DART D2 Preliminary Ventilation Report

DART GPC6

DRAFT, Issued for DART Review
Dallas, Texas
February 28, 2020

This Report was Prepared for DART Review and Comment
General Planning Consultant Six Managed by HDR

Document Revision Record

DART D2 Draft Ventilation Report	**HDR Report Number:** Click here to enter text.
Project Manager: Andy Stone	**PIC:** Click here to enter text.

Revision Number: 0	**Date:** February 28, 2020
Version 1	*Date: Click here to enter text.*
Version 2	*Date: Click here to enter text.*

Originator	
Name: **Triet Tran** **Sean Cassady** **Suraj Parayil** **Yunlong Liu**	**Firm:** HNTB Corporation
Title: Draft Ventilation Report	**Date: 02.21.2020**

Commentors		
Name: Click here to enter text. **Firm:** Click here to enter text. **Date:** Click here to enter text.	**Name:** Click here to enter text. **Firm:** Click here to enter text. **Date:** Click here to enter text.	**Name:** Click here to enter text. **Firm:** Click here to enter text. **Date:** Click here to enter text.
Name: Click here to enter text. **Firm:** Click here to enter text. **Date:** Click here to enter text.	**Name:** Click here to enter text. **Firm:** Click here to enter text. **Date:** Click here to enter text.	**Name:** Click here to enter text. **Firm:** Click here to enter text. **Date:** Click here to enter text.

Approval

Task Manager: Sanja Zlatanic	**Date:** Click here to enter text.
Verified/Approved By: Click here to enter text.	**Date:** Click here to enter text.

Distribution		
Name: Click here to enter text.	**Title:** Click here to enter text.	**Firm:** Click here to enter text.
Name: Click here to enter text.	**Title:** Click here to enter text.	**Firm:** Click here to enter text.

Contents

Tables

Figures

Appendices

Acronyms and Abbreviaations

AHJ	Authority Having Jurisdiction
DART	Dallas Area Rapid Transit
DCM	Design Criteria Manual
DFT	Dry Film Thickness
FCC	Fire Command Center
FDC	Fire Department Connection
FPM	Feet Per Minute (velocity)
FT	Feet (Length)
GPM	Gallons Per Minute (Flow)
In w.g.	Inches of Water Guage (pressure)
LRV	Light Rail Vehicle
NFPA	National Fire Protection Association
SLRV	Super Light Rail Vehicle
SF	Square Feet (Area)
TXDOT	Texas State Department of Transportation

1 Introduction

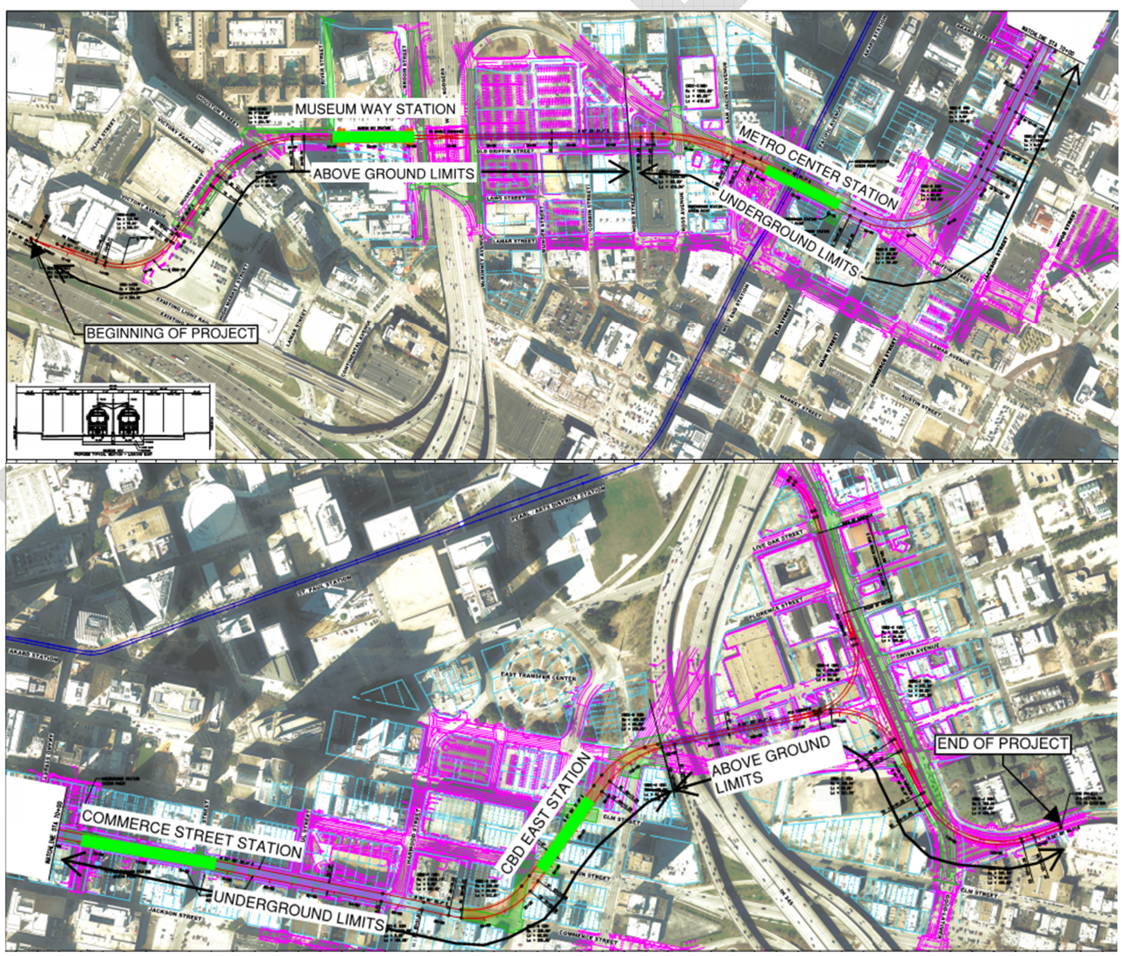
1.1 General

The preliminary ventilation report provides presents the evaluation of emergency ventilation within the underground portion of the DART D2 Subway extension. The Authority Having Jurisdiction is the Texas State Department of Transportation (TxDOT). This report will address the fire life safety systems in place for the underground trainway and station portion of the DART D2 Subway project for.

1.2 Project Description

The DART D2 Subway Project is comprised of a subway system that would begin southeast of Victory Station and end west of Bylor University Medical Center Station. The subway extension will include one at-grade station (Museum Way), and three underground Rail stations (Metro Center, Commerce Street, and CBD East).

Figure 1. Layout indicating approximate extents of DART D2 Subway alignment



Ventilation systems will need to be considered for the underground segment of the DART D2 Subway system to help with exhaust during normal train operations, as well as during a fire emergency to prevent smoke spread.

