Ergonomic Design of Tunnel Ventilation System for Underground MRT Station using CFD Simulation

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Abstract

Ventilation is considered as one of the engineering controls to remove or control contaminants released in indoor work environments. It is one of the preferred ways to control human exposure to air contaminants. It is commonly used to remove contaminants such as fumes, dust, and vapors; and to provide a healthy and safe environment. Industrial systems are designed to move out and bring in a specific amount of air at a specific speed, which results in the removal of undesirable contaminants. While all ventilation systems follow the same basic principles, each system is designed specifically to match the type of work and the rate of contaminant release in that area (CCOHS, 2020). One of the types of the industrial ventilation system is a tunnel ventilation system. Tunnel Ventilation System (TVS) is an essential part of maintaining a safe environment inside the tunnel during congestion and emergency operation. During the congestion scenario, TVS will operate to maintain the design temperature inside the tunnel. During the fire mode scenario, TVS will automatically operate via push-pull ventilation to control smoke direction away from the people to provide a safe escape pathway. It was also validated from the computational fluid dynamics (CFD) analysis that the result of subway environmental simulation (SES) airflow capacity for congestion and fire mode scenarios are sufficient throughout the tunnel. CFD analysis using Fire Dynamic Simulator (FDS). FDS is the software used for analyzing smoke behavior in terms of airflow, temperature, relative humidity, velocity, and soot visibility. As part of the simulation result, the researchers were able to see the results on every part of the tunnel. One of the major advantages of CFD simulation is that the researchers can do trial and error on every possible scenario and location of the fire heat load to best analyze the situation in the worst-case scenario. Time is also an essential factor during fire mode, and the CFD simulation can be used as a basis for the emergency response team for a proper fire escape plan.

Keywords
Tunnel ventilation system, underground station, CFD simulation, subway environmental simulation, fire dynamic simulator

1. Introduction
According to OSHA, indoor air quality has become an important health and safety concern. IAQ problems result from interactions between building materials and furnishing, activities within the building, climate, and building occupants. IAQ problems may arise from one or more of the following causes such as inadequate temperature, humidity, poor air circulation, ventilation system issues, indoor air contaminants, and insufficient outdoor air intake. Occupants of buildings with poor IAQ report a wide range of health problems which often include Sick Building Syndrome (SBS), Building-Related Illness (BRI), and Multiple Chemical Sensitivities (MCS) (CCOHS, 2012).

Given these conditions, it became the research interest of the authors to design a tunnel ventilation system for the underground metro rail station using a CFD simulation software, which is required to achieve a safe and clean environment inside the tunnel, maintain design temperature, and control the smoke during a fire. As part of this research design on tunnel ventilation, the section of the tunnel is analyzed between two (2) stations. These stations are situated on the underground level with the lowest tunnel section almost 14 meters below the road level. With these types of tunnel configuration, Tunnel Ventilation System (TVS) is needed as stated by the National Fire Protection Agency (NFPA) 130: Standard for Fixed Guide Way Transit and Passenger Rail System.

This study will address the ventilation requirement of the tunnel during the fire and congested conditions. This study also aims to design tunnel ventilation that will control smoke propagation during fire emergencies, determine critical velocity inside the tunnel during fire mode, develop an operational control system for tunnel ventilation fans during normal, congested, and fire mode scenarios, and evaluate simulation result of the one-dimensional program using CFD analysis.

This research will study the design of tunnel ventilation system utilizing two (2) simulation software analysis. The first is one is the subway environmental simulation (SES) which is a one-dimensional network analysis and the other one is the fire dynamic simulator (FDS) that uses graphical and animated representations of the result in a 3D environment. The research design study utilized the software result of the SES that is already simulated, and then the researchers validated and compared the result using the CFD analysis to have a more accurate outcome and more presentable animated result for better understanding especially on the presentation of result.

However, this study focuses only on the CFD simulation part of the tunnel ventilation design. For this specific study, the researchers concentrated on an underground tunnel, which involves two (2) Tunnel Ventilation Fan (TVF) that are strategically located on both ends of the Station platform. The TVS design would normally start with the one-dimensional analysis using SES to calculate the required airflow on the tunnel during the operational mode of congestion and fire scenarios. The most critical calculation is the critical velocity and SES can simulate longitudinal airflow through the fire model of the program. This fire model calculation is required to overcome the smoke back layering and to simulate the smoke airflow movement in a tunnel. The researchers verified and investigated the results using the CFD analysis program via a fire dynamic simulator to determine the smoke and temperature accurately in terms of distribution in both state conditions of steady and transient. The three-dimensional CFD analysis modeling can use the output result from the SES as part of its input on initial boundary conditions.

