AIR QUALITY ANALYSIS FOR NATURAL VENTILATION IN AN OPEN TRENCH RAILWAY STATION

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Used properly, computational fluid dynamic modelling provides detailed information that cannot be obtained from other types of modelling. The author focuses on some of the challenges associated with getting the most value out of CFD modelling to maximize the design of an open trench train station with natural ventilation. FDS5 was the software used.

New Lynn's new train station, which is an open trench design, will replace the existing at-grade station. This design offers a solution to the always bottle-necked roundabout in the town centre (Figure 1)

Figure 1. The always bottle-necked roundabout in New Lynn's town centre.

The new station is located in the busy city centre so our client, the local council of Waitakere City, wanted to maximize the usable surface area for cyclists and pedestrians. The client also preferred natural ventilation for the station instead of mechanical ventilation. An ideal naturally ventilated railway station is an open air station or an open trench, as the efficiency of natural ventilation for an underground railway stations with partial or full ceiling covers is never as good. While natural ventilation is a sustainable technology that requires no maintenance and eliminates costs for power, it requires sufficient open-roof area.

Our Design Challenge

Diesel powered trains, which generate a lot of smoke emissions, will be used on this railway line until electrification occurs in about ten years. The local council requires the station's island platform to be located between the tracks where it will serve passengers travelling in either direction. If wide cantilevers on each side of the station are included, as proposed, to provide surface for pedestrians and cyclists, then the emissions from the diesel train can be trapped in the trench (Figure 2). These pollutants could be harmful to station occupants, including railway workers, vendors and police, and to travellers both on the platform and inside trains dwelling at the station.

PB's objective was to control the pollutant levels in the station to be within the regulatory acceptance limits. Pollutant emissions to the urban areas outside the station were not considered a problem because the train emissions will be dispersed once vented out of the station trench.

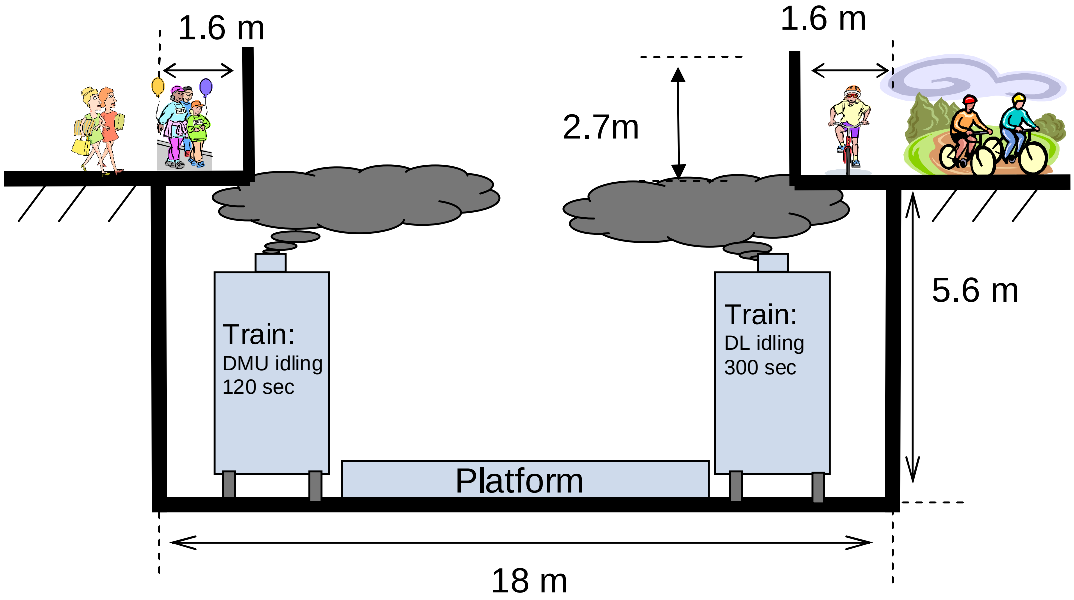

Figure 2. Cross section of the proposed railway station.

CFD Modelling and Analysis Overview

We investigated the impact on air quality in a trenched station against the regulatory standard by using FDS5, a computational fluid dynamics (CFD) modelling software package, to model air flow and pollutants transport. Various configurations were considered to find an optimized solution.