1.3 Applicable Codes, Standards and Requirements

The following standards are applicable for the Fire Life Safety Analysis for the DART D2 Subway:

1. International Building Code (IBC) as amended by the City of Dallas
2. International Fire Code (IFC) as amended by the City of Dallas
3. NFPA 130 2014 edition – Standard for Fixed Guideway Transit and Passenger Rail Systems
4. DART, Emergency Operating Procedure, Publication Number: 101.01, 04/01/2004
5. DART, Fire Smoke (Tunnel) Operating Procedure, Publication Number: 101.07, 04/01/2004

In addition to the standards listed above the DART Design Criteria Manual (DCM) 2003 edition by ACT 21 is used to evaluate any applicable design features, but note that the DCM is project specific and does not directly apply to the current DART D2 Project

Table 1 Fire Life Safety Concept Design Principles Code Matrix

Design Feature	Code/Standard Basis	Discussion
Fire Rated Construction	2014 NFPA 130; 5.2.4.1	Interconnection between floor levels is allowed with special provisions.
Fire Rated Construction	2014 NFPA 130; 5.2.4.3	Fire Rated separation between ancillary occupancies as required by NFPA 101
Fire Rated Construction	2014 NFPA 130; 5.2.4.2	All Public areas shall be fire separated from adjacent non-public areas
Corridor Width	2015 IBC; 1020.2 2014 NFPA 130; 5.3.4.2	Minimum corridor width 44 in. Additionally applies to platforms from NFPA 130
Stairway width	2015 IBC; 1011.2	Minimum stairway width 44 in.
Number of exits	2015 IBC; 1006.2.1.1	Three exits or exit access doorways shall be provided from any space with occupant load of 501 to 1000
Definition of Point of Safety	2014 NFPA 130; 3.3.35	Special provisions allow point of safety at the following: trainway, station, at grade point beyond vehicle
Evacuation	2014 NFPA 130; 5.3.1.1 2014 NFPA 130; 5.3.1.2	Platform Evacuation Time – Evacuate platform in 4 minutes or less Evacuation Time to a Point of Safety in 6 minutes or less
Exits	2014 NFPA 130; 6.3.1.4	Maximum distance between exits shall not exceed 2500 ft

Cross Passage	2014 NFPA 130; 6.3.1.6	Cross-passageways shall not be farther than 800 ft
Exit Signs	2014 NFPA 130; 6.3.5.5	Enclosed trainways greater than 1 train length shall be provided with directional signs as appropriate for emergency procedures
Mechanical Ventilation	2014 NFPA 130; 7.1.2.2 2014 NFPA 130; 7.2.3	Mechanical Ventilation required at: 1. Enclosed Stations 2. Trainway greater than 1000 ft Design should incorporate: 1. Fire Heat release rate 2. Fire Growth rate 3. Station and trainway geometries 4. Elevation, temperature differences wind etc.
Fan ramp up time	2014 NFPA 130; 7.3.1.1	Fan motors designed to achieve full operating speed in no more than 30 seconds from stopped position, and no more than 60 seconds for variable-speed motors.
Standpipe	2014 NFPA 130; 5.4.5 2014 NFPA 130; 5.4.5.2	Class I standpipes shall be installed in enclosed stations in accordance with NFPA 14 Standpipes are required to be enclosed in fire rated construction unless: 1. System is cross-connected or fed from two locations. 2. Isolation valves are installed not more than 800 ft apart
Hydrants	2003 DART DCM Vol 1 by ACT 21; 29.6.1	Hydrants within 150 feet of Fire Department Connection to a Standpipe system Within 150 feet of each subway station entrance or access point.
Hydrants	2015 IFC; 507.5.1.1	Standpipe system shall have a fire hydrant within 100 feet of the fire department connections.
Ventilation Requirements	2003 DART DCM Vol 1 by ACT 21; 25.3.2	Maintain a single Evacuation path from the train that is clear of smoke and hot gases.
Ventilation Requirements	2003 DART DCM Vol 1 by ACT 21; 25.4.5	Tunnel Ventilation Fan Dampers: Max velocity 1800 FPM Tunnel Ventilation Fan Sound Attenuators: Max velocity 1800 FPM Isolation Dampers: Max velocity 2000 FPM

		Concrete Ducts/Plenums/Shafts: Tunnel Ventilation Shaft: Nominal velocity of 1800 FPM, Max velocity of 2200 FPM Other concrete ducts/plenums/shafts: Nominal velocity of 1500 fpm, Max velocity of 1800 FPM

2 Station Ventilation Concept

2.1 Design Objective

The objective of the ventilation and fire safety design is to mitigate hazards to provide adequate level of safety for tunnel or station area occupants during periods of revenue and maintenance operations. Ventilation system configuration and sequence of operations are established to provide tenable environment to facilitate self-evacuation from tunnel and station areas.

2.2 Design Principle

Stations of the subject project has been proposed with platform screen doors (PSD), which separate the platform and the trackway into two zones. Therefore trackway fires and platform fires are managed separately. Moreover, it can also achieve energy savings for climate control, as the station cooling air will not be lost into the tunnel as it is separated from the platform of the station.

2.3 Smoke control and ventilation strategy

Table 2: Fire Scenarios

ID	Fire Location	Fire HRR	Smoke control strategy
(a)	Train fire	14.9 MW (Medium growth rate)	Over Track Exhaust (OTE) Over Platform Exhaust (OPE)
(b)	Trackway Fire	1.5 MW (UF)	OTE
(c)	Platform Fire	3.5 MW (UF)	OPE

2.3.1 Fire Scenario (a) Train fire OTE and OPE on:

During a train fire the over track exhaust (OTE) dampers will open to exhaust the smoke from the incident track. The platform screen doors are open to allow passengers to exit the train. Since the doors are open there is a concern that smoke will develop in the platform as well. So platform exhaust dampers are opened as well to help with the exhaust of smoke.

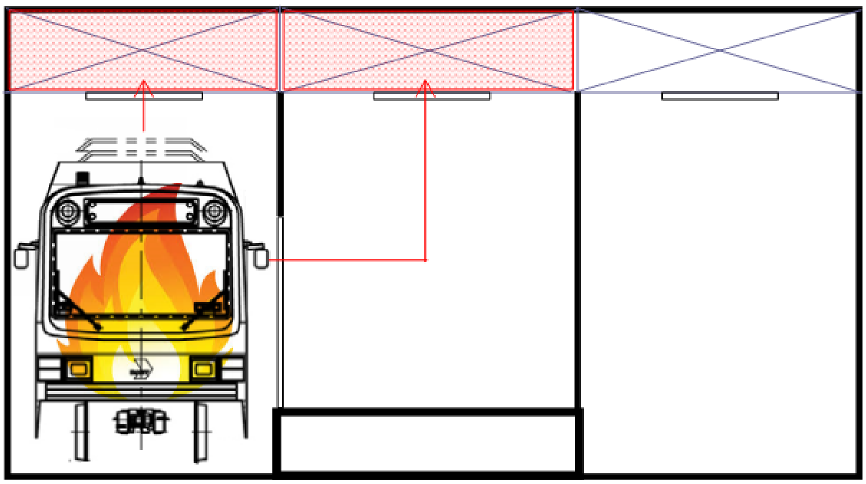


Figure 2: Fire Scenario (a)

2.3.2 Fire Scenario (b) Track fire:

Trackway fire is non-rolling Stock fires occurring in the trackway within the Station length.
For such an incident – where a train is not located within the incident station trackway – the PSDs on the incident track will remain closed and the incident track OTE will be operated in smoke control mode, exhausting 60m3/s, as shown in Figure 3.

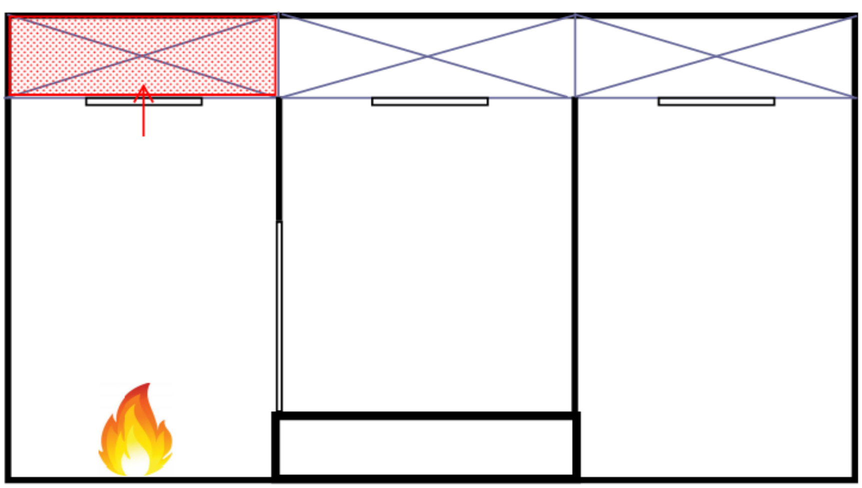


Figure 3: Fire Scenario (b)

2.3.3 Fire Scenario (c) Platform fire:

For a station fire originating within a platform zone, the objective will be to limit smoke to the incident zone. On activation, the Station Smoke Management System (SSMS) will utilize the OTE fans to exhaust through the duct above the platform to provide over platform exhaust as shown in Figure 4.

