES AND DISCUSSION

Unlike NFPA 130 that considers occupant evacuation in a train fire scenario, in this study, the method for evaluating occupant escape differed. The fire scenario considered critical to occupant life safety was a potential fire within one of the additional commercial spaces. In such a scenario, all occupants within the station fabric would have to be considered as part of the evacuation. These would include people walking through the station concourse to go to and from trains at platform level (transit), people walking through the station concourse (unpaid areas) as a convenient route to reach a separate station exit (pedestrians), people within the proposed commercial spaces (retail) and people using the station concourse (unpaid areas) as a meeting point (assembly). In all the three subject stations, the proposed additional commercial spaces were located within both the paid and unpaid areas of the concourse, occupying existing public spaces.

In the evacuation study, people were distributed at the beginning of the evacuation as described according to their intent within the station. Using STEPS evacuation model [7] and as-built architectural drawings, the layout of the existing stations were modelled based on two scenarios – a base scenario in order to establish the evacuation time using the existing means of escape and station layout, and a scenario with the proposed additional commercial spaces in order to evaluate the impact of these spaces on the station evacuation patterns, as shown in Fig. 1.



Base Scenario



With proposed additional commercial spaces, indicated in hatched lines

FIGURE 1. Evacuation model of Clarke Quay station showing the base scenario (using current station layout) and the scenario with proposed additional commercial stations at a movement time of 2 minutes

TABLE 1. Occupant movement in the base scenario and with proposed additional commercial spaces

Station	Movement time (minutes)	
	Base scenario without additional commercial space (existing station layout)	With additional commercial spaces
Dhoby Ghaut NEL	14.9	14.3
Clarke Quay	7.3	7.2
Tanjong Pagar	7.2	7.1

It was shown from the evacuation modelling that flow patterns and movement times in both scenarios remained largely unchanged. Though there were some flow patterns varying slightly around areas proposed to be demarcated as commercial spaces, but based on the modelling, the effect on the evacuation times was minimal.

As part of the study, smoke modelling of the existing station using Fire Dynamics Simulator Version 4.07 [8] demonstrated that due to the relatively low ceiling heights within underground stations, and the enclosed and limited space, it would be difficult to maintain visibility required for way-finding within the station concourse if significant smoke spread occurred from a commercial unit into the public areas.

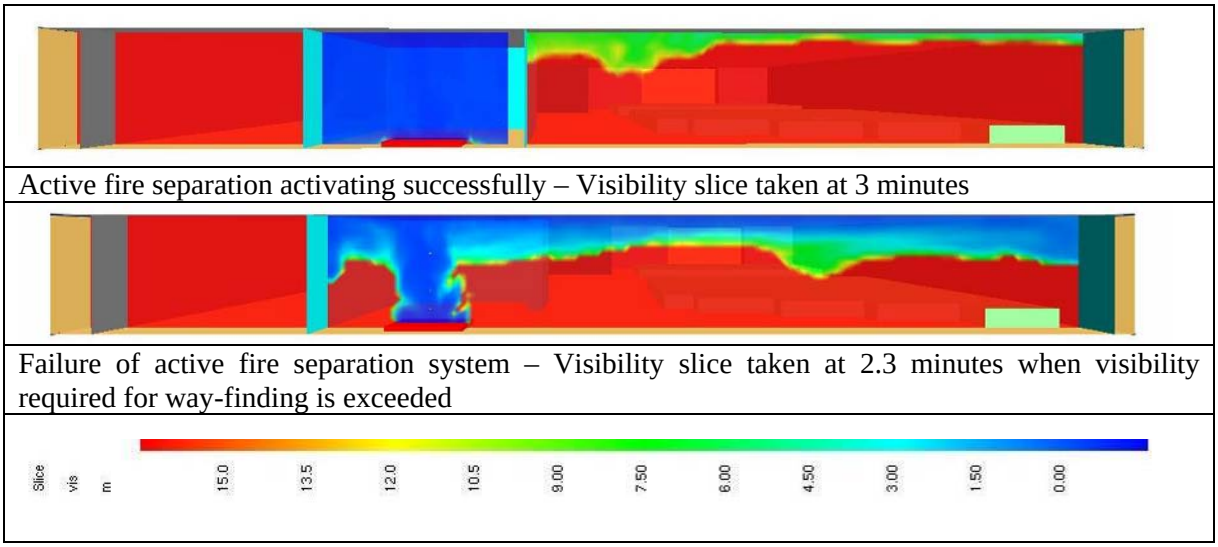


FIGURE 2. Smoke movement model of Clarke Quay station showing the proposed additional commercial fire separation activating successfully and scenario with failure of the active fire separation system

