# A Numerical Simulation of Smoke Spread and Fire Evacuation in a Large MRT Multilevel-Platform Station

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## ABSTRACT

This paper presents a coupled fire and evacuation simulation in a large MRT multilevel-platform station via a well-known CFD fire model, FDS+Evac. The objectives of this study were to demonstrate compliance of the station evacuation times with the evacuation times required by NFPA 130 and to perform a safety analysis of passengers in the station based on the simulation results. Four simulations based on worst case scenario concept were performed. In all cases, the total station passenger load based on the ridership forecast data was 2,594 persons. The calculations were performed for both no wind and wind blow from East at a speed of 9.25 m/s boundary conditions. The simulation results showed that the platform evacuation times for all cases were less than 4 minutes. The station evacuation times for all passengers to reach the point of safety, which was defined as the concourse level as permitted by NFPA 130 for an above ground open station, were approximately within 5 minutes. Both platform evacuation times and station evacuation times were complied with the evacuation times required by the NFPA 130. The tenable environments of the station were maintained for all the evacuation processes and therefore the passengers for all cases were considered to be safe from fire hazard. The study suggested that coupled of fire and evacuation simulations provided more useful information inside the station during fire and evacuation processes which was not feasible to obtain via a full scale test. These simulation results can be used by a fire safety engineer to improve an egress efficiency of a large MRT multilevel-platform station.

**Keywords:**

fire evacuation; MRT station; FDS+Evac; fire modeling

## 1. INTRODUCTION

Many large Mass Rapid Transit (MRT) stations have been constructed with innovative designs and new architectural features during the last decade in Bangkok, Thailand. These designs might have some difficulties in complying with the prescriptive fire codes such as the NFPA (National Fire Protection Association) 130 standard for fixed guideway transit and passenger rail systems [1] in term of the station evacuation times. Most of the MRT stations are always crowded with passengers during the peak hours in the morning and in the evening. Detailed scenario investigation of the evacuation of occupants during the crowed condition should be considered. Accordingly a large MRT multilevel-platform station in Bangkok was selected to demonstrate a fire safety analysis of the station evacuation process based on the worst case scenario concept.

It is not feasible to carry out an actual experiment of the evacuation process for the under construction MRT station. Therefore, a computational fluid dynamics (CFD) fire model is employed to provide useful data to analyse the fire conditions of an environment inside the station. There are a number of computational models that were created to simulate fire and evacuation processes of large building structures. Each model has its strength and limitation. For examples, the models that are capable to simulate evacuation are EXODUS [2], SIMULEX [3], LEGION [4], STEPS [5], and Pathfinder [6]. The model used to simulate fire and combustion is SMARTFIRE [7]. To date, the model that can simulate both evacuation and fire within one program is Fire Dynamics Simulator with Evacuation (FDS+Evac) [8, 9]. Many researchers around the world have used computer models to simulate fire and evacuation. For examples Chow et. al. [10] employed SIMULEX and EXODUS to simulate evacuation process of crowded airport in Hong Kong. Ronchi et. al. [11] used Pathfinder to investigate large-scale evacuation behavior of music festivals in Europe. Yanfeng et. al. [12] examined evacuation process of underground subway station fire using FDS+Evac. Ronchi [13] utilized three evacuation models (FDS+Evac, STEPS, and Pathfinder) to simulate evacuation process of a road tunnel fire in Europe. Chalermwat and Boonmee [14] used FDS+Evac to simulate fire evacuation on an offshore oil and gas processing platform. Recently, Pittharat and Kittichaikarn [15] employed FDS+Evac to examine evacuation behavior in a large distribution center warehouse. Extensive reviews of computational fire and evacuation models and their uses as an experimental tool can be found in references [16] and [17]. Because FDS+Evac is capable to simulate both fire and evacuation, the FDS+Evac was used in this study. The study employed FDS+Evac [8, 9], to simulate smoke spread and fire evacuation in a large MRT multilevel-platform station. Fire and evacuation were coupled in the simulations in order to investigate tenable environments and evacuation behavior inside the station. The main objectives were to demonstrate compliance of station evacuation times with the NFPA 130 and to perform a safety analysis of passengers in the station based on the simulation results.

## 2. SIMULATION SETUP

### 2.1 Description of the Station

The MRT multilevel-platform station depicted in this study is a 4-story high building. The station is arranged in a cross configuration as shown in Figure 1. The station dimension is 175 m wide, 189 m long and 32.65 m high. A typical floor to floor is 9.2 m high. Station area utilization is shown in Table 1.

**Table 1** The station area utilization.

| Level | Area utilization |
|---|---|
| Ground | Four ground level entrances and one ground level exit |
| Level+1 | Concourse (CC) level |
| Level+2 | Blue Line (BL) platform: side platform |
| Level+3 | Purple Line (PL) platform: center platform |

The Purple Line (PL) platform is at station level +3. The layout is center platform configuration. The platform lays on North-South direction. There are 4 stairs and 4 escalators on this level. The Blue Line (BL) platform is at station level +2. The platform layout is a side platform. A BL train arrives and departs on East-West direction. On the East-Bound (EB) of BL platform, there are 4 stairs and 2 escalators. The West-Bound (WB) of BL platform has 4 stairs and 2 escalators. There are 4 enclosed fire exit stairs located on the BL platform where two of them are on the EB platform and the other two are on the WB platform. The Concourse (CC) is at level+1. There are 5 exit stairs that can be used in cases of fire and emergency which lead to the ground level. These 5 exits are located on North-East (NE), North-West (NW), East (E), West (W), and South (S).

### 2.2 Computational Model Setup

Numerical simulations of smoke spread and fire evacuation on the MRT multilevel-platform station were performed via a well-known CFD fire model, Fire Dynamics Simulator with Evacuation (FDS + Evac) version 5 [8, 9]. FDS+Evac solves numerically a form of the Navier-Stokes equations for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires. Turbulence is treated by means of the Smagorinsky form of Large Eddy Simulation (LES). The conservation equations for mass, species, momentum and energy are written as the followings.

$$\frac{\partial \rho}{\partial t} + \nabla.\rho\mathbf{u} = 0 , \quad (1)$$

$$\frac{\partial(\rho Y_i)}{\partial t} + \nabla.\rho Y_i\mathbf{u} = \nabla.(\rho D_i)\nabla Y_i + \dot{W}_i''' , \quad (2)$$

$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}.\nabla)\mathbf{u}\right) + \nabla p - \rho\mathbf{g} - \mathbf{f} = \nabla.\tau , \quad (3)$$

$$\frac{\partial(\rho h)}{\partial t} + \nabla.\rho h\mathbf{u} - \frac{Dp}{Dt} = \dot{q}''' + \nabla.k\nabla T + \nabla\sum_i h_i(\rho D)_i\nabla Y_i , \quad (4)$$

where the fluid variables are density , time t, velocity vector u = (u,v,w) for a Cartesian coordinate system x = (x,y,z), mass fraction of the ith species Yi, diffusion coefficient Di, production rate of the ith species per unit volume $\dot{W}_i'''$, gravity vector g, external force vector (excluding gravity) f, the viscous stress tensor  for a Newtonian fluid, enthalpy h, pressure p, heat release rate per unit volume $\dot{q}'''$ , thermal conductivity k, and temperature T.