Five-minute train stops were assumed. Three types of pollutants—CO, NOx and fine particulate matters (PM)—were examined by monitoring some key locations, such as at the intakes of air conditioning units (ACU) on two typical engine cars and at 1.5 m (5 feet) above the platform.

Temperature and humidity were not considered because the opening area of the roof is quite large.

FDS numerically solves a form of the Navier-Stokes equations for low speed, thermally-driven flow with an emphasis on smoke and heat transport from fires. Its core algorithm is an explicit predictor-corrector scheme, second order accurate in space and time. Turbulence is treated by means of the Smagorinsky form of Large Eddy Simulation (LES). CFD is capable of modelling any thermal driven flows and other room air flow problems. Additional pollutant species can be solved by introducing additional scalar transport equations. Transient 3-D transport of pollutants (PM, NO_x and CO) was modelled in this way.

Q & A

Question: FDS is used traditionally for fire simulation due to the assumptions used in its development. Is it suitable for pollutant dispersion/natural ventilation? Is verification required when it is used for this purpose?
Dicken Wu, Guest Technical Reviewer; and Steven Lai, PB Network International Advisor

Answer: FDS can handle natural ventilation without any problem, and it can handle any additional scalars, such as PM10, NOx, etc. The only input is the generation source and the molecular/laminar diffusion coefficient, as the later one is always dominated by the turbulence, therefore no need to input it. So, if you wish to solve any additional species, just define the equation, then input the generation source. The reason is that FDS solves the N-S equation along with other additional transport equations just like what is did in other general-purpose CFD packages, but FDS has extra capabilities specially designed for fire dynamics and smoke modelling. Kevin McGrattan, a developer of FDS, recommends a report by Amy Musser and others of the Building and Fire Research Laboratory, National Institute of Standards and Technology that covers the range of uses of FDS and verification. See Related Web Sites below: http://www.fire.nist.gov/bfrlpubs/fire01/art052.html

Based on the emission data calculated from the specific diesel train, total mass flow and mass fraction of CO, NO_x and PM_{10} were imposed at the smoke discharge location of the train. A constant generation rate of CO, NO_x and PM_{10} were specified as boundary conditions in the CFD modelling when a train was idling at the station. The temperature of the emission mass flow stream was assumed to be 170°C (338° F).

Air pollution concentrations at outside air intake points were measured to account for the influence of the ACU on the in-train air quality. Train walls in the CFD model were constructed from metal with zero thickness. Airflow inside the train carriage was generated by the air conditioning system. In the CFD model, a fixed exhaust rate of $1.2m^3/s$ (42 cubic feet/s) was specified at the ACU exhaust.

CFD Modelling Challenges

Appropriate Mesh Size. The challenge for CFD modelling is to obtain accurate results with minimum modelling time. Using a very fine mesh to model the subject train station would have taken more than two weeks using multi-processor parallel computing. It is a normal element in a CFD project to establish a mesh independent solution early on, and that some criteria exist with which this can be judged, such as Courant number for temporal divisions in a transient analysis, and Y^+ thresholds for near-wall meshing. We had to find the acceptable mesh size that could capture the physics of the pollutants transport phenomena. As the acceptable mesh size is case dependent, there is no universal answer for every engineering case.

We started by using a coarse mesh. It took one day to get the result for each scenario. An issue that was identified, however, was that the pollutant concentrations were over-predicted, and the result was so conservative that the design could not satisfy the regulatory standards. This problem was caused by the numerical errors brought up by the so called numerical diffusion, which dominates if too coarse a mesh is used.

Careful analysis showed that a mesh size of 0.12m (4.7 inches) in the longitudinal direction was acceptable, with the two other directions had an even smaller mesh size. The expense was that the modelling time increased to one week for each case with a train dwelling time of five minutes.

Calculation of Emissions. Another issue was related to the calculation of emissions of diesel combustion products. Our analysis found that excessive air that is drawn into the combustion chamber of the engine influences the discharge velocity and temperature of the emissions. This air should be considered to accurately account for the actual smoke discharge flow characteristics.

Excessive air is that which enters the combustion chamber but does not participate in the combustion and gets discharged with the combustion products. Based on calculations using the combustion formula, the excessive air was 46 percent of the total external air intake into the combustion chamber, so the emission flow velocity almost doubled after this parameter was considered.