Hence, it was deemed critical that the barrier between the commercial unit and the public areas be maintained in the event of a fire. This was also driven by the consideration that the provision of smoke control would be difficult to implement practically in the three stations due to the limited space available to house additional equipment, as well as structural and operational implications with adding smoke vent shafts through the existing structure.

Various failure scenarios involving the most critical aspects of the fire safety strategy were studied as part of a qualitative risk assessment with the LTA and FSSD. In it, the fire separation between the commercial and public spaces and the fire detection system within the commercial unit were identified as being critical aspects of the performance-based solution. Further detailed assessment of these failure scenarios studied the various methods in which these systems could fail, either entirely or partially, and the consequences of such an event.

Consultations with the FSSD identified that failure to respect the tenancy line by stacking merchandise outside the shop was a serious concern, based on experience during inspections of existing commercial units, as well as failure of any active fire separation systems.

Though an option of overcoming this issue would be to severely limit the amount of shop front opening into the station public areas, in order to function as a viable commercial space, a degree of open shop front is required for commercial visibility. However, this is balanced by the need to limit the 'openness' onto the escape access path during a fire within the commercial unit, such that occupant evacuation would not be unduly hampered from smoke and flames from within the unit. Feedback was sought from the operators on what would be an acceptable percentage of shop front opening required for a typical commercial unit to function, and it was established that 50-percent of the shop perimeter would be the maximum required. This meant 50-percent of the shop perimeter would be opened while the remaining 50-percent would have to be of permanent, solid fire-rated construction.

In order to address the dual concern that merchandise would prevent the fire separation from closing completely or the active fire separation system would fail to close completely or partially due to a fault, a buffer zone of 0.5 m would be established at the shop front. At the front the 0.5 m, a second layer of fire separation would be provided. It was rationalized that the buffer zone would be a means of dealing with careless stacking of merchandise, though wilful violations of the tenancy line would still have to be dealt with a measure of vigilant fire safety management and enforcement. Introduction of the second layer of fire separation and increased maintenance and inspection of the active fire separation systems was nominated as a means of dealing with possible failure mechanisms arising from failure of the fire detection system, mechanical failure of the active system itself and similar failures. Additional fire safety measures, such as not having more than 25-percent of active fire separation system on a single connection to the fire detection system were also included to limit the consequence of failure of any single component of the design. Both layers of the active fire separation system would activate upon fire detection within the commercial unit or the localised smoke detector provided outside the buffer zone (within the station public areas).

FINAL DESIGN CONCEPT

The proposed performance-based solution or design concept for the additional commercial spaces was formulated to limit fire and smoke spread from the commercial unit of fire origin by the provision of fire-rated separation between the public areas and the commercial spaces. It was envisaged that any additional commercial space would be introduced as a self-contained fire-rated box into the station concourse.

The advantages of the 'box' concept were that it would contain any additional fire hazard within the commercial unit itself and limit any spread of the fire and smoke into the existing unsprinklered station concourse. This was in lieu of introducing additional fire safety systems into the public areas that could impact the integrity of existing systems and the operational status of the stations. Fire-rating of the box was necessary to maintain a level of separation between the fire and the station concourse escape access path outside the commercial unit. The final design concept is shown schematically in Fig. 3.