The 3D model for FDS was created from a 3rd party tool, PyroSim [18]. A computational domain was 220 m long, 200 m wide and 40 m high to cover all the station structure.

An extensive grid refinement study has been performed to ensure that the numerical result was adequately resolved. A smoke temperature was used as a key parameter as it was a main driving force that drives smoke to spread through the station. Three grid sizes of 0.5 m (medium grid), 0.25 m (fine grid), and 0.125 m (ultra-fine grid) around a fire train engine, and 1.0 m outside the fire area were employed. All the simulations were performed on a personal computer, Intel Core i7 CPU, 16 GB ram. The CPU times for 700 seconds simulation time were approximately 23 hours, 37 hours, and 106 hours for medium grid, fine grid, and ultra-fine grid, respectively. The percent differences of the steady state temperatures for various locations near and far away from the fire train when decreasing the grid sizes were calculated. When decreasing the grid size from medium grid to fine grid, the maximum percent difference was about 10% and when decreasing the grid size from fine grid to ultra-fine grid, the maximum percent difference was about 5%. Therefore within 5% difference of the smoke temperature throughout the computational domain with an acceptable CPU time (within 2 days per case), the fine gird size of 0.25 m around the fire train and 1.0 m outside the fire area was employed (see Figure 2). The total grid cells employed in both fire and evacuation simulations were approximately 2 x $10^6$ cells.

The side and top boundary conditions were set as open to the surroundings. All the simulations were performed with an initial ambient temperature of 40$^o$C. To simulate the worst case scenario, two set of boundary conditions were considered: 1) No wind and 2) wind blow boundary conditions. The wind speed and direction was based on a wind map plotted from wind data obtained from the Thai Meteorological Department [19]. The wind velocity profile was assumed to follow the power law [18] where the speed was varied with height from the ground. The atmospheric wind velocity profile is:

$$u = u_0 \left( \frac{z}{z_0} \right)^{0.1} \quad (5)$$

Where u is wind speed (m/s), $z$ is height (m), $u_0$ is wind speed at a reference height of $z_0$.

In the simulation, the wind data from the Thai Meteorological Department [19] provided a value of $u_0$ as the maximum wind speed on the East of 9.25 m/s at height $z_0$ of 10 m. Figure 2 illustrates a 3D station model used in the calculation.

A t-square fire with maximum heat release rate of 7 MW and ultra-fast growth factor was assumed. The maximum heat release rate of 7 MW fire was recommend for a modern train car with a minimum fire load by Barber [20], and Li and Ingason [21]. For a large structure fire simulation such as an airport or a train terminal hall, Yuen [22] also suggested that a 7 MW fire was reasonable to simulate smoke and heat spread. NFPA 130 [1] suggested that the fire location should be on a train engine due to the fire load in the station was typically limited. In this study a 7 MW fire on a train engine (either on BL or PL) was employed. Based on the definitive design provided by the MRT project consultant [23], the train engine occupies approximately 1/3 length of a train car and thus the simulating fire area was assumed to cover all the train engine resulting in approximately a burning area of 58 $m^2$. Full capacity of 6 train cars including the train engine was assumed. The BL trains both East-Bound (EB) and West-Bound (WB), and the PL trains both North-Bound (NB) and South-Bound (SB) were set to park at the platforms when the fire started.

In the estimation of soot and CO from fire, the combustion model used in the simulation could be described as the followings. The fire combustion was based mixture faction combustion model [8]. The fuel chemistry was based on heptane ($C^7H^{16}$). The prediction of CO production subroutine was turned-on. The soot and CO yields were 0.015 and 0.006, respectively. The atomic fraction of hydrogen in the soot was 0.1. For more information of the combustion model could be found in reference [8].

For the wind blow boundary condition, comparing between a fire on BL and PL train engine, a worst case scenario was more likely to occur when the fire was on the BL platform because the BL platform was lower than the PL platform. Therefore, the fire on BL level creates more hazardous effects than on the PL platform. The BL train engine was on the East (EB platform), thus the maximum wind speed on the East direction was selected as the wind speed for wind blow boundary condition.

From the boundary conditions and fire locations, the simulations were carried out for 4 cases in order to simulate the worst case scenario and the effects of fire and wind blow to the station evacuation time. Table 2 summarizes all 4 simulation cases for smoke spread and fire evacuation.