CFD can give detailed field distribution of pollutant concentrations of every species. With other models, such as zone model or analytical model, it is not possible to gain such detailed information. With reasonable assumptions, CFD can be regarded as a computer virtual reality of an actual engineering design, non-compatible issues can be detected if it is used properly.

How Results Impacted Design

The final recommended cantilever width was 1.6 m (5 feet) on each side, for a total gain in width of surface area of more than 3 m (10 feet). CFD modelling results are illustrated in Figure 3.

This investigation revealed that the opening of the partial enclosure of a trenched railway station has a big impact on the ventilation of the train emitted pollutants, and many parameters can play a role and influence the result. Optimization of cantilever width to comply with the regulatory standards requires conducting a performance-based assessment using proper design tools. Every possible parameter needs to be considered before a decision is made, including pollutants removal, type and size of train engines dwelling at the station, the dwelling times, operation details of the train's ACU system and the ventilation strategy for the station.

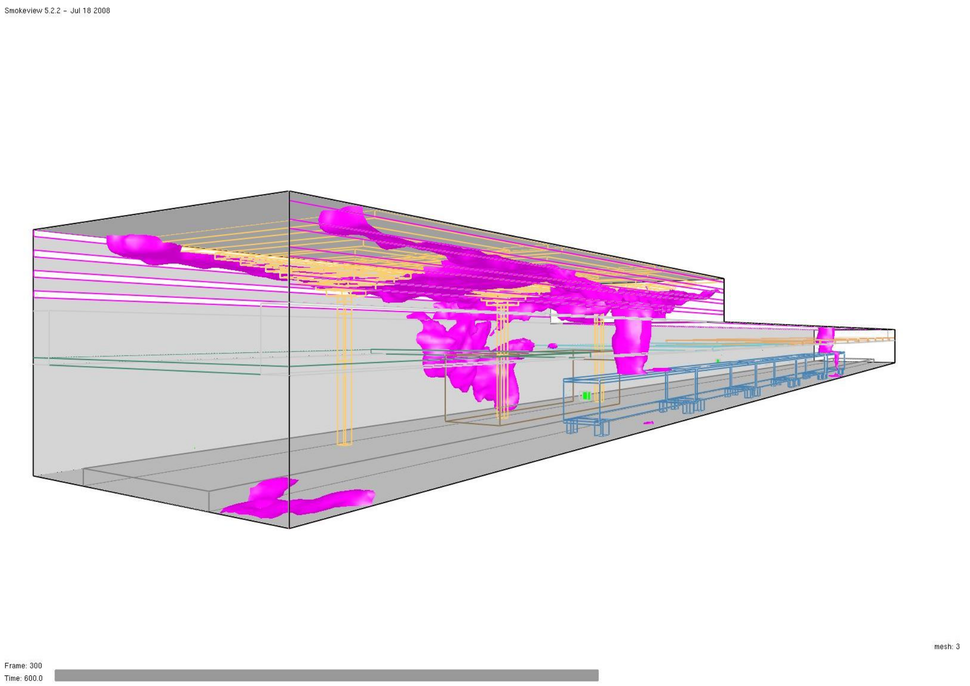

Figure 3. CFD modelling of fine particulate matters.

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Related Web Sites:

- *Evaluation of a Fast, Simplified Computational Fluid Dynamics Model for Solving Room Airflow Problems* by Amy Musser, Kevin McGrattan and Jeanne Palmer; NISTIR 6760, National Institute of Standards and Technology, June 2001: http://www.fire.nist.gov/bfrlpubs/fire01/art052.html

KEY WORDS

Publication Name	PB Network
Edition	Issue No.70
Date of Publication	July 2009
Edition Title	The Engineer's Crystal Ball: Computational Fluid Dynamics, Modeling and Simulation, Virtual Design and Construction
Main Topic	Tunnel Ventilation
Title of Article	Natural Ventilation Design for New Lynn Railway Station
Author (s)	**Liu, Yunlong**
Project Name	New Lynn Railway Station
Location Country	Australia
Location State	New South Wales
Location City	Waitakere City
Client	Local council of Waitakere City
Market Sector (s)	**Transportation** **Rail**
Discipline (s)	**M&E** **CFD**
Topics, and other key words	Natural ventilation Tunnel Railway station Emissions CFD Mesh size Diesel engine Train.
Language	English