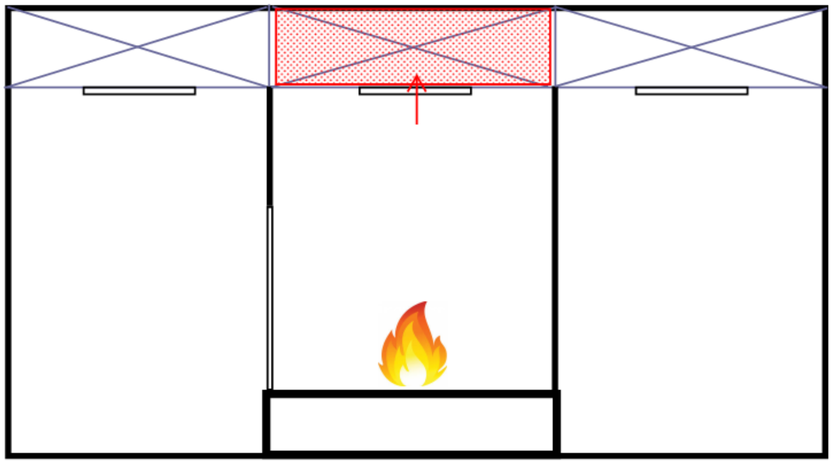


Figure 4: Fire Scenario (c)

2.4 Ventilation airflow diagram

Ventilation airflow diagrams for two options are presented for fire scenarios (a) (b) (c) in Figure 5 and Figure 6.