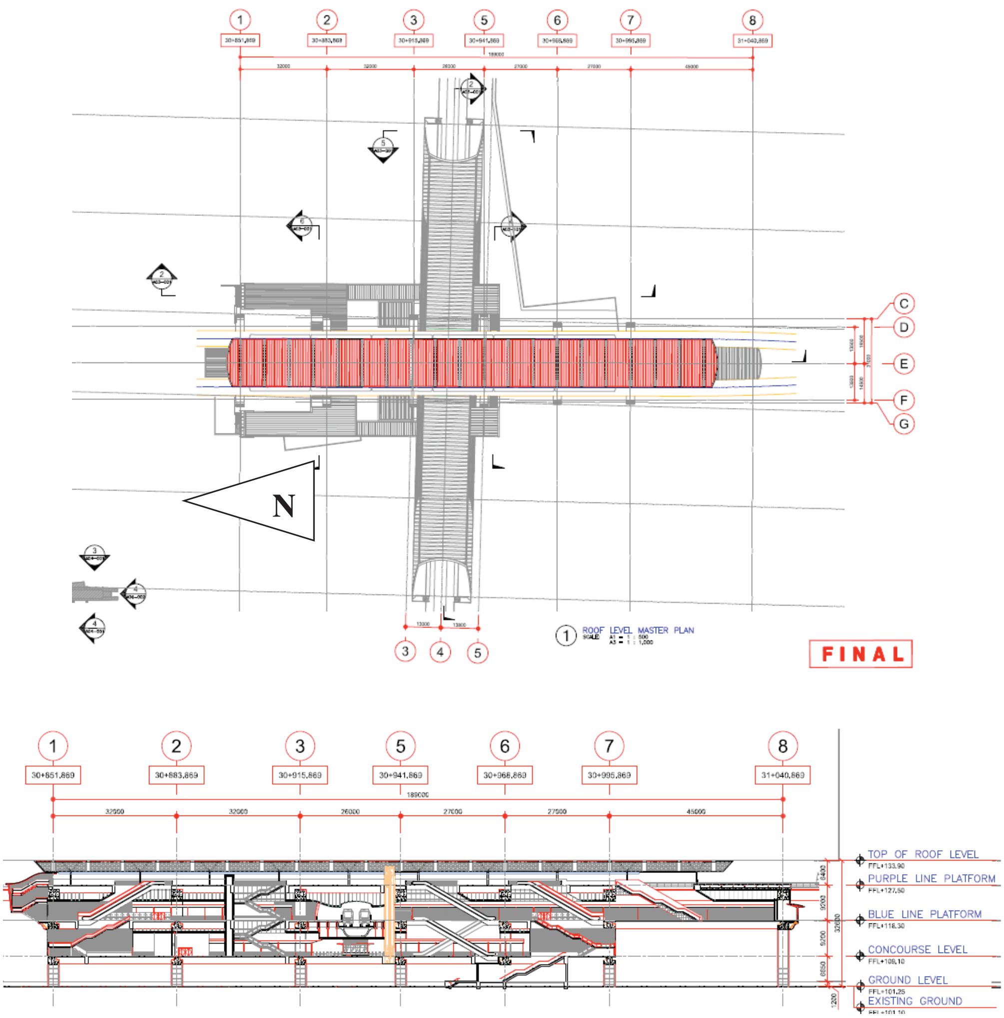



**Figure 1:** Plan view and elevation view of the MRT multilevel-platform station.

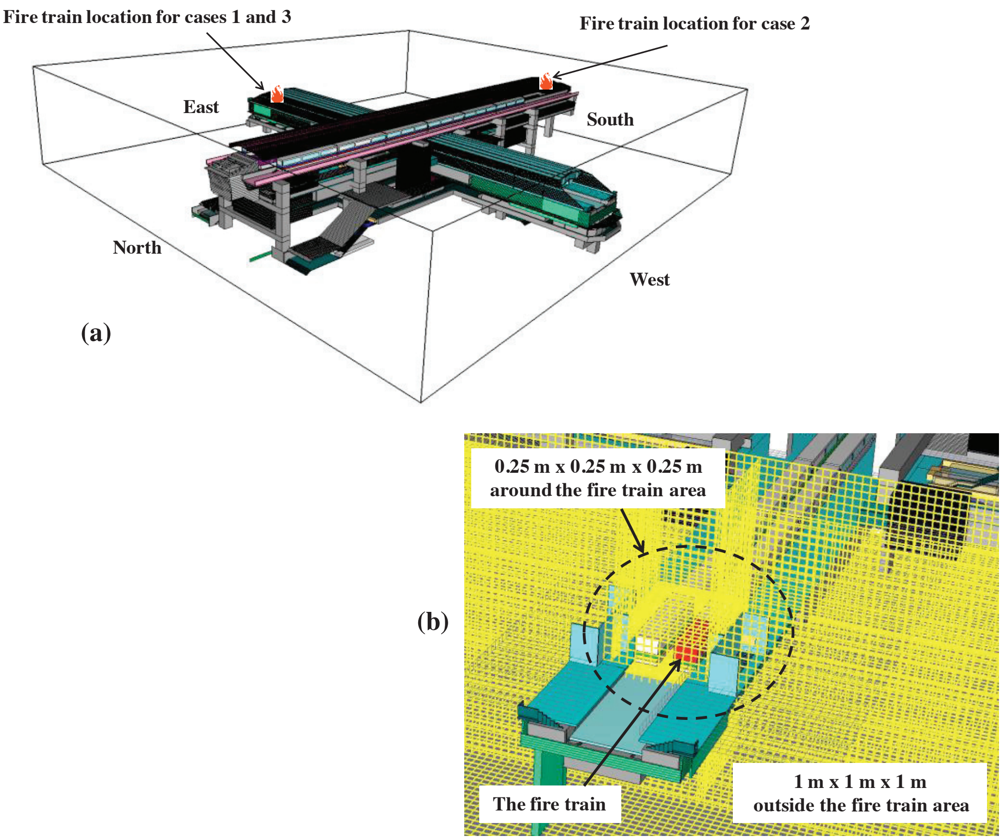



**Figure** 2: (a) A 3D station model and fire locations and (b) an enlarged view of the grid sizes employed in the simulation.

**Table** 2 Summary of the simulation cases

| Case | Boundary condition | A 7 MW fire location on a train engine |
|---|---|---|
| 0 | No Wind | No Fire |
| 1 | No Wind | EB BL |
| 2 | No Wind | SB PL |
| 3 | Wind East at 9.25 m/s | EB BL |

In case 0, the simulation was performed with no fire either on BL or PL trains. The purpose of this calculation was aimed to evaluate the station evacuation behavior as when a station fire-drill is performed. In cases 1 and 2, the simulations were carried out for a fire on EB BL train engine and SB PL train engine respectively. These simulations were intended to investigate the effects of fire to station evacuation behavior as when fire occurs on BL and PL platforms. Due to station layout is symmetry, therefore simulating one fire location per platform level was justified. In case 3, the simulation was performed for a fire on EB BL train engine with wind blow from East to West at speed of 9.25 m/s. This simulation was carried out to study the effects of wind on fire and smoke spread inside the station to compare with case 1 and case 2.

In the evacuation simulation, each passenger was treated as a separate entity called an "agent". Each agent has its own personal properties and escape strategies. The movement of the agents is simulated using two-dimensional planes representing the floors of buildings. Each agent movement speed is calculated based on the Newton's law of motion. The summation of all forces acting on each agent is equal to a product of mass of an agent and its acceleration. When an agent is be able to move freely with no contact with other agents or walls that agent speed can accelerate up to a predefined unimpeded walking speed. More details of evacuation simulation technique can be found in reference [9].

The station initial occupant load was based on the detailed and definitive designs of the station [23] provided by the MRT project consultant. The passenger load employed in the simulation was based on year 2032 of the ridership forecast data which based on 6 train cars per platform. The train headways of 2 minutes in the morning peak period were used. The total passenger load estimated from the 2-minute accumulation of the morning peak hour on the PL and BL levels were 1,462 persons and 1,132 persons, respectively. The fire scenario was assumed as the trains were malfunction and parked on both BL and PL platforms for 2 minutes before the fire started. As suggested by the MRT project consultant, according to the MRT emergency protocol, no new passengers would allow to enter the station on the CC level for this emergency situation; hence, there were no passengers initially on the CC level. Accordingly, the station total occupant load was 2,594 persons. The passengers were uniformly distributed over the BL and PL floor areas. Based on the ridership forecast data provided by the MRT project consultant, the ratio of passenger type for adult to children was 95% to 5%. Adult and children passenger types have different body size and unimpeded walking speed. It was not feasible to obtain actual passenger properties; therefore the default passenger properties for adult and children defined in PyroSim [18] were employed in all calculations. The passenger density on the EB BL platform was 0.624 person/$m^2$, the WB BL platform was 0.177 person/$m^2$, and the PL platform was 1.354 person/$m^2$. The PyroSim default human response time of 10 seconds was assumed.

## 3. DESIGN OBJECTIVES

The numerical simulation was carried out to demonstrate compliance of the station evacuation times for the large MRT multilevel-platform station with NFPA 130 standard for fixed guide way transit and rail systems [1]. NFPA 130 requires that the platform evacuation time shall not exceed 4 minutes and the station evacuation time to points of safety shall not exceed 6 minutes. The points of safety according to the code employed in this study were the followings: 1) an enclosed fire exit stair that lead to safe location outside station, 2) an at grade point beyond the station, and 3) a concourse level below the platform as permitted for an above ground open station.