2. Review of Related Literature

2.1. Tunnel Ventilation System

To control the temperatures in a subway system, an introduction of air from the outside is needed. This is to provide passengers dwelling with enough incoming fresh air for healthy and safe breathing and in the event of an emergency, outside fresh air is operating to control and divert the smoke flow that would give a safe escape pathway for the passengers (Tabarra & Sadokierski, 2004).

During normal mode, both air temperature and air quality must be accepted into the environment and appropriate ventilation must be provided. A certain mechanical cooling system is necessary for warm tunnel environments. The piston effect of trains can provide ventilation on tunnels and stations, and this can be achieved through the use of strategically located blast shafts, which must be properly sized (Tabarra & Sadokierski, 2004).

As stated on NFPA 130, a mechanical emergency ventilation system shall be provided in the following locations: (1) in an enclosed fixed guideway transit station and (2) in a fixed guideway transit underground or enclosed train way that is greater in length than 304.8 meters (1000 feet).

2.2. Control Smoke Propagation

One of the principal consideration of safety in the tunnel/subway design of ventilation system is fire safety, the fire scenario must be considered for the smoke control movement and provide passengers and occupants to have an acceptable atmosphere and tenable environment for proper evacuation during fire emergencies (Grant & Jagger, 2012).

Tunnel ventilation systems along the passengers' escape routes must provide conditions that are tenable during a fire occurrence in a vehicle inside the tunnel and this is must be provided also on an additional route that will be accessed by the emergency personnel during firefighting and operational rescue inside the tunnel. The tunnel ventilation may also be used for temporary safe refuge so tenable conditions must be maintained. With the assistance of tunnel ventilation forced airflow, the underground fire can be under control and can improve the visibility of smoke and fire on the upstream side (Grant & Jagger, 2012).

The greatest threat to every building user is the smoke that is produced in a fire that can be quickly produced in massive amounts. The smoke produced can cause direct fatalities, intoxicate any unsuspecting surprised occupants and the smokes can travel long distances. To eliminate or at least limit this threat, engineers have approach different technical designs and solutions that fall under a common terminology of the smoke control system. A smoke control system can be subdivided into many physical mechanisms that can be achieved like buoyancy, airflow, pressurization, compartmentation, and dilution (Wegrzynski, 2017).

2.3. Critical Velocity

One of the principal consideration of safety in the tunnel/subway design of ventilation system is the fire safety, fire scenario must be considered for the smoke control movement and provide passengers and occupants to have an acceptable atmosphere and tenable environment for proper evacuation during fire emergencies (Grant & Jagger, 2012).

The tunnel ventilation system is designed to control the migration of smoke if a vehicle fire occurs in a tunnel by generating an airstream with a velocity larger than the required amount when passing the fire to deter the formation of smoke back layering. This phenomenon is known as "Critical Velocity". It is reckoned based on the heat release rate from the vehicle, the geometry and annular area of the tunnel, gradient, and ambient air temperature.

"Backlayering" symbolizes the tendency of hot gases and smoke to move to the opposite direction of the incoming ventilation flow. The backlayering happens in the upper portion of the airway (tunnel) because of the temperature disparity between the hot gases/smoke and the incoming air. The Critical Velocity is estimated by solving the following equations concurrently.

$$V_c = KgK\ \left(\frac{gHQ}{\rho\infty Cp}ATf\right)1/2 \qquad (1)$$

$$T_f = (Q/\ \rho\infty Cp\ AVc\ ) + T\infty \qquad (2)$$

Where Vc is the critical velocity in m/s, Kg is a grade correction factor which is dimensionless, K is 0.61 which is a dimensionless constant, g is the acceleration due to gravity in m/s2, H is tunnel height in meter, Q is fire heat release rate in Watts, ρ∞ is ambient air density in kg/m3, Cp is the specific heat of air at constant pressure in J/kg-K, A is an area in m2, Tf is the hot air temperature in Kelvin, T∞ is the ambient air temperature in Kelvin.

Smoke control issue has become great attention that requiring the ventilating airflow to prevent smoke backflow from a fire has a big variation with the HRR. Overall, engineers and designers have focused on the critical velocity, well defined as that the needed airflow, which just stops any air stream upstream of the ongoing fire (Grant & Jagger, 2012).