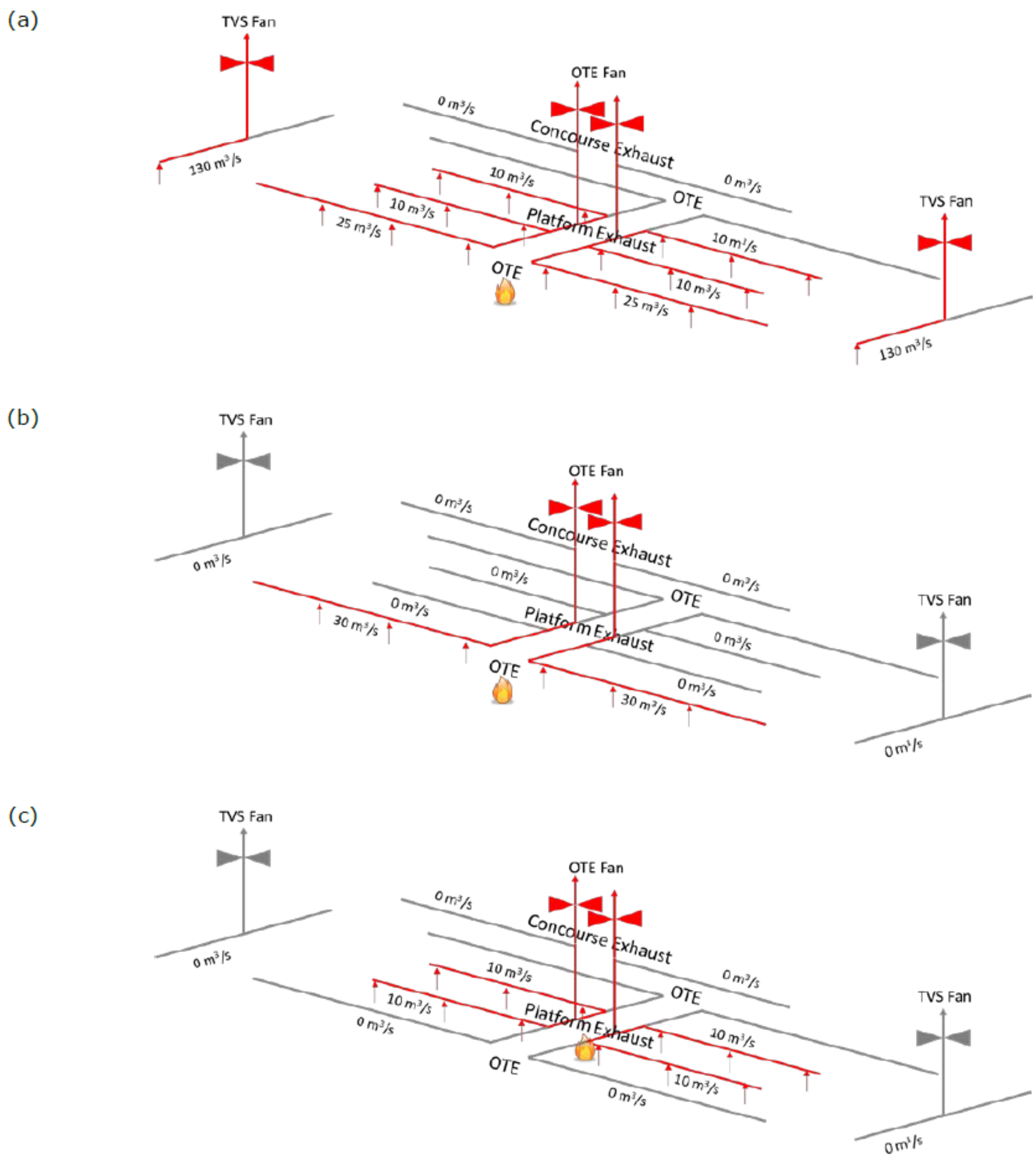


Figure 5: Fire Scenario Option 1

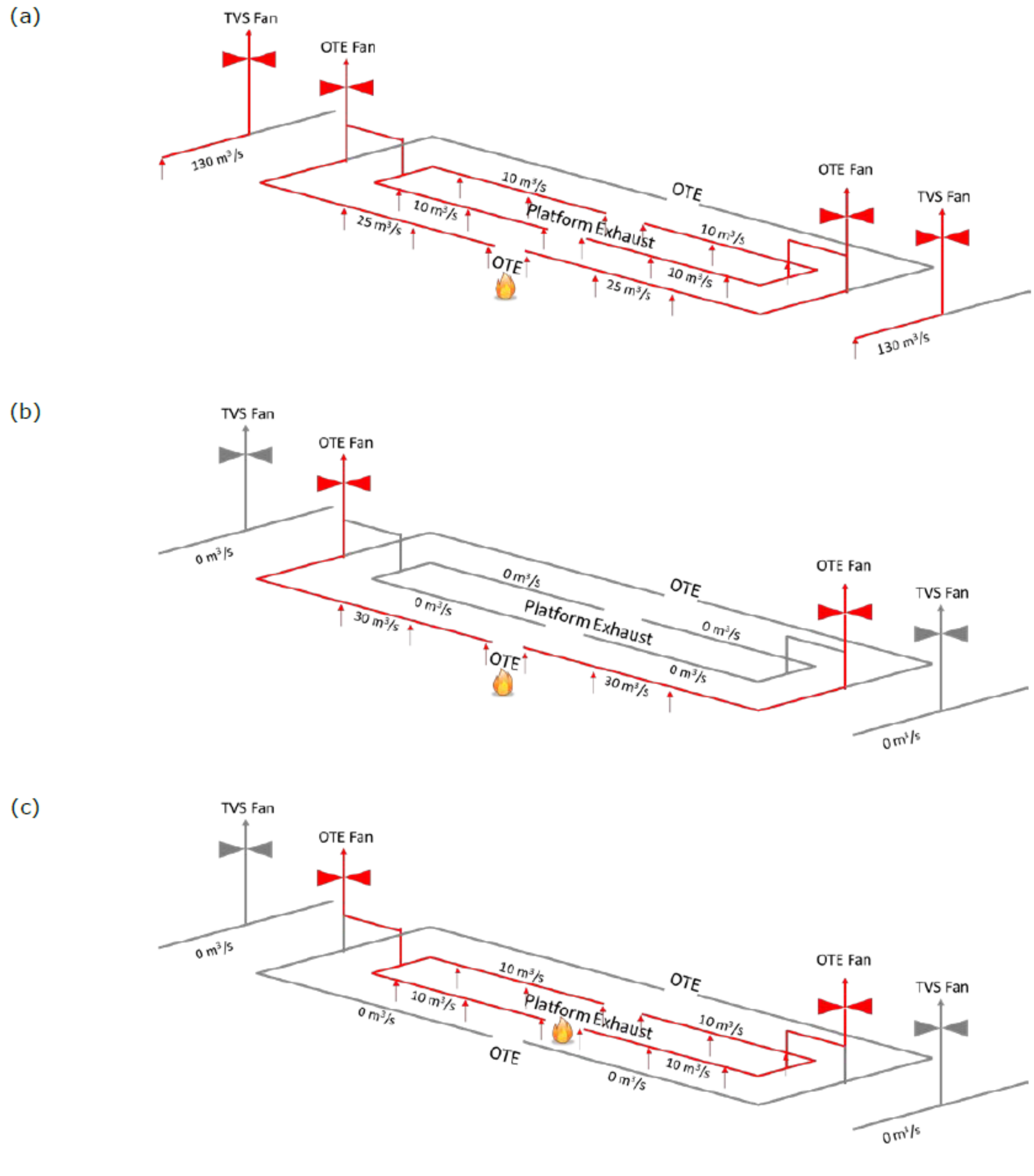


Figure 6: Fire Scenario Option 2

2.5 Ventilation Plant Schematic

The preliminary ventilation plant layout includes a set of 3 fans per fan plant, each with a capacity of 250kcfm. It is assumed that a maximum capacity of 500 kcfm will be required at each fan plant location. This results in a maximum of 2 fans on at a time with and an additional fan on standby for redundancy. Figure 7 demonstrates the ventilation configuration for Commerce Station.

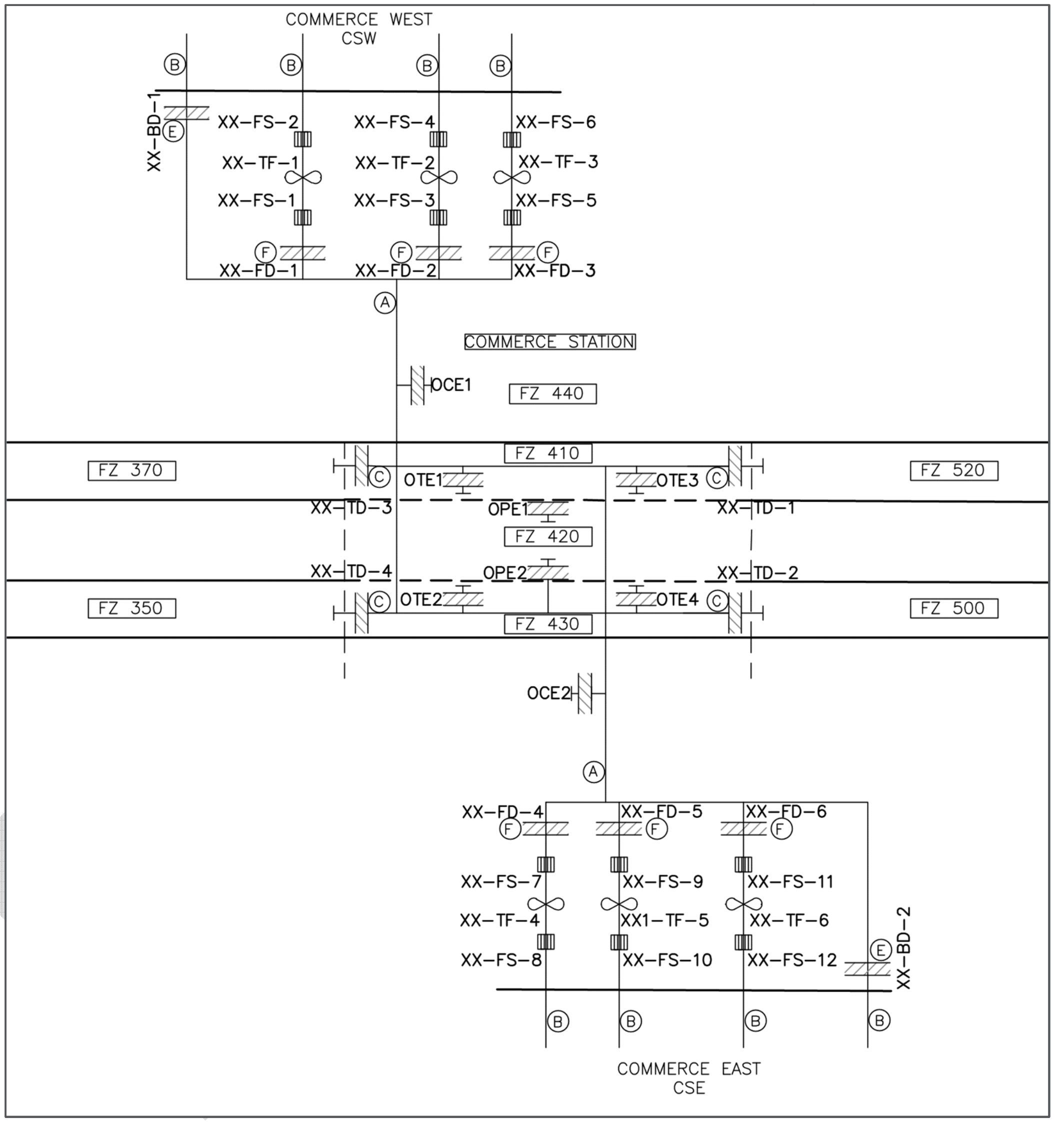


Figure 7: Commerce Station Ventilation Schematic

The ventilation fans have been preliminarily sized for 250 kcfm at 3.6 in w.g. this corresponds to a 400 hp fan. See Appendix A for preliminary fan pressure calculation. Calculations were based on preliminary assumptions for duct and plenum sizes in order to provide adequate ventilation.

Fires can occur at multiple locations along the Dart D2 Extension. Providing adequate ventilation for different fire scenarios can prove to be challenging because of the different components that need to be configured, such as damper opening positions, which fans to turn on, and whether the fans are in supply or exhaust mode. For this reason, a preliminary mode matrix is created to establish the different configurations that will be implemented within different fire zones along the length of the alignment. Figure 8 shows a preliminary layout of the different equipment involved for emergency ventilation.