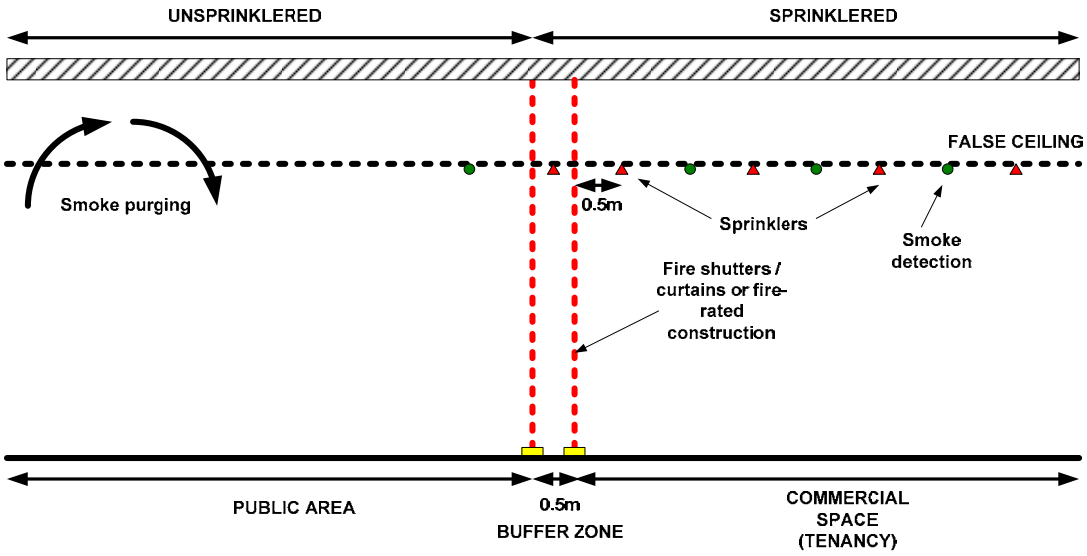


FIGURE 3. Final design concept for the additional commercial spaces within the three subject stations

Fire detection for occupant warning and activation of relevant fire safety systems within the proposed additional commercial spaces was proposed to be provided via two means – the primary means of fire detection via automatic smoke detection (by means of point-type detectors), and the secondary means via the automatic sprinkler system (by means of a water flow switch).

Localised occupant warning within each commercial unit would be provided by means of immediate action by staff (i.e. fire safety training of staff) to direct occupants within the commercial unit to leave. This is in line with existing fire safety plans, whereby individual occupant alarm is only provided within staff-only areas to avoid confusion and premature evacuation of the station in the event of a false alarm. Subsequent steps to deal with the fire incident after the initial fire detection and notification to staff would be in line with existing station fire safety plans, where limited commercial units are already permitted as part of the prescriptive fire code.

Though a smoke purging system is provided in all three subject stations as part of the existing fire safety measures, these systems varied in volumetric extract rates and differed in location of extract points from station to station, as they had been initially designed based on air-changes per hour. In the performance-based solution, the intention of the smoke purge system in the design was limited only to dilute any smoke that may leak through the fire separation, rather than for the purpose of maintaining a clear smoke layer height.

Feedback from RTS operators established that the largest commercial unit required would be 150 m^2, for banking and financial services, in comparison to the 100 m^2 permitted by the prescriptive fire code. Due to the relatively small sizes of the commercial units and low expected number of patrons within each shop at any one time, means of escape from the commercial unit to the station public areas was straightforward. It was agreed that this part of the design would be code-compliant, and was not addressed as part of the study.

Generally, all aspects of the existing means of escape in compliance with the existing NFPA 130 were to be maintained. The only exception to this was within NEL Dhoby Ghaut station. On Basement 2 of the station, an existing open stair serving the linkway between the two Dhoby Ghaut stations was required to be indicated and incorporated as part of the station exit access path as a result of the performance-based fire safety assessment. This stair is currently in use solely as a circulation stair, but the occupant evacuation analyses demonstrated that additional exit access path capacity was required to expedite evacuation of people from the linkway.

FIGURE 4. Linkway between NSL and NEL Dhoby Ghaut during station operating hours

In part, this was also driven by the assumption that people would not be able to cross over to the existing NSL Dhoby Ghaut station in order to evacuate, even though both stations are linked and access is available during emergencies. It was necessary to make this assumption as it is part of the existing fire plans for both stations that for a fire incident within the NEL station, occupants from that station would not be required to move to the adjacent NSL station to escape. Though realistically, as the linkway serves both Dhoby Ghaut stations, it would be expected that people would use the NSL station as an escape route as this would be a primary exit and entrance for people within the linkway itself.