2.4. Operational Control System

Every road tunnel network must have a tunnel ventilation system designed, tested, and commissioned properly. A simulation using a one-dimensional network numerical method has been used for the control system design and optimization. A system test is very important in the growing complexity of the ventilation system and the demanding constraints of time and quality. There is an assumption that needed to be performed that the system will not work if it has not been tested. In able to have enough time to test the system, all the involved control systems must be tested first before site installation. As done in the report, a numerical simulation model analysis of the tunnel was used, and the control and ventilation system was used (Riess & Alterburger, 2006).

It is a very important matter that during fire incidents as well as during normal operation there is an appropriate ventilation control system. Standard operation of the ventilation system during a fire incident is automatic, and severe damage to tunnel users may happen if there is a failure. Maintaining the criteria of pollution inside and outside the tunnel during normal operation is also a challenging task. If there is excessive pollution in the tunnel, the operator in the tunnel can suffer severe penalties. The maximum fresh air requirement which may occur during the congested traffic inside the tunnel is the basis of the required exhaust flowrate (Riess & Alterburger, 2006).

Mechanical ventilation required for the long rail tunnels is the most power powerful in most cases. Operational safety of TVS would always require a smoke management system that is high level besides the typical control requirements on normal operations and maintenance. To achieve a reasonable cost for operation and also keeping the investment low, the optimization of the ventilation even in concept is very important in achieving the proper safety and performance of a TV (Betteloni & Rigert, 2014).

2.5. CFD Analysis

In optimizing the ventilation of the subway with the configuration of side-platform, in terms of velocity and temperature, the researcher configured and built three-dimensional models from the original design and rebuilt again for the optimized design. The researchers used computational fluid dynamics (CFD) simulation for the subway that has a station configuration of a side-platform to collect the simulation result computation with the boundary conditions and used a physics model with two-equation turbulence model of a (Yuan & You, 2006).

Models from CFD can be realistically modeled without having an expensive investment on the experimental method of trial and error. CFD has the wide capability of simulating a model that has a vast variety of fluid problems. With the various parameters prediction such as visibility, air velocity, vehicle emission dispersion, etc. a proper Tunnel Ventilation System can be developed accordingly (Yuan & You, 2006).

The study of air behavior is very important in the distribution of the air velocity inside a tunnel or galleries; this can quickly be identified using the computational fluid dynamics (CFD) simulation software. On the turbulence model used, the results show that there had been a good relationship between the experimental results from measurements and the simulated data on the CFD analysis. From the results, the model that is constant turbulent eddy viscosity model was noted very estimated maximum (Torano, Rodriguez & Diego, 2006).

It was shown clearly the CFD or computational fluid dynamics can study the behavior of the airflow with a steady-state of the art tool. With the continuous transfer of particulate matter via conveyor belt, it was taken into considerations that it is very important to always take into account the proper velocity distribution estimate (Torano, Rodriguez & Diego, 2006).

3. Methodology

The researchers intend to use action research methodology since the study focuses on designing a new tunnel ventilation system for a specific metro subway station. This methodology will also include the location or the research settings, the data gathering, and the software tools needed to conduct simulation analysis. The methodology will be from the one-dimensional network analysis using SES and CFD analysis using Pyrosim software. From the identification of design criteria which includes the temperature parameters and velocity requirements, there is needed information from the train heat release rate that impacts the size of fans, and then the location can be strategically be coordinated for effective ventilation. Going through these preliminary information requirements, the researchers will go to deeper information in terms of codes and standards. In addition, simulation software will be used to study the proposed location of the fans.

3.1. Design Criteria Identification

As per the tunnel ventilation system requirements, it is needed to establish the design criteria requirements inside the tunnel. For the tunnel requirements considerations, the design of TVS must maintain the tunnel bulk air temperature at normal, congested and emergency situation. The requirement for design criteria based on NFPA 130 is shown in Table 1.

Table 1. Design Criteria

Train Operation	**Criteria**
Normal	Running tunnels: 38 °C
Congested	Running tunnels: 45 °C
Emergency	1. Tunnel air annular velocity > critical velocity 2. Smoke from train fire within the tunnel will not enter station platform

3.2. Determination of Heat Release Rate (HRR)

In controlling the smoke in a tunnel ventilation system, heat release rate (HRR) is an important factor. HRR has the characteristics of certain combustible products that correspond to the fire hazard flammability and the release of heat energy that is generated thru burning. HRR is measured in terms of kilowatts (kW) as the rate of heat energy. It can be calculated through different techniques and parameters, although code requirements have already established the parameters in terms of the type of trains. Basic calculations would have to add the heat release rate of every combustible material inside the train, from motors, seats, floors, ceiling, doors, etc. Every material has its characteristic rate of combustion in terms of how fast the material will burn and how much carbon dioxide and carbon monoxide it can generate. From that values, an HRR curve can be developed as a reference for designing the TVS. The HRR established for this project is a 20MW fire load per car that is given by the train manufacturer.