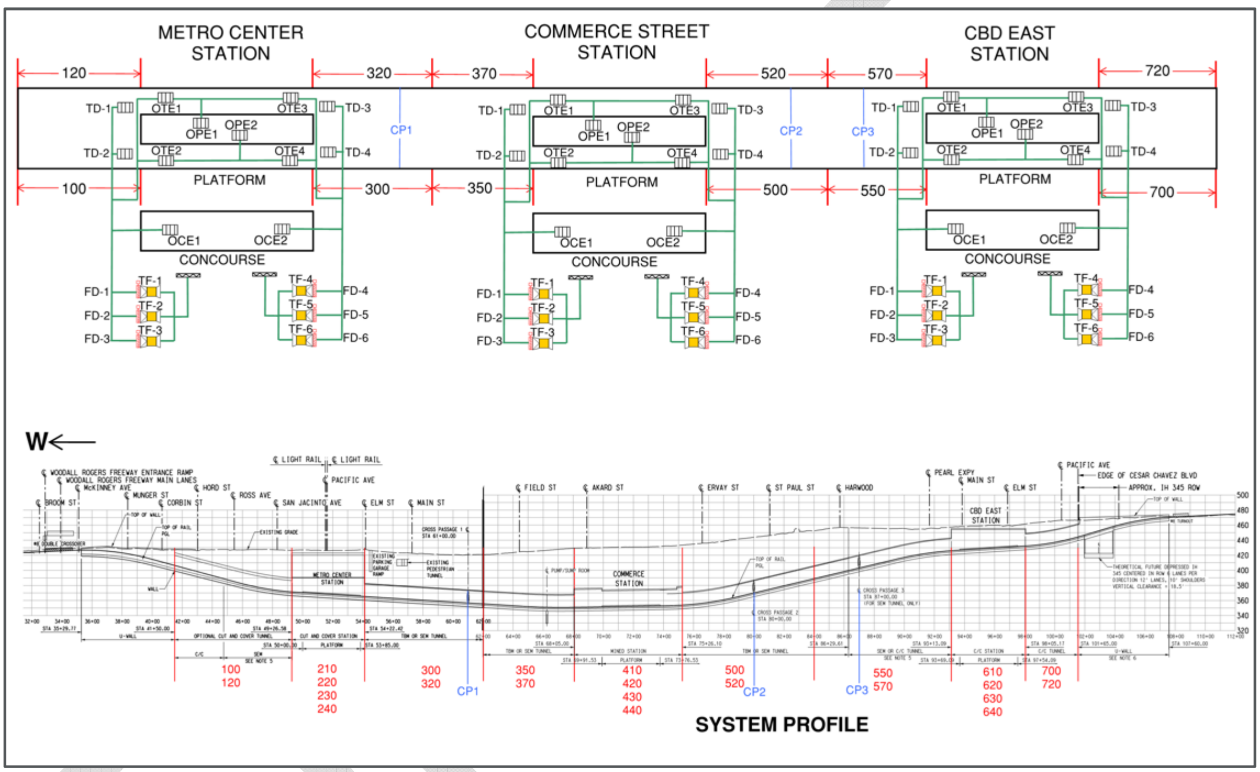


Figure 8: Mode Matrix Diagram

3 Methodology and Analysis

3.1 Design Methodology

Tunnel ventilation design for the project will be configured to manage environmental conditions within the enclosed underground trainways and public circulation areas for normal, congested and emergency fire scenario conditions. Conceptual space proofing requirements will be established by emergency fire scenarios for tunnel and station fires. A segment wide ventilation flow network model created with the SES (Subway Environmental Simulation) tool is created for the underground portion of the Dart D2 extension. A series of SES simulations are developed to test the different fire scenarios and establish flow rates. A 3D model of the station is created and set up to run scenarios aligned with SES cases, using results from SES as boundary conditions. The methodology applied for this analysis is broken into the following steps:

1. **Gather data:** Gather geometrical data, walkway tunnels/stairs, platforms, and ventilation shafts.
2. **Evaluation & Simplification of Geometry:** Evaluate detail of features such as signages, beams, and other projections in space to determine if they introduce significant impacts on ventilation flow conditions generated by a fire in the station.
3. **Establish domain:** Determine fire and airflow region for proper model domain. Use ancillary calculations as needed to validate an adequate model size prior to solid modeling.
4. **Solidify model:** Create a three-dimensional computer solid model of station features determined to be of significance to ventilation flow field.
5. **Meshing:** Evaluate the solid model for decomposition and meshing schemes. Generate the Mesh model.
6. **Solve:** Read mesh into Fluent software solver and prepare inputs for iterative solution scheme including boundary conditions, model equations, solver schemes, and other customized time-dependent inputs. A detailed discussion of model inputs for fire source term is included in Section 3.2.1, of this report.
7. **Simulation:** Initiate iterative solution based on assumed time step interval for managing stable transient solution.
8. **Monitor:** Checkpoint simulation with the following activities: monitor residual values generated by momentum, continuity and energy equations of the simulation, evaluate wall function metrics generated for dataset at intermediate time steps, evaluate flow velocity conditions verses cell dimensions to confirm flow transit criterion is maintained, review simulation inputs for any incorrect boundary condition settings. Reconfigure simulation and restart if any issues are discovered.
9. **Verify:** Verify simulation is complete.
10. **Post process:** Post process simulation to show smoke visibility conditions or other parameters that are of interest
11. .**Analyze:** Analyze results for compliance with intended scope and pertinent code requirements
12. **Repeat:** Repeat steps 3 through 11 as needed for subsequent simulations, such as varying fire location(s), ventilation modes, or other environmental characteristics to accurately represent project conditions and goals

Key features and project dimensions of the overall facility for this analysis were developed from the architectural drawings. Simplifications for details not relevant to the solution were made and applied to the CFD model to help reduce computational time. The engineering team analyzed the fire scenarios then applied them to the 3D constructed model along with ambient characteristics. Results gathered from the CFD analysis allowed the engineering team to verify if the proposed ventilation meets the project criterion for safe egress.

3.2 Inputs and Assumptions

Makeup airflow from emergency ventilation operations comes from headhouses above, this assumes that public accessways will remain open during an emergency event. This can be achieved by either having magnetic hold open doors or doorless open entryways.

1. Platform is enclosed with platform screen doors. It is assumed that smoke and airflow from trackways will only travel to the platform through open platform screen doors that will align with open train doors.

2. Elevators and emergency egress stairways where doors typically remain closed are assumed to have no contributions to airflow and are therefore modeled as a solid obstruction
3. The objective for emergency ventilation is to provide a pressure differential between the incident location and the non-incident location. A higher pressure at a non-incident location is desirable so that the direction of airflow is from the non-incident location towards the incident location. Indicating a resistance of smoke ingress to the non-incident location.
4. Initial indications for successful emergency ventilation operation includes maintaining critical velocity. This is the air velocity in the incident bore required to prevent the back layering of smoke. Critical velocity applies to push pull ventilation scenarios where on one side of the fire is in exhaust and one side is in supply providing longitudinal airflow. An initial pass/fail criterion for a push-pull ventilation scenario is a velocity greater than 459 FPM within a tunnel segment, and 481 FPM for a station track with platform screen doors. See 4.2.1Appendix F for critical velocity calculations.
5. Assumptions will further be refined at a later time.

3.2.1 Design Fire Scenario

The DART D2 rolling stock is a SLRV. The peak fire heat release rate is assumed to be 14.9 MW. The fire growth rate is based on a medium fire growth rate defined by:

$$\dot{Q} = \alpha t^2$$

Where
$\dot{Q}$ is the heat release rate in W
α is the growth rate coefficient 11.722 w/s^2
t is time in seconds

Fire growth rate curve is shown in Figure 9.