## 4. RESULTS AND DISCUSSIONS

4.1 Fire Simulation

The CFD simulation provides useful information of tenable environments inside the station during fire. The tenable environment parameters considered were temperature, CO and $CO^2$ concentrations. The temperature, and CO and $CO^2$ concentrations time histories were recorded on various locations near stairs, escalators, and exit entrances at height 2.0 m above the floors of PL, BL, and CC levels as illustrated in Figure 3. The measurement of tenable environments at height 2.0 m above floor was chosen to represent the worst case scenario. Due to the nature of hot smoke that will rise and stratify near the ceiling, the environment near the ceiling is more hazardous than near the floor. Therefore, if the environment at height 2.0 m is tenable, the environment at height below 2.0 m is also tenable. This criterion was used in the passenger safety analysis.

Due to limited space, only temperatures at height 2 m above the fire train platform were presented here. Temperature time histories for case 1 where the fire train on BL platform, case 2 where the fire train on PL platform and case 3 where the fire train on BL platform with wind blow from East at speed of 9.25 m/s were plot in Figures 4, 5, and 6, respectively. The data legends on the graphs are referred to the name tags of gas data locations shown in Figure 3.

Figure 4 shows that the temperatures near the fire train at locations 7 and 11 reached a steady state at approximately 100 seconds with the values of 70 $^{o}$C and 80 $^{o}$C respectively. The temperature at height 2 m above the BL platform at location 7 is lower than the temperature at location 11 even though the location 7 is closer to the fire train than the location 11. This is due to the difference in the ceiling height. Typically, the smoke temperature at the point near a ceiling is higher than the point where it is far away. According to the station architecture design, the BL platform ceiling height varies from approximately 2.5 m up to 3 m. The ceiling height at location 7 is about 3 m where the height at location 11 is about 2.5 m. Therefore the temperature at location 7 is slightly less that location 11. Further away from the fire train at locations 8 and 12 the temperatures at height 2 m above the BL platform approached a steady state value of approximately 62 $^{o}$C. The rest of the BL platform far away from the fire train and other levels of the station including PL and CC levels, the temperatures remained approximately at the initial ambient temperature of 40 $^{o}$C. This was because the BL platform was directly open to the surroundings; therefore no smoke was accumulated inside the station far away from the fire train. The temperature above 70 $^{o}$C could cause the passengers to be incapacitated within 6 minutes [1]. However, the evacuation simulation result showed that all the passengers were able to egress from the fire zone and leave the BL platform within approximately 1 minute (see Figure 9).

Figure 5 shows the temperature time histories of PL level for case 2. The PL platform is the station highest level; therefore, heat and smoke from the fire train can rapidly dissipate away to the surroundings. Only little heat and toxic gases were accumulated inside the PL level. The maximum steady state temperature of 50 $^{o}$C was observed at location 5 and gradually decreasing as it progressed into the PL platform (locations 4, 3, etc.). The steady state temperature at location 6 is low (approximately 42.5 $^{o}$C) ever though it is closed to the fire train. This is because the location 6 is also closed to the open space outside the PL platform. Therefore, fresh air from surroundings is induced into the station by natural convection diluting the smoke temperature at location 6.

Figure 6 plots the temperature time histories of BL level for case 3. The simulation conditions of case 3 were exactly the same as case 1 except that a wind blow from East at speed of 9.25 m/s. Because the station was directly open to the surroundings, the wind blow caused smoke and heat to rapidly flow outside the station as well as drew fresh air from outside to dilute the smoke inside. Therefore the tenable environments inside the station of case 3 were less severe than case 1. The vortex shedding behavior was found and caused the temperature, and gas concentrations to fluctuate. The highest average temperature of approximately 55 $^{o}$C was obtained at locations 7 and 11.