For banking and financial facilities (between 100 m² and150 m²), fast response in lieu of standard sprinklers heads (RTI < 50 $m^{1/2}s^{1/2}$ and RTI < 150 $m^{1/2}s^{1/2}$ respectively) were proposed as a cost-effective measure of dealing with the perception of increased fire hazard associated with a larger floor area per fire compartment. In all types of commercial spaces, all sprinkler heads were required to be of exposed type, to limit delays in activation times associated with concealed sprinklers or sprinklers with flush caps.

Within the 0.5 m buffer zone between the first and second layer of fire separation, a line of cut-off sprinklers were required provided within the 500 mm buffer zone between, such that upon activation the sprinkler spray would cool the outer surface of the first layer and the inner surface of the second layer of fire separation. Similarly, a line of sprinklers was to be provided within 0.5 m of the first layer of fire separation forming part of the tenancy line within the commercial unit.

The introduction of multiple commercial units posed unique problems as well, as it was envisaged that it was possible that one unit could be undergoing renovation whilst an adjacent shop would be operating. Hence, in order to avoid a scenario whereby a row of commercial units shared a single sprinkler branch and would be unsprinklered in the event such works, each individual commercial unit was required to have its own monitored isolation valves, such that only the sprinkler system in the unit involved in the additions and alterations works would be turned off for maintenance and/or refurbishment at any one time.

Other measures to maintain the reliability of the sprinkler system included having security features to prevent tampering with the sprinkler system, and having all isolating valves locked and alarmed. A fault signal would be sent to the fire command centre (FCC) and/or Passenger Service Centre (PSC) to indicate if any sprinkler zone or commercial unit had been isolated. Fire safety management of maintenance or refurbishment work areas by contractor or site staff was also identified as critical to on-site fire safety.

Stringent fire safety management of the additional commercial spaces would be essential in the proposed performance-based design concept. Though mentioned in passing previously, they are described as follows:

- No merchandise is permitted beyond the line of the tenancy. The station fire safety manager would be required to undertake daily checks to ensure that all merchandise is within the line of the tenancy. This is to include any non-combustibles, such as furniture or fixtures for F&B units, even though while such objects may not pose a fire risk, they might obstruct means of escape access. Records of any non-compliance by tenants are to be maintained by the RTS operators, with a copy to the station owner (LTA).
- The line of the tenancy will be marked and indicated of such distinctive colour and design that it is readily visible and will provide contrast with decorations, interior finish, or other signs. No decorations, furnishings, or equipment that impairs the visibility of the tenancy marking will be permitted. All such markings will be permanent and non-movable.
- All trades and services within the commercial spaces will be limited to those indicated in the approved list in the SFSRTS to limit the fire risks and fire loads.
- A 3-monthly testing and maintenance schedule is proposed for the active fire separation system forming part of the commercial unit shop front. This testing and maintenance schedule would include full activation of the system to check for mechanical damage or obstructions to the fall of the separation.

The fire safety management procedures required as part of the performance-based solution was documented in an Operations & Maintenance manual, intended to be incorporated as part of the existing stations' fire safety plans. However, it is recognized by the principal stakeholder - the LTA and FSSD – that fire safety management procedures form only part of effective fire safety management. An equally important part is the willingness to enforce the limits set down.

As a result of the discussions with the FSSD, the LTA reinforced their role as being responsible for the enforcement of the prescribed rules of operation for the stations, and their willingness to take strong deterrent action against operators and the errant tenants. Among measures discussed included penalising the operators for non-compliance and requiring the operators to terminate the tenancy contract of errant tenants. Regular audit checks were also proposed to ensure that safety standards and procedures will be adhered to, and the RTS operators would be requested to participate in table-top emergency exercises with SCDF regularly to maintain the level of fire and life safety within the station.