Additional user defined characteristics were implemented as well:
- Heat of Combustion of 39.4 MJ/kg.
- Soot Yield of 0.165 kg (soot) /kg (fuel).
- Water Yield of 0.695 kg (water)/kg (fuel).
- CO Yield of 0.14 kg (CO)/kg (fuel).
- Mass specific extinction coefficient for smoke produced by pyrolysis Km=4703 m^2/kg

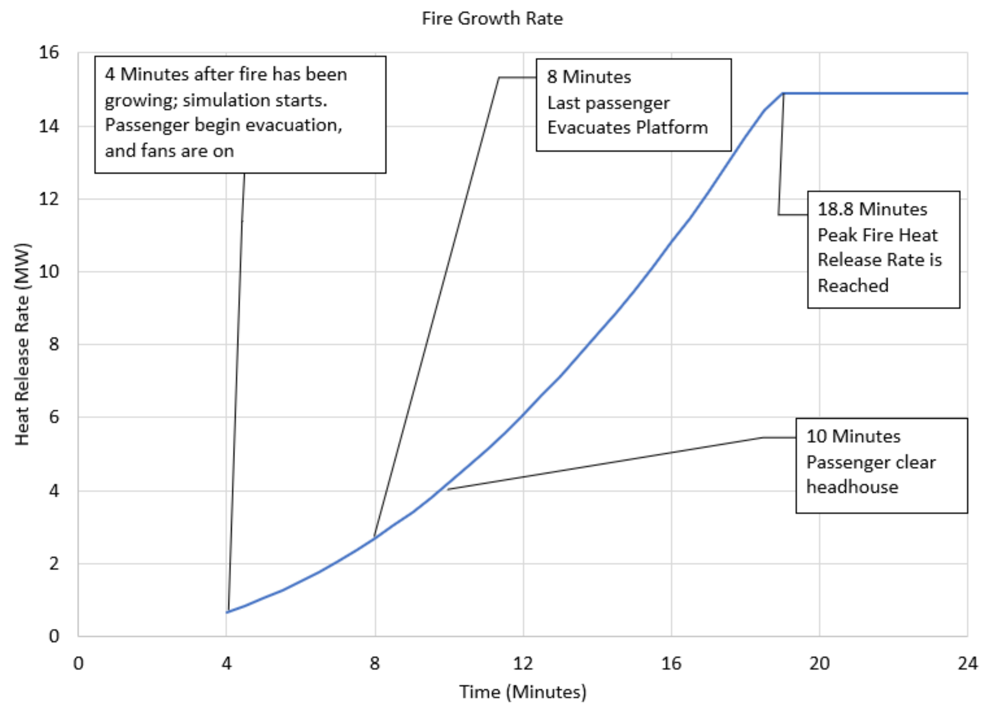


Figure 9: Fire Growth Rate

Carbon Monoxide Model

One product of combustion includes Carbon Monoxide (CO) Species development for Carbon monoxide which is specified by 0.14 kg/kg at the fire source. Although carbon monoxide exposure is an important characteristic in determining tenability of an egress path this study used visibility obscuration due to smoke as the determining factor for tenability.

Smoke Model

Species development for smoke in the CFD simulation is guided by a soot yield factor of 0.165 kg/kg. A custom field function in fluent is used to visualize areas within the station that would be impacted by smoke. The numerical scale used to visualize smoke obscuration in CFD Fluent model is from 0 to 10 m where 0 represents an area where smoke completely obscures the visibility of passengers and 10 represents an unobstructed sight range of 10 meters.

3.2.2 SES Inputs

SES software is an engineering tool programmed to evaluate complex flow relationships throughout an underground rail system envelope by ventilation system operations in multiple locations. Used as a standard method in the transportation industry, SES provides accurate prediction of airflows in managing underground hazard conditions. SES software incorporates evaluation of radiation and convection heat transfer, climatic influences on airflow, pressure and airflow relationships, and influences of train piston effect in its calculations.

Inputs and assumptions for the SES simulations include:

1. Outdoor air temperature is 70.6 degrees F and 61.6 degrees F wb[1]
2. Tunnel air temperature is 81.2 degrees F and 63.3 degrees F wb
3. Rolling stock is DART Kinkisharyo
4. Friction loss was calculated based on input of wall roughness of 0.01 ft on concrete surface, and the other areas with fixtures such as lightings, wirings, etc are assumed 0.127 ft.

To develop the appropriate pressure losses associated with the underground station. A non-dimensional factor k applied at various locations where cross section area changes, turns, and other locations there would be a resistance to airflow.

Table 3: SES K Factors

	K factor	
Geometry	Forward Positive	Forward Negative
Cross sectional area changes from Tunnel to Station	0.06	0.04
Open Track Damper	2.205	2.205
Open Over Track Exhaust	2	2
Open Over Platform Exhaust	1	1
Fan Plant	0.259	0.259
Open Platform screen doors	4	4

3.2.3 CFD Input

Geometry Simplifications

CFD model of current Commerce Station configuration is shown in Figure 10: CFD Model. Modifications were made to the station configuration to simplify the CFD analysis, these include simplifying the ventilation path to surface, excluding limited airflow paths from the model, which includes emergency egress stairs, and elevators.

[1] Reference ASHRAE Climatic Design Conditions 2017

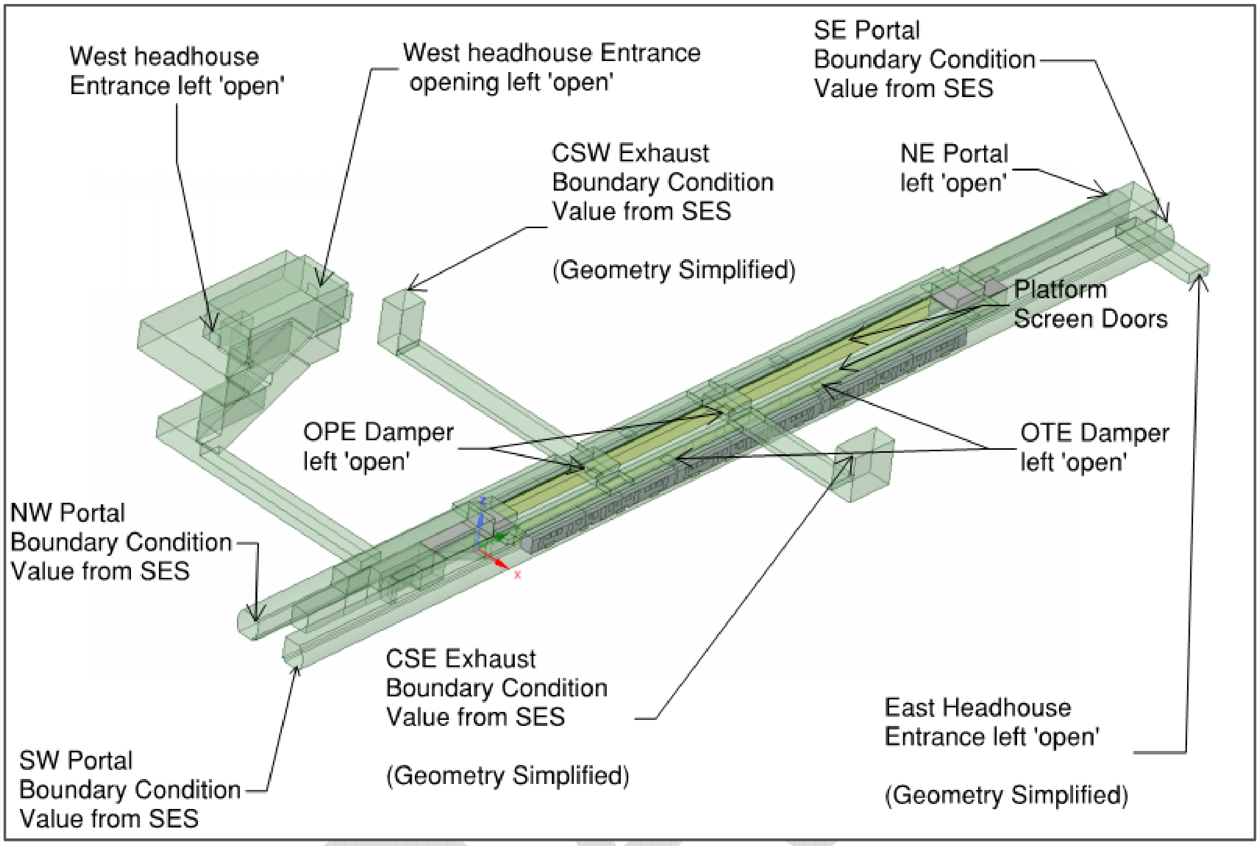


Figure 10: CFD Model

Initial CFD simulations wall thermal boundary condition assumes the wall as no slip boundary, standard wall roughness with a roughness constant of 0.5 is assumed. The walls participate in the thermal radiation calculation and conjugate heat transfer boundary condition are applied.