3.3. Fan Room and Tunnel Portal Location

Based on the given architectural plan of the stations and the tunnel geometry configuration. The researchers studied the following: (1) location of the tunnel portal, (2) means or location of the tunnel opening, and (3) location of fan rooms based on the tunnel length. Fan room location is critical because it will have a factor in tunnel ventilation operation for push-pull smoke extraction. The tunnel portal will determine if the tunnel would need ventilation based on the tunnel length and the tunnel portal opening must be directly open outside ambient air. Fan room location must be coordinated carefully because intake and exhaust air above tunnel must be clear with obstruction from the establishment and thus the safety of this location from the elements that may cause a problem during train operation.

3.4. Tunnel Configuration Identification

Tunnel configuration will have a major effect on the sizing of the TVS, because the fan sizes do not rely on the tunnel length but it is on the tunnel geometry, the bigger the cross-section area of the tunnel the bigger would be the size of the TVS. Other factors to consider are the tunnel alignment, chainage, gradient, and level. Tunnel configuration with a dividing wall in between tracks will have a different set-up of TVS than the tunnel without one. Platform screen door affects the TVS, as the station will not be considered as a portal by the system because it is already closed. However, for this particular study, platform screen door is not part of the station platform.

Establishing a major input parameter is vital at the very beginning of the design stages. Major parameters are the summer outdoor dry temperature, relative humidity, design condition inside the train, design condition at air condition spaces, train headway, peak hour train loading, and peak demand of train services that were being used on the SES software to run the simulation. Table 2 shows the major input parameters for tunnel configuration identification.

Table 2. Input Parameters

Item	Data	Source of information
1. Summer outdoor dry temperature (°C) / Relative humidity	38.6 °C / 84%	MRT performance requirements
2. Design condition inside train	28.6 °C / 65%	MRT performance requirements
3. Design condition at concourse and platform	N/A	No air conditioning
4. Design condition at air conditioned space	28.6 °C / 65%	MRT performance requirements
5. PSD at platform	No	Station drawings
6. Dividing wall between tracks at platform	No	Tunnel section drawings
7. Train headways	2 mins (i.e. 30 trains/hour/direction)	MRT performance requirements
8. Peak hour train loading	Peak load -1294; crash load – 2342	Train manufacturer
9. Peak demand of train services	18:00-19:00 hrs	MRT performance requirements

3.5. Preparation of Design Reference and Code Requirements

For the tunnel ventilation system design, we have several codes that are used as references namely: (1) NFPA 130 2017 Edition, Standard for Fixed Guideway Transit and Passenger Rail System, (2) NFPA 92 2015 Edition Smoke Control System, (3) ASHRAE 2015 Hand Book-Chapter 15 Enclosed Vehicular Facilities, and (4) Subway Environmental Design Handbook.

3.6. Model Set-up

In order to prepare the subway environmental simulation (SES) model, there is a need to conduct a detailed review of drawings and other data sources to form the basis of accurate analysis and to develop viable ventilation alternatives. For this, design criteria, drawings, and other data sources obtained from the project are reviewed to understand initial design objectives, status, and planned activities. To place trains in the tunnels, descriptions of the trains in the format required by SES are developed, including vehicle physical characteristics, auxiliary heat loads, and propulsion equipment. Model set-up must include the areas of the tunnel that would affect the air characteristic and smoke behavior thru the simulations and these are the vent shaft, tunnel portal, supply and exhaust fans, stairs, and doors. Modeling for the CFD analysis will have the set-up of converting the 2D layout of the architectural plans into 3D plans on the software model sketch tab that includes all the openings or portal of the whole area of simulation. Spaces for the openings on walls, stairs, doors, are important to consider on the whole geometry of the model set-up. Figure 1 shows the 3D Model setup of the simulation area.