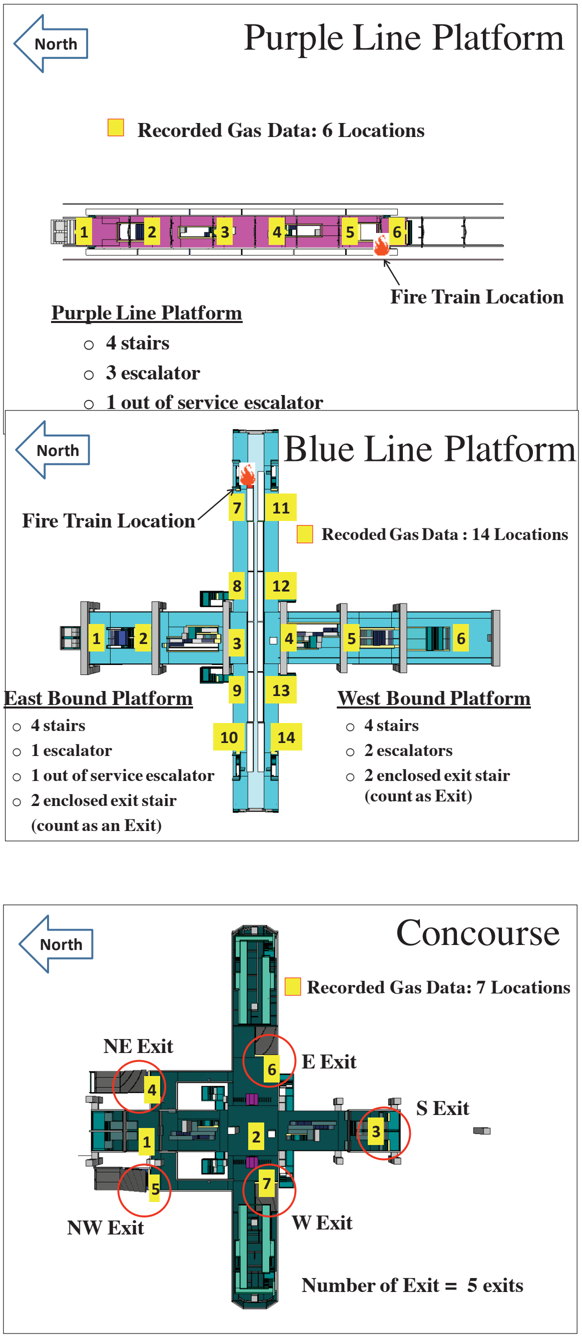



**Figure** 3: Locations of recoded gas data at height 2 m above the floors of PL, BL, and CC levels.

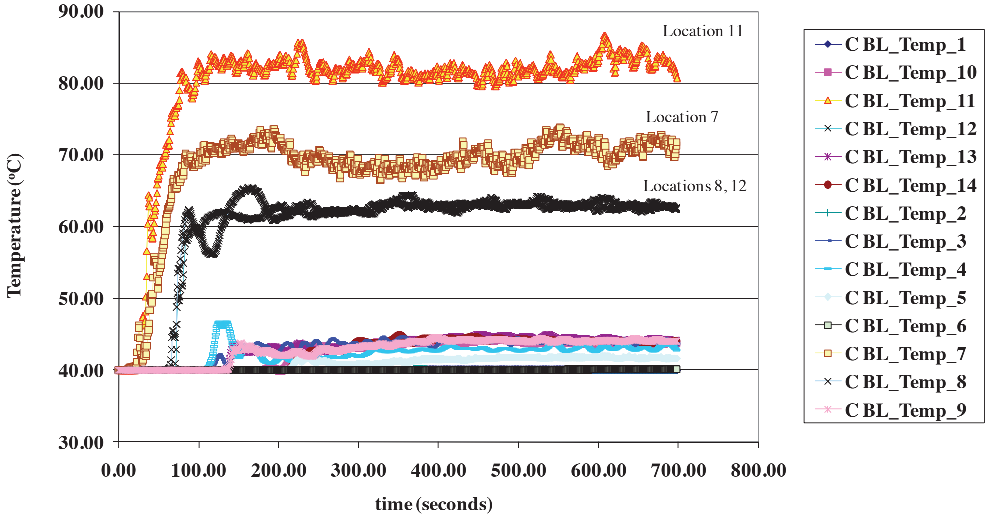



**Figure 4:** Temperature time histories at height 2 m above BL platform for case 1 (fire on EB BL).

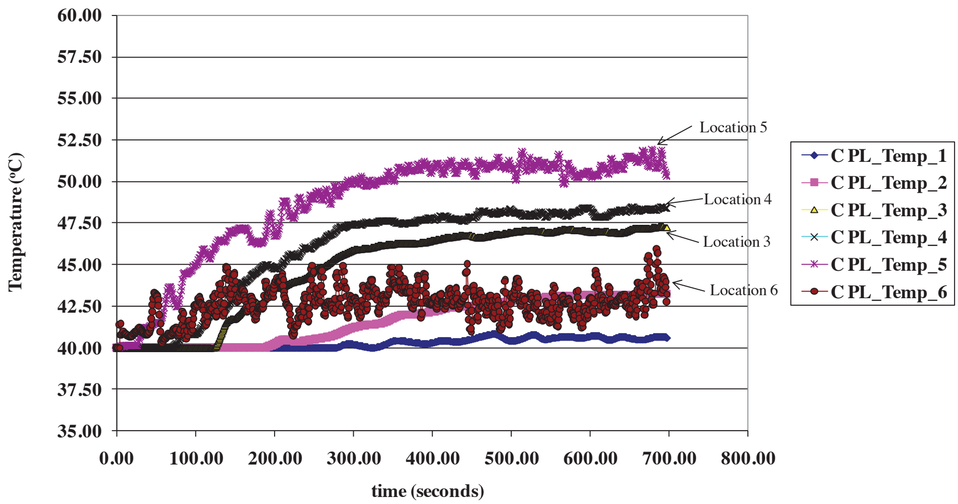



**Figure 5:** Temperature time histories at height 2 m above PL platform for case 2 (fire on SB PL).

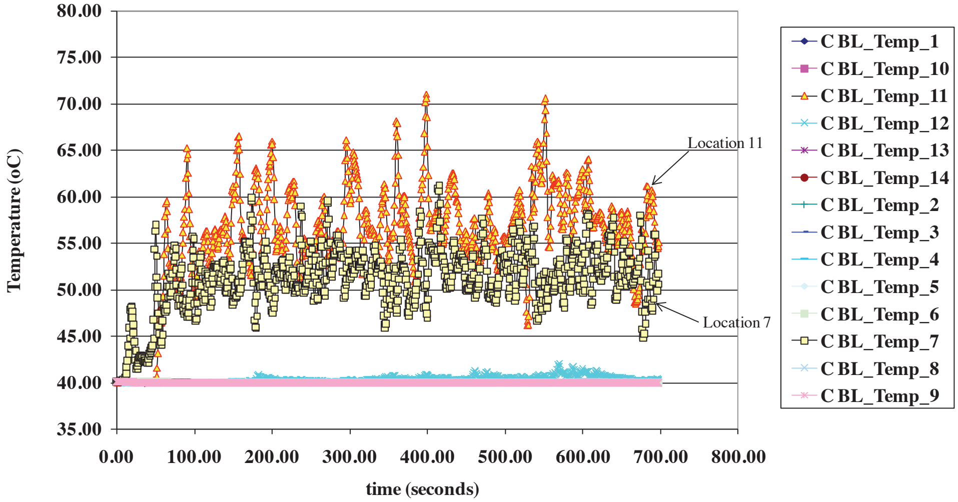



**Figure 6**: Temperature time histories at height 2 m above BL platform for case 3 (fire on EB BL)

Because the station was directly open to the surroundings; the toxic gases from fire were significantly diluted by the ambient air. The simulations found that the highest steady state CO concentration of 14 ppm was obtained at location 11 (on EB BL platform) for case 1. For cases 2 and 3, the maximum CO concentrations were about 3 ppm and 7 ppm, respectively. These values were well below the incapacitated limits of 50 ppm given by NFPA 130 [1]. The calculations showed that the maximum concentration of $CO^2$ for case 1 was approximately 4500 ppm near the fire train. The maximum $CO^2$concentrations were less than 1000 ppm for case 2 and less than 3000 ppm for case 3. NFPA 130 does not provide a minimum concentration of $CO^2$ for tenable environment; however, the $LC_{50}$ valve of 150,000 ppm to cause lethal within 5 minute reported by Klote and Milke [24] shall be used as a limit. The LC50 is the concentration that would be lethal to 50 percent of the exposed subjects for the specified time. Accordingly, the maximum $CO^2$concentrations for all cases were well below the $LC_{50}$ limit. For all cases, the passengers could escape from the fire area before the environment inside the station became untenable; therefore, the passengers were considered to be safe from the fire hazard.

The impact of smoke toxic gases on a single passenger was investigated based on the parameter called Fraction Effective Dose (FED). The FED is the sum of the effects of the toxic gases toward the total effect on the exposed person [24]. The FED based on Purser's correlation [25] was employed. The FDS+Evac used the concentrations of the narcotic gases CO, $CO^2$, and $O^2$ to calculate the FED value for each passenger individually [9]. A passenger is considered to be incapacitated (dead) when the FED value exceeds unity (FED >1). An incapacitated passenger is model as a passenger with a zero movement speed. In the simulation, when the passenger reached the point of safety, that passenger was then removed from the computational domain. The FED for that particular passenger was set back to zero.

Figure 7 plots the maximum value of FED and maximum FED of alive-passenger inside the computational domain (station) for cases 1, 2, and 3, respectively. The plots show that simulated FED for each individual passenger from all cases was well below one and thus there was no passenger dead; all passengers could reach to the point of safety. It should be noted that no fire simulation data for case 0.