Ventilation related boundary conditions as show in Figure 10 are listed in .

Table 4: Ventilation flow parameters for fire scenario (a), (b), and (c)

CFD Simulation No.	R9_3r3	R9_4	R9_5
Fire Scenario	(a)	(b)	(c)
CSW Exhaust	-105.3	-78.8	-79.5
CSE Exhaust	-97.6	-73.1	-79.5
NW Portal	11.6	10.2	11.7
NE Portal	Open	Open	Open
SW Portal	74.5	67.2	32.8

SE Portal	-66.1	-39	-31.4
West Headhouse Entrance	Open	Open	Open
East Headhouse Entrance	Open	Open	Open
OPE Damper	Open	Open	Open
OTE Damper	Open	Closed	Closed

Notes:

1. Table will be updated upon Completion of simulations
2. Positive values refer to airflow into the station domain, negative values indicate airflow out of the station domain.

The train geometry for the DART D2 project is modeled after the Kinkishayo SLRV (Super Light Rail Vehicle). It is assumed during a fire scenario at a station only the doors on the platform side would be open to allow passenger egress. Windows would be broken due the heat of the fire and is there simulated as open as well.

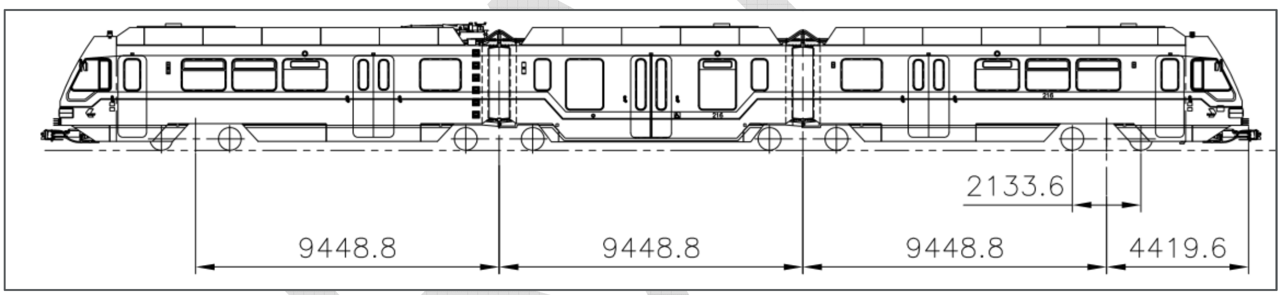


Figure 11: CFD Train

Geometry simplifications were made to the CFD model to improve cell quality and count. For example, the semicircular space above the trackway is has been represented with rectangular duct with a similar hydraulic diameter as shown in Figure 12. After applying geometry simplifications, overall cell count of the model after meshing is 3.8 million cells. The cell size around the simplified duct ranges from (0.25^3) ft^3 to roughly 1 ft^3.

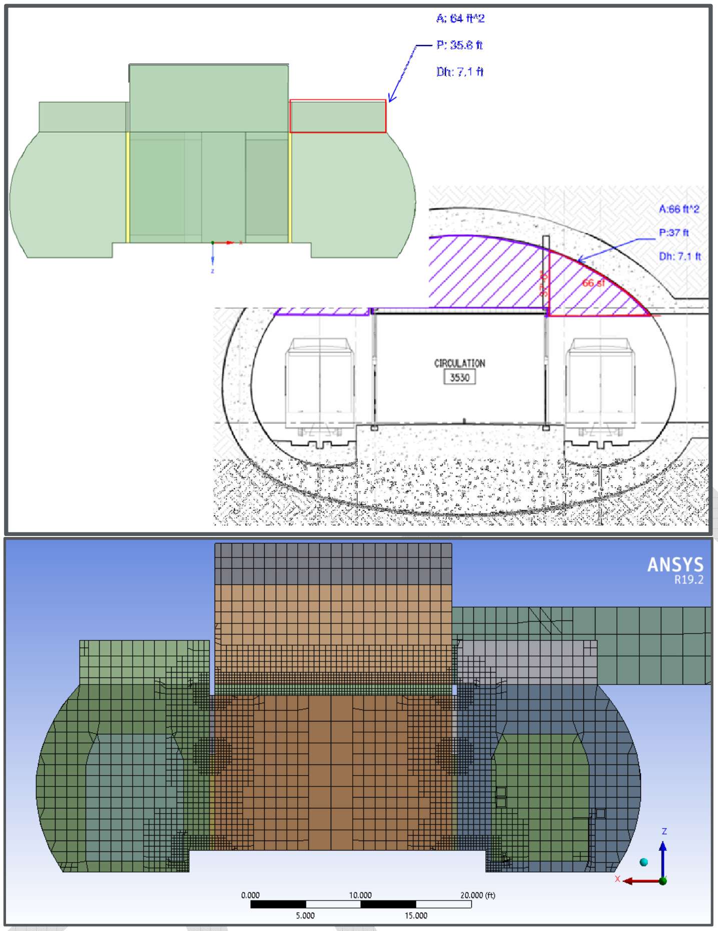


Figure 12: Geometry Simplification

Fires within the station will be exhaust through over track dampers. Current size for over track dampers are assumed to be 50 SF.

Boundary Conditions for the CFD model are determined by SES results.

4 Results and Discussion

4.1 SES Results

A summary of the SES simulations are shown in Table 5, more details are provided in the SES simulation tracker in Appendix B. SES simulations are used to establish the entire airflow network within the underground alignment. SES runs can typically provide an initial indicator of a pass or fail criteria with longitudinal ventilation schemes, detailing whether a simulation has achieved ‘critical velocity’ for push pull scenarios. For station extraction cases the airflow rates from SES simulations are used as boundary conditions for subsequent CFD simulations.

Table 5: SES Simulations

SES Simulation No. (Case #)	3r1	4	5	6	7	10	11	9
Station Fire Scenario	(a)	(b)	(c)	N/a	N/a	N/a	N/a	N/a
SES File Name	D2_case3r1	D2_case4	D2_case5	D2_push pull_01	D2_push pull_02	D2_push pull_03	D2_push pull_04	D2_push pull_01r2
Fire Location	625	625	605	106	306	118	318	302
Fire Zone	410	410	420	120	100	300	320	100
Evac. Direction	West/East	West/East	West/East	West	West	East	East	West
Smoke Direction	Extraction	Extraction	Extraction	East	East	West	West	East
MCW	-	-	-	2E	2E	-	-	3E
MCE	-	-	-	-	-	2E	2E	-
CSW	1E	1E	1E	-	-	2S	2S	-
CSE	1E	1E	1E	-	-	-	-	-
CBW	-	-	-	-	-	-	-	-
CBE	-	-	-	-	-	-	-	-
Pass/Fail	N/a	N/a	N/a	Pass	Pass	Pass	Pass	Pass

Notes:

1. For further detail see the node network diagrams in Appendix C. As well as results in Appendix B
2. See Appendix D for ventilation schematic with ventilation zones labeled.
3. Critical velocity applies to longitudinal ventilation, and not extraction ventilation.
4. Pass Fail criteria undetermined in extraction ventilation cases using SES of the 2D nature of its analysis CFD simulation is required to determine if simulation passes.
5. There are 2 fan plants in each station, each fan plant consists of three fans, 2E refers to two fans in a fan plant operating in exhaust mode, 2S refers to two fans in a fan plant operating in supply mode.