CURRENT STATUS

In-principle approval was granted by the FSSD for the proposed performance-based solution subject to strict compliance of a list of conditions. Certain conditions imposed by FSSD were either assumed or already incorporated in the design, but the additional requirements are summarised below:

- Installation and use of CCTV to monitor for infringement of the tenancy line at the shop front, and to reduce the time needed by station staff to verify the occurrence of a fire within one of the commercial units.

- Installation of fast response sprinklers within all additional commercial units, regardless of floor area size, in order to reduce activation time of the sprinkler system
- Installation of remote manual triggering at the Passenger Service Centre (PSC) for the active fire separation system forming part of the commercial unit shop front.
- Station fire alarm system to be connected directly to SCDF, either by direct connection or automatically relayed via the Operations Control Centre (OCC) to SCDF. Further consultations with SCDF highlighted that this was intended to remove the existing human interface in manual transmissions and reduce fire brigade intervention response time.
- Existing commercial units, in stations where the additional commercial units are to be introduced, would be required to be retrofitted to meet the requirements of the proposed fire safety solution. This was clarified by the FSSD as being required to maintain a level of uniformity with regards to fire safety provisions within the same station.

For new underground stations with commercial spaces over and beyond the prescriptive limits, FSSD requested that an engineered smoke control system to be provided for the entire station premises, including enclosed services corridors. Further consultations clarified that an alternative solution using performance-based fire safety engineering would still be permitted if it could be demonstrated that performance objectives of the SFSRTS could be met.

Currently, the two RTS operators in Singapore have made tentative steps towards implementing the performance-based approach in order to introduce additional commercial spaces within most existing stations. In order to guide their efforts, a design guidelines document was also produced as part of this study. This design guideline document is not intended as a guide to performance-based fire engineering design, as many such guidance documents already exist. It is instead intended as a means of documenting the important factors that any future performance-based design introducing additional commercial spaces into MRT stations would have to consider. Such factors include the size of the commercial units, location within the station, its impact on occupant escape, methodologies of determining the occupant loads for evacuation analysis, and the use of potential alternative systems in lieu of fire separation to achieve an adequate level of life safety for occupant evacuation, such as engineered smoke control.

CONCLUSIONS

Performance-based fire safety design was conducted to investigate the possibility of additional commercial spaces beyond and above that permitted under the prescriptive SFSRTS in existing operational stations, taking into account the existing constraints and the need to maintain the station operations. Qualitative risk assessment was conducted for various fire safety systems failure scenarios and detailed quantitative analysis were carried out using FDS and STEPS fire modelling tools to evaluate the identified credible fire scenarios. The design concept that was developed was in the form of a ‘box’ concept to contain additional fire hazard within the commercial unit itself and to limit spread of the fire and smoke into the existing unsprinkered station concourse. The design concept addressed the concern of having to introduce additional fire safety systems into the public areas that could impact the integrity of existing systems and the operational status of the stations. FSSD granted in-principle approval for the proposed fire safety solution and a design guidelines document has also been developed to guide other fire safety engineers engaged in undertaking similar performance-based fire safety design for commercial spaces in future underground stations as well as other existing ones.

REFERENCES

1. LTA, Average Public Transport Ridership, Land Transport Authority, Singapore, 2007.

2. NFPA 130, Standard for Fixed Guideway Transit and Passenger Rail Systems, National Fire Protection Association, Quincy, MA, USA, 2003 edition.
3. SCDF, Standard for Fire Safety in Rapid Transit Systems, Singapore Civil Defence Force, Singapore, 2005 edition.
4. AGC, Fire Safety Act (Chapter 109A), Attorney-General's Chambers, Singapore, 2007
5. SCDF, Code of Practice for Fire Precautions in Buildings, Singapore Civil Defence Force, Singapore, 2002 edition.
6. ABCB, International Fire Engineering Guidelines, Australian Building Codes Board (ABCB), Department of Building and Housing New Zealand, International Code Council® (ICC) and the National Research Council of Canada (NRC), 2005 edition.
7. STEPS, STEPS User Manual, Mott MacDonald, 2004.
8. McGrattan, K. and Forney, G., Fire Dynamics Simulator (Version 4) User's Guide, NIST Special Publication 1019, National Institute of Standards and Technology, USA, 2006.