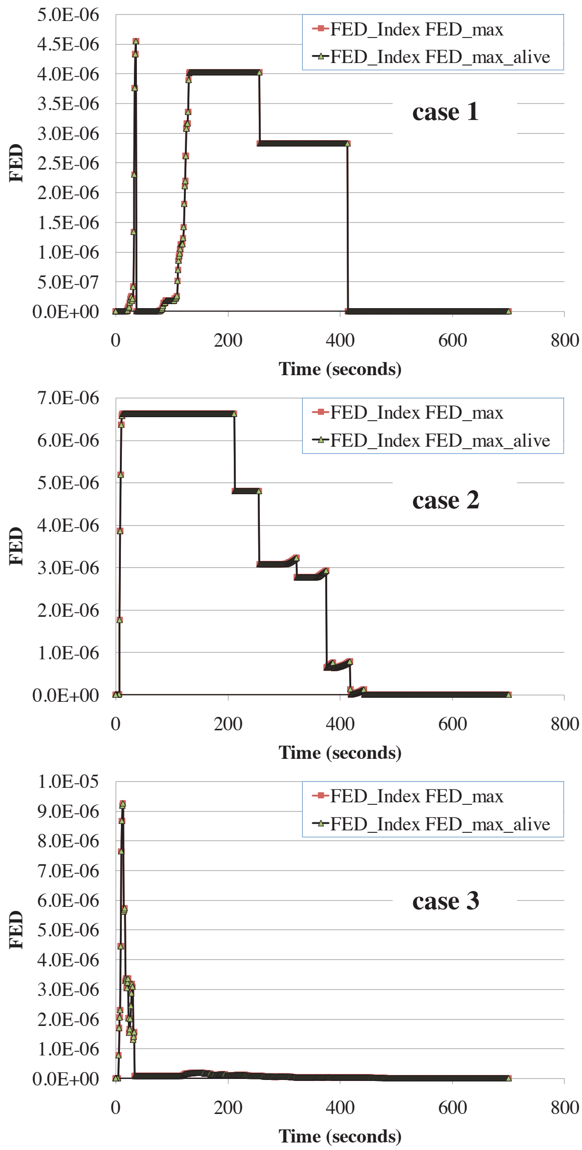



**Figure 7**: Maximum FED and maximum FED alive time history.

4.2 Evacuation Simulation

Passenger load per level time histories are illustrated in Figure 8. For all simulations, the initial passenger load on PL level was 1,462 persons, and BL level was 1,132 persons

(824 persons on EB platform and 308 persons on WB platform). There were no passengers initially on the CC level. The passengers were distributed uniformly over the floor areas. The default human response time of 10 seconds was assumed. For all cases, the plots show almost the same behavior. At the beginning within 10 seconds, no passenger loads changed according to the passenger time delay. After that, the passengers on PL level started to move. The loads on PL platform decreased as the time goes by. All the passengers on PL level leaved the platform and reached the BL level within 3.18 minutes for case 0, 3.23 minutes for case 1, 3.32 minutes for case 2, and 3.28 minutes for case 3. These evacuation times were also the platform evacuation time for PL platform. All the PL platform evacuation times were less than 4 minutes as required by NFPA 130 (see Figure 9).

The passenger loads on BL level slightly increased at the beginning of the simulation (see Figure 8) as the passengers from PL level were accumulated on the BL level. After approximately 60 seconds, the BL loads started to decrease as the rate of the passenger leaving the BL level to CC was greater than the rate of the passenger moving down from PL to BL level.

All the passengers leaved the BL level and reached the CC level within 5.03 minutes for case 0, 5.08 minutes for case 1, 5.03 minutes for case 2, and 4.97 minute for case 3 (see Figure 9). The platform evacuation times for BL were 0.92 minutes for case 0, 0.93 minutes for case 1, 0.93 minutes for case 2, and 0.90 minutes for case 3. All the BL platform evacuation times were less than 4 minutes as required by NFPA 130 (see Figure 9).

The passengers leaved the CC level and reach the ground level within 8.40 minutes for case 0, 8.42 minutes for case 1, 8.18 minutes for case 2, and 8.10 minutes for case 3 (see Figure 9). Even though the passengers evacuated from the station building more than 6 minutes, but the tenable environments in the station were provided for all the evacuation process. Therefore all the passengers were considered to be safe. However, as permitted by NFPA 130 for an open above ground station, the CC level can be considered as a point of safety. The evacuation times for all passengers to reach the CC were less than 6 minutes. Therefore if consider the CC level as a point of safety, the station evacuation times were complied with NFPA 130. For all 4 cases the platform evacuation and station evacuation times were approximately the same. This was because the passengers started to move away from the fire train area before fire and smoke could affect the evacuation process. Therefore, it can be concluded that fire locations and wind did not significantly affect the passenger evacuation times

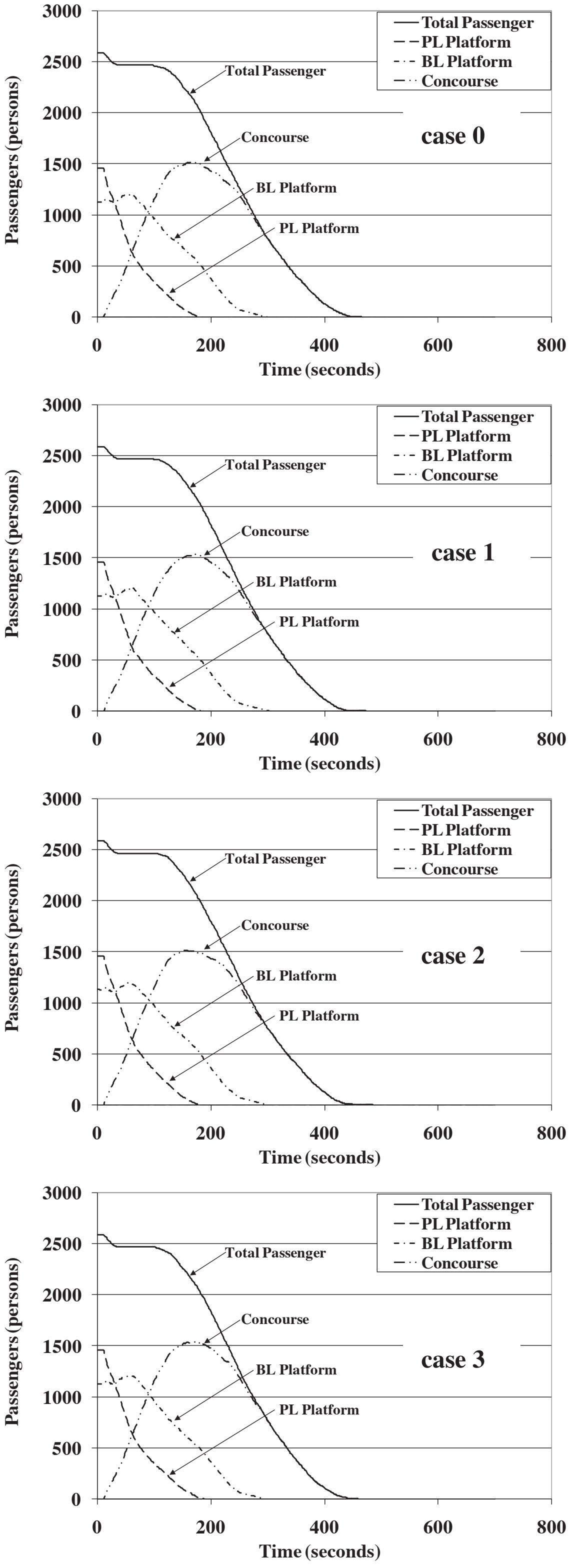
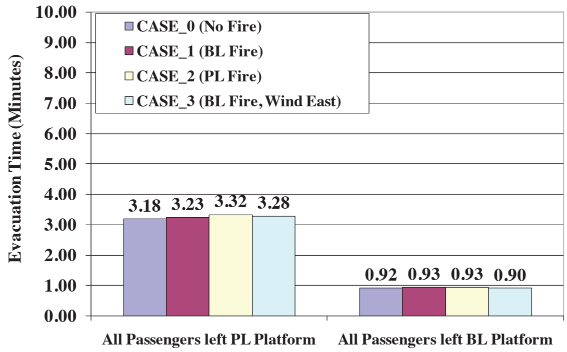
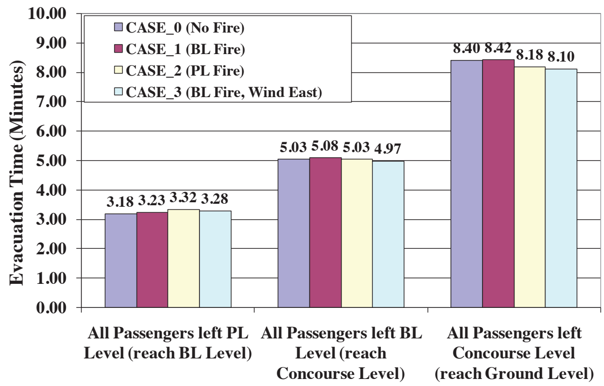