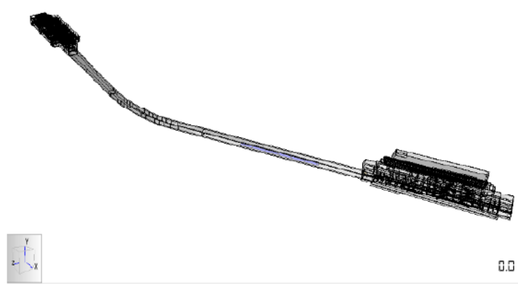

Figure 1. 3D model set-up

3.7. Simulation on SES Software

Subway environmental simulation (SES) is a very known program that is being used worldwide by engineers to create a model with different aspects of the train that is in motion through the underground subway line and its effect on the environment surrounding. The system model will be developed in the form of a node diagram. This node diagram will serve as the basis for preparing the data that describes the physical features of the system as well as the characteristics of the flow path junctions. The tunnel design will be reviewed and resistance factors will be developed. The network junctions will be described so that the airflow head losses at each flow split or merge could be accounted for. The train routes including grade, curve, and the speed limit for each section of track was prepared along with the progression of the route through the tunnels. The vehicle Heat Release Rate (HRR) used to design the ventilation system for emergency conditions were confirmed to be 20MW. It was assumed that only one train at a time was on fire and that no other train was in the tunnel section between the upstream and downstream ventilation shafts or running in the adjacent trackways.

3.8. Design Plan Layout for TVS Room

After getting the simulation result, with the airflow capacity already known, the researchers selected the tunnel ventilation fan by coordinating with fan suppliers for specific tunnel applications. The researchers will have had to give the specifications for airflow, static pressure, fire rating requirements, and operational direction among others. These selections of tunnel fans will have the dimensions, clearances for maintenance, weight, and power requirements. In coordinating with the architect and structural engineer, the researchers had to position the TVF at the end of the beginning and the end of the station; this set-up is based on the project tunnel alignment configuration. Fan operational flexibility and redundancy were considered, as this TVF equipment will serve the life and safety of the passengers in the tunnel and stations. TVF rooms were sized with three (3) fans, with two (2) units are operational during the fire mode scenario with one (1) unit as 100% back-up redundancy. The design layout of TVS room is shown in Figure 2.

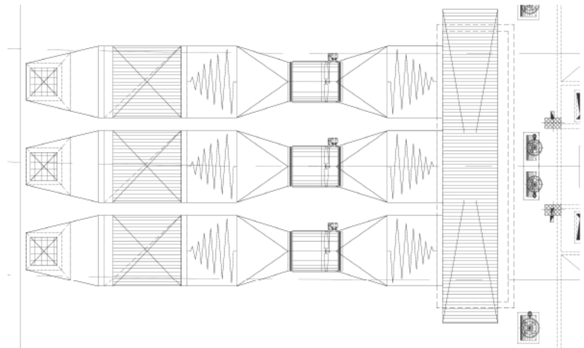

Figure 2. TVF room layout

3.9. Gathered Results from SES for CFD Analysis

TVS operation was based on two (2) scenarios, congested mode and fire mode. Each mode will have different operations in terms of start-up and tunnel location quantity of unit in operation. TVS operation during congestion mode requires mechanical ventilation to maintain the tunnel temperature within design criteria with the following signaling conditions: (a) the congested train stopped inside the tunnel and (b) only one congested train is stopped within the tunnel ventilation zone.

TVS during Emergency operations occur due to the malfunction of a train. The most serious scenario happens when there is a train fire with mechanical problems. Passengers inside the train car have to evacuate as the train is disabled. The general approach ("Push-Pull" or "Push") was applied to ventilate the affected tunnel section such that smoke back layering was controlled in one side direction (downstream direction), permitting all the passengers to safely evacuate in the other side direction (upstream direction).

The design criteria for the emergency condition simulations are the following: (a) the design of the tunnel ventilation system shall meet the critical velocity in the downhill direction, (b) meet critical velocity for a train fire HRR, (c) only one train on fire will be considered (no multiple, simultaneous fires), (d) emergency fans shall withstand the smoke temperature of 250°C for one hour and of single speed and truly reversible. The design of the control diagram for the tunnel ventilation system is shown in Figure 3.