**Figure 8:** Passenger load time history




platform evacuation time




station evacuation time

**Figure 9:** Summary of evacuation times (case 0 to case 3 starting from left to right).

### 4.3 Passenger Evacuation Behavior

Typical evacuation behavior observed on the PL level is illustrated in Figure 10. The passenger movement speeds and their egress paths tracked back for 16 second are shown. The red color indicates a fast movement speed and the dark blue indicates a slow movement speed. Congestions occurred on the North-end stair entrances of the platform. Most of the passengers up to 43% used these two stairs. As a result, congestion was observed. The congestion acted as a temporary barrier to egress from the PL platform.

Typical evacuation behavior observed on the BL level is illustrated in Figure 11. The BL level has to serve the station load from both BL and PL levels. Although there were totally 15 stairs and escalators available, only 2 stairs had to serve a majority of the passengers (see Figure 11). The average percent stair usage for all cases was approximately 40% for the North stairs and 22% for the South stairs. Long queuing times were observed on both stairs. On the North stairs, two passenger flows from the PL level merged on the EB BL platform to use the North stairs. This caused a major congestion. Moreover, the evacuees from the PL level needed to make a U-turn before they could find stair entrances on the EB BL platform; thus a passenger movement speed decreased dramatically.

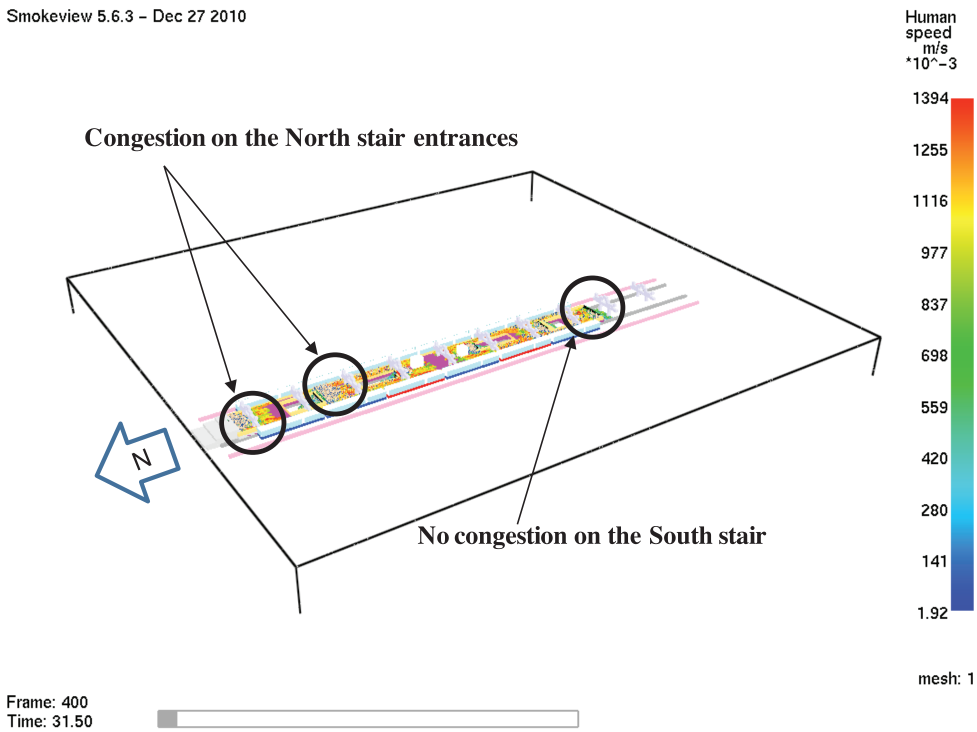



**Figure 10:** Typical evacuation behavior of the PL level.
(For color, the reader is referred to the web version of this paper.)