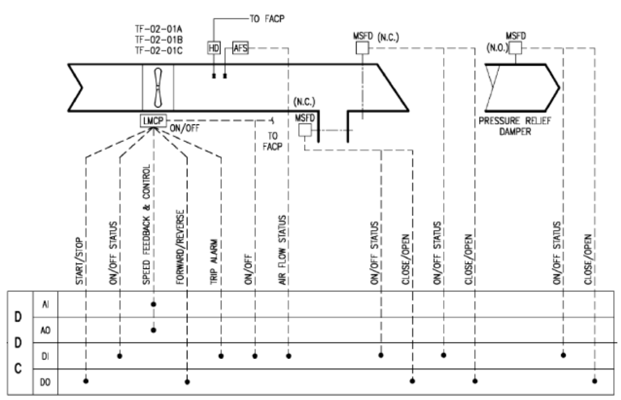

Figure 3. Control Diagram

3.10. Congestion and Fire Operation Analysis

Results from the Normal operation mode have the temperature achieved from using the piston effect of the train in which no mechanical ventilation is operational. Results from Congestion operation have the temperature inside the tunnel during the train stoppage; Heat load from the train A/C system produced heat and accumulate to increase tunnel temperature. The efficiency of the A/C has degraded capacity at higher ambient temperature. Airflow capacity on this result was on input airflow for CFD analysis.

Fire operation results have the temperature inside the tunnel at a higher value due to fire and smoke. From the train HRR, it produced heat and smoke that the SES software will simulate to properly size the TVS. This airflow was inputted on the CFD analysis to accurately check the smoke movement, behavior, and characteristics. Another result that is vital for the CFD analysis is the calculated critical velocity. To prevent smoke back layering, annular velocity must be greater than the critical velocity.

For the CFD analysis software, a 3D model was developed using Pyrosim 3D modeler, and then determine the surface of the model that will be supply and exhaust, with the airflow input from the simulation result of SES. Materials were identified and reactions were indicated as we are dealing with fire mode. Heat sources will be identified on the model as this affects the simulation result on temperature. The computational domain is set for the calculation simulation limitation on the 3D set-up model. Boundary conditions were used to set the parameters inside and outside the computational domain and affect the final result of the CFD simulation in terms of temperature, flowrate, smoke behavior, flow trajectories, and velocity. Fire Dynamic Simulator (FDS) will be used to present a visual presentation of the behavior of air and smoke including its respective properties relating to the ventilation system and the tenability of the space in consideration. FDS is a large-eddy simulation (LES) code that is used for low speed flows, that has an emphasis on the result of smoke and heat from fires. FDS is a CFD model of a fluid flow that is fire-driven and can solve Navier-Stoke equations numerically that is appropriate for low speed. Results have an emphasis on the transport of smoke and heat from the fire that is thermally driven flow.

FDS solves the Navier-Stokes equations, which are formulations of mass, momentum, and energy conservation laws for fluid flows. The equations are supplemented by fluid state equations defining the nature of the fluid, and by empirical dependencies of fluid density, viscosity, and thermal conductivity on temperature. Inelastic non-Newtonian fluids are considered by introducing a dependency of their dynamic viscosity on flow shear rate and temperature, and compressible liquids are considered by introducing a dependency of their density on pressure.

4. Results and Discussion

4.1. Congestion Operation Analysis vis SES

The congested operations analysis considered the mechanical ventilation requirements for the following signaling conditions: (a) the congested train will stop at 60m away from the station platform (assumption based on previous project experience), (b) only one congested train is stopped within the tunnel ventilation zone, and (c) congested train is at full load passenger capacity.

Based on the simulation, it shows the fan operation mode and predicted temperature in an underground tunnel. It demonstrates that the maximum temperature was estimated to be 37.36°C for the congested train by using 1 x 70 m3/s TVF operational as supply fan at Station East end (Fan Room 02-02) and 1 x 70 m3/s TVF operational as exhaust fan at Station West end (Fan Room 03-01.) It was an acceptable result as the ambient supply air is at 33.2 °C and adding the heat load of the train air conditioning condensing unit, the tunnel temperature will have an increase in temperature. The results of the simulation verified that based on the proposed tunnel ventilation fan airflow configuration and capacity, underground tunnel temperature will not exceed 45°C in compliance with the design criteria. Figure 4 shows the SES congestion result.

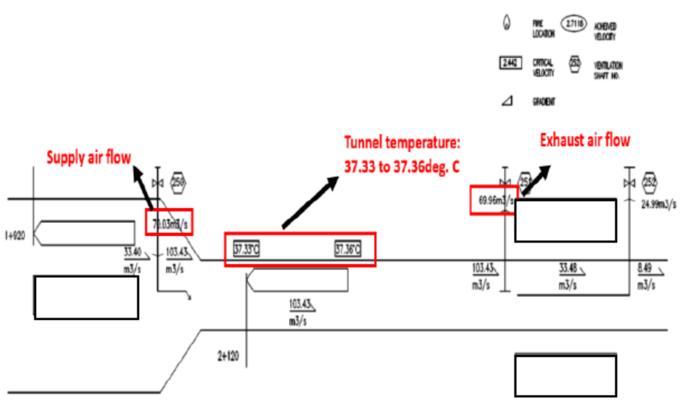

Figure 4. SES Congestion Result

4.2. Congestion Operation Analysis via Pyrosim

The congested operations analysis is considered the result of the SES analysis. Based on the simulation, by using 1 x 70 m3/s TVF operational as supply fan at Station East end (Fan Room 02-02) and 1 x 70 m3/s TVF operational as exhaust fan at Station West ends (Fan Room 03-01), it shows the fan operation mode and simulated underground tunnel temperature to be from 33.2 °C to 37.4 °C. This temperature has a lower result from the SES because this shows the airflow temperature from the start of the underground tunnel where the supply fan is located then up to the tail end of the train where the heat from the train air conditioning condensing unit is concentrated as shown in Figure 5.

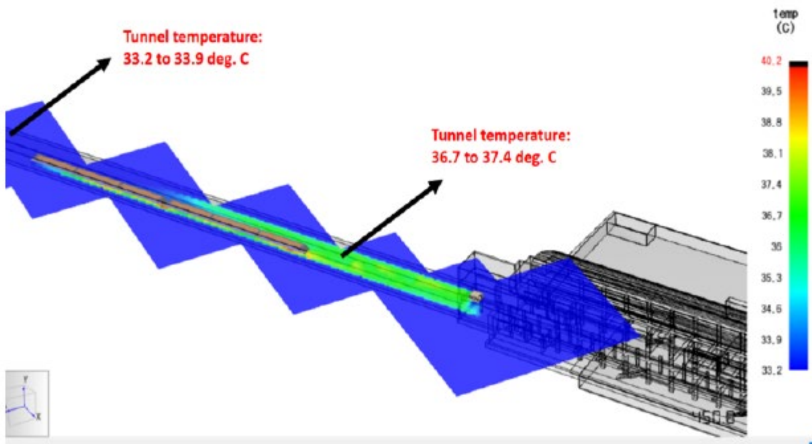

Figure 5. Pyrosim Congestion Result

From the Pyrosim simulation result, it shows that at the front side of the congested train, the temperature of the tunnel is almost the same as the supply air at 33.2 deg. C. Then after the supply air passed the train, with the accumulated heat load from the train driving motor and the train air conditioning condenser unit, the tunnel temperature resulted in 37.4 deg. C maximum, in which it is within range of the design criteria of maintaining the tunnel temperature at 45 deg. C during congestion. This is to eliminate the problem of train A/C's operation and maintain its operation at the acceptable ambient temperature inside the tunnel.

4.3. Emergency Ventilation Operation Analysis via SES

Generally, emergency operations occur due to the malfunction of a train. The most serious scenario happens when there is a train fire with mechanical problems. Passengers inside the train car have to evacuate as the train is disabled. The general approach ("Push-Pull" or "Push") was applied to ventilate the affected tunnel section such that smoke back layering was controlled in one direction (downstream direction), permitting passenger evacuation in the other direction (upstream direction). The design criteria for the emergency condition simulations are: (a) the ventilation system shall be designed to meet the critical velocity in the downhill direction, (b) meet critical velocity for a 20MW train fire, (c) only one train on fire will be considered (no multiple, simultaneous fires) and (d) achieved velocity must be greater than the critical velocity to prevent smoke back layering.

SES result shows that the critical velocity developed is at 2.34 m/s and the achieved velocity as resulted is at 2.42 m/s. The smoke velocity is achieved via the smoke behavior of buoyancy. Smoke will develop velocity as it goes to a natural flow of going up. With the TVF on the operational mode by using 1 x 70 m3/s TVF operational as supply fan at Station East end (Fan Room 02-02) and 2 x 70 m3/s TVF operational as exhaust fan at Station West end (Fan Room 03-01), critical velocity is achieved as shown in Figure 6.