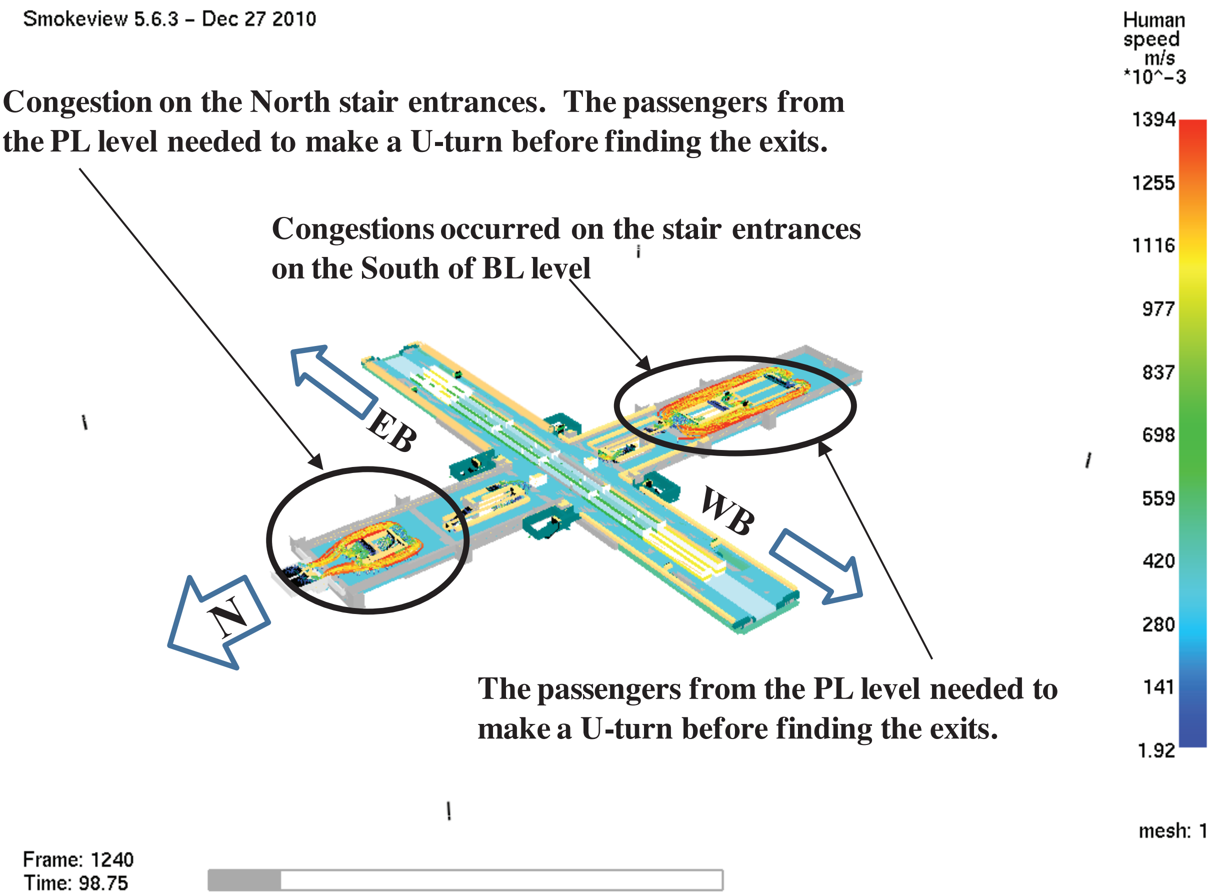



**Figure 11:** Typical evacuation behavior of the BL level.
(For color, the reader is referred to the web version of this paper.)

**Figure** 12 illustrates typical observations found on the CC level. No passengers were initially on the CC level. Egress flow through the CC level was reasonably fluid. The passengers could be able to move at approximately their maximum unimpeded speed. The NE and NW exits processed substantially more passengers due to most of the passenger on the EB BL level employed the North-end stairs. However, the egress capacities of the NE and NW exits were adequate to process the demand without considerable queuing. Minor congestion occurred on the South exit. This was because the South exit was the only one obvious exit for the passengers who used the stair on the South of WB BL platform. However, the South exit stair could handle the egress load as the passengers were be able to move near their maximum unimpeded speeds.

The total station exits were 9 exits. There were 5 exit stairs leading to the ground on the CC level and 4 enclosed exit stairs leading to ground on the BL platform. As discussed above, most of the passengers on the EB BL employed the NE and NW exits where the passengers on the BL WB employed the S exit. The exit usages of the NE, NW, and S exits were summed up to approximately 80% of the station load.

## 5. CONCLUSIONS

Smoke spread and fire evacuation in a large MRT multilevel-platform station in Bangkok, Thailand was investigated via a well-known CFD fire model, FDS+Evac. The study was intended to demonstrate compliance of the station evacuation times with the evacuation times required by NFPA 130 and to perform a safety analysis of passengers in the station based on the simulation results. Four simulations based on worst case scenario concept were performed. In all cases, the station passenger load was 2,594 persons based on the ridership forecast data on year 2032. The study showed that the platform evacuation times of PL and BL platforms for all cases were less than 4 minutes. These simulated platform evacuation times were complied with the platform evacuation time required by NFPA 130. The station evacuation times for all passengers to reach the point of safety, which was defined as the CC level as permitted by NFPA 130 for an above ground open station, were approximately within 5 minutes. These evacuation times were complied with the 6 minutes or less station evacuation time required by NFPA 130. These simulation results can be used by a fire safety engineer to improve an egress efficiency of large public transport terminals such as a MRT multilevel-platform station or an airport arrival hall.

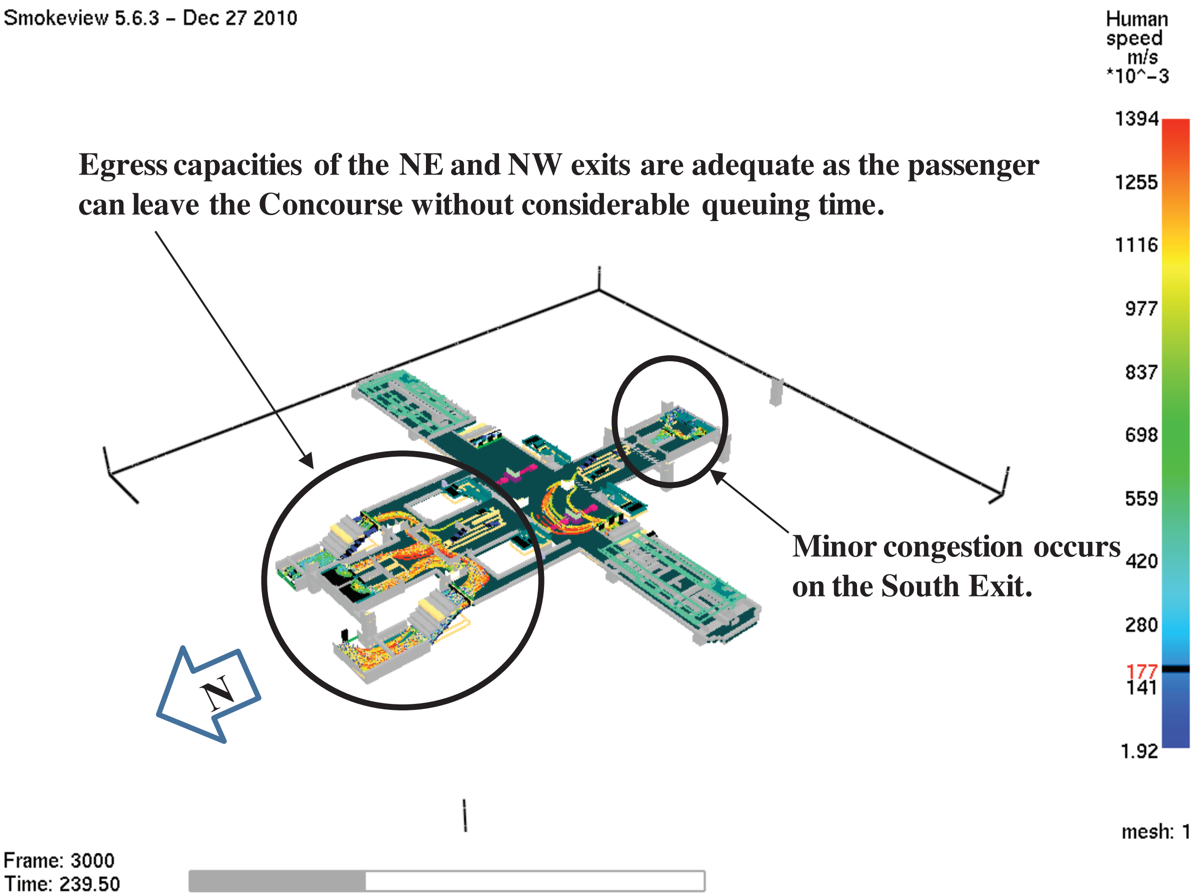



**Figure 12**: Typical evacuation behavior of the CC level.
(For color, the reader is referred to the web version of this paper.)

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