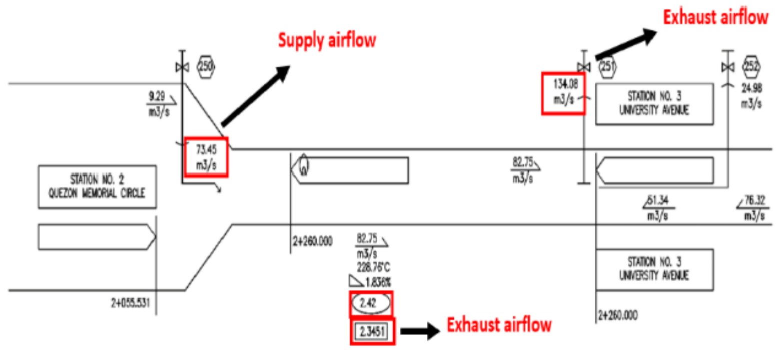

Figure 6. SES Emergency Result

4.4. Emergency Operation Analysis via Pyrosim

The emergency operations analysis is considered the result of the SES analysis. Based on the simulation in Figure 7, by using 1 x 70 m3/s TVF as supply fan at Station East end (Fan Room 02-02) and 2 x 70 m3/s TVF as exhaust fan at Station West end (Fan Room 03-01), it shows the fan operation mode and simulated underground tunnel achieved a velocity of up to 9 m/s. Results from this software are higher as it has a more accurate and specific location to get the air velocity. From the Pyrosim simulation result, it shows that at the front side of the train on fire the achieved airflow velocity is at 2.7 m/s during TVF emergency operation. This airflow velocity is greater than the critical velocity initially calculated on the SES which is 2.34 m/s. This interprets that during the start of the fire, and the smoke develops inside the tunnel, there will be no smoke backlayering going back to the station. As the achieved result, the proposed escape route will be against the supply airflow where the passenger will exit to the Station. For the full load operation of the TVF, the achieved velocity ranges from 7 to 9 m/s. This higher value of velocity is caused by the area of the tunnel became smaller on the part where the train is located.

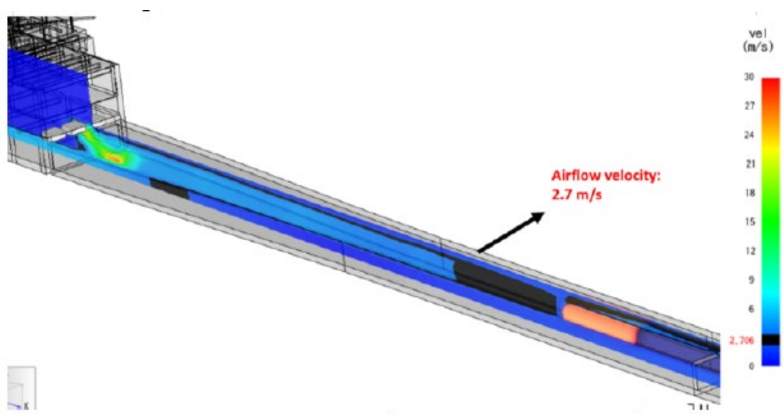

Figure 7. Pyrosim Emergency Result

5. Conclusion

From the SES result during congestion scenarios, the Push-Pull ventilation operational strategy shows the effectivity of maintaining the tunnel temperature at 37.36 deg. C below as indicated on the design criteria of 45 deg. C. With direct airflow towards the incident train within the tunnel, with one (1) TVF unit is for supply air from Station east end and one (1) TVF unit for exhaust air from Station west end. These results are verified via Pyrosim CFD analysis, using the airflow capacity of the TVF developed on the SES result, the tunnel temperature has the result of 36.7 °C to 37.4 °C. With the temperature of the tunnel not exceeding the design criteria, the push-pull ventilation strategy is the proper way of ventilation for the underground tunnel.

From the SES result during emergency scenarios, smokes from the fire train is effectively directed towards the station platform farthest from the fire to give way for the passengers to escape free of smoke on the opposite side where the platform is nearest. As a requirement to prevent smoke back layering the annular velocity result of 2.42 m/s is greater than the critical velocity of 2.34 m/s. One (1) TVF unit is for supply air from Station east end and two (2) TVF unit for exhaust air from Station west end.

It is highly recommended to perform a CFD analysis verification for this kind in the application as this can simulate the possible condition more accurately than the SES one-line diagram results. CFD can give you the condition on every part of the simulated scenario, and visually by color map, it can be analyzed more easily. SES had a limited output result that of one-dimensional means you can only see the result at a specific area or location on the tunnel, disparate to CFD analysis, results are given for the whole area of the simulation and the researchers can have more understanding of the scenario as it can show the full picture of the simulation.

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