- Case No. 3r1: This case represents Fire Scenario (a). This scenario entails a middle train fire event within the south track. The ventilation system is postured in an extraction configuration where the west and east fan plant (CSW) and (CSE) are both in exhaust. Platform screen doors on the south track are open, and eastbound over track ventilation dampers are open, as well as over platform dampers.

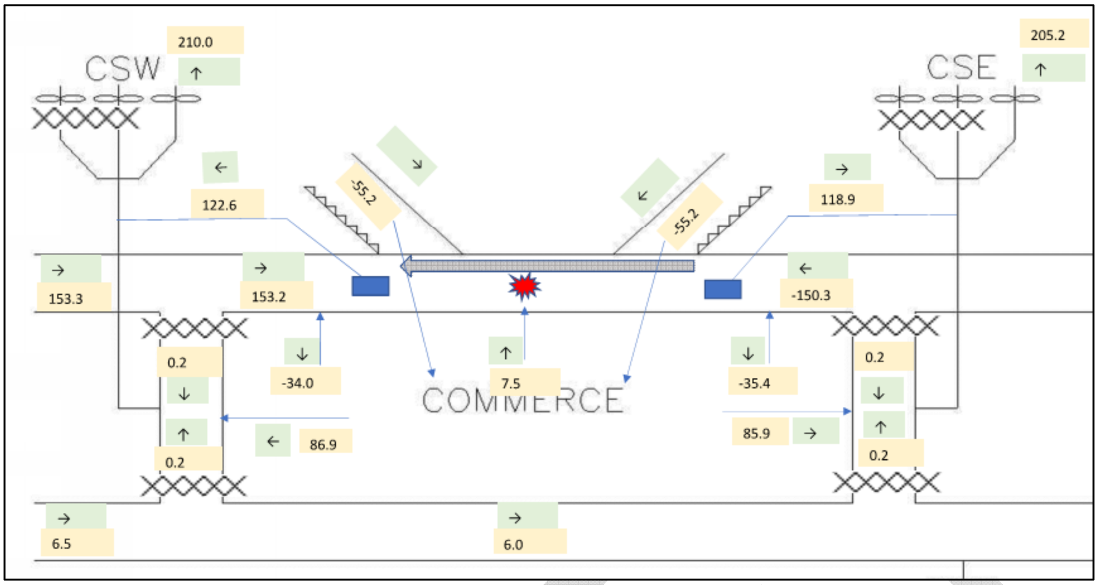


Figure 13: SES Case No. 3 Diagram

- Case No. 4: This case represents Fire Scenario (b). This scenario entails fire event within the south track with no trains present. The ventilation system is postured in an extraction configuration where the west and east fan plant (CSW) and (CSE) are both in exhaust. Platform screen doors on the south track are open, and eastbound over track ventilation dampers are open.

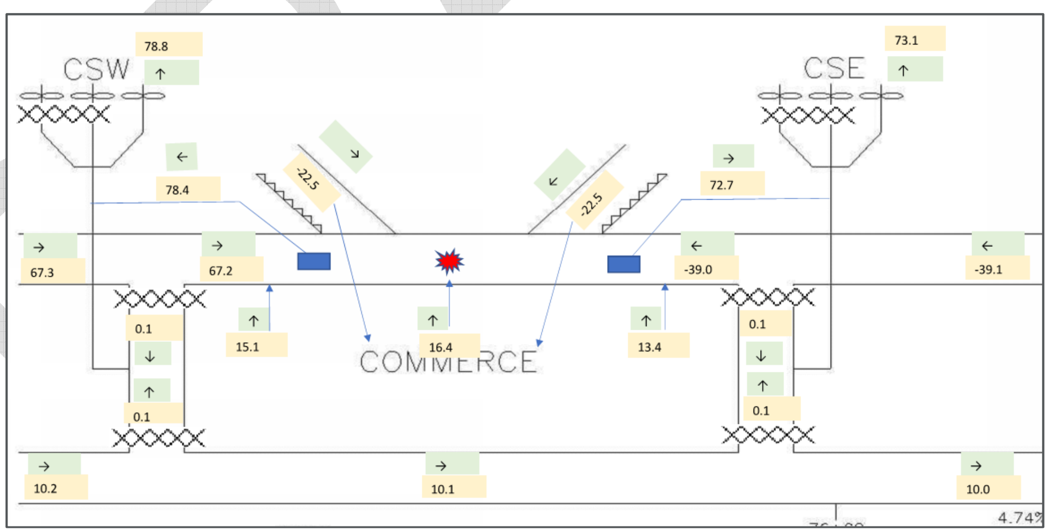


Figure 14: SES Case No. 4 Diagram

- Case No. 5: This case represents Fire Scenario (c). This scenario entails a fire event within the enclosed platform. The ventilation system is postured in an extraction configuration where the west and east fan plant (CSW) and (CSE) are both in exhaust. Dampers within the enclosed the enclosed platform are open.

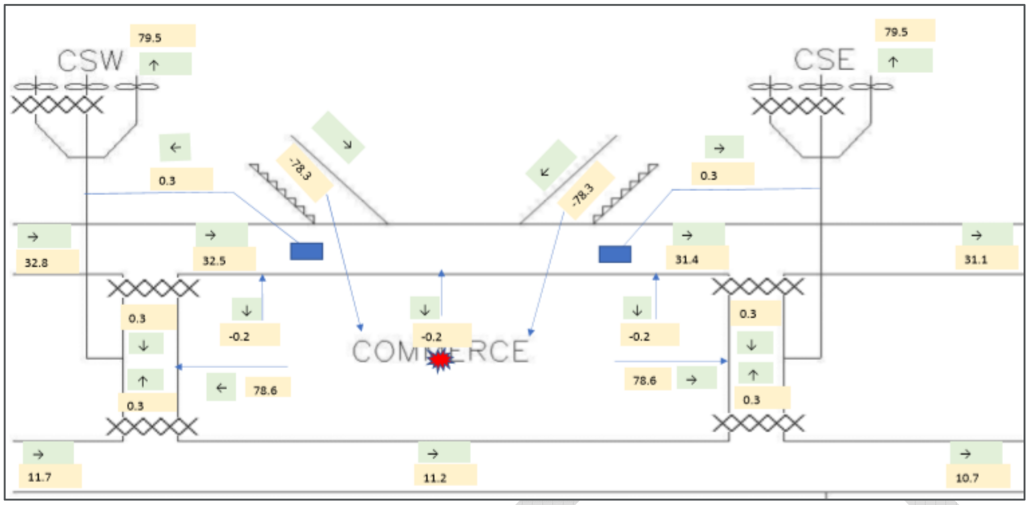


Figure 14: SES Case No. 5 Diagram

- Case no. 6: This case represents a tunnel fire in Eastbound track between west portal and metro station. For this case the evacuation direction is towards the portal (west) and the smoke extraction direction is towards metro station (east). Fire zone is 120. Two fans in the metro station west plant (MCW) are operating in exhaust mode. Critical velocity is achieved. Non incident tunnel track dampers 902 and 907 are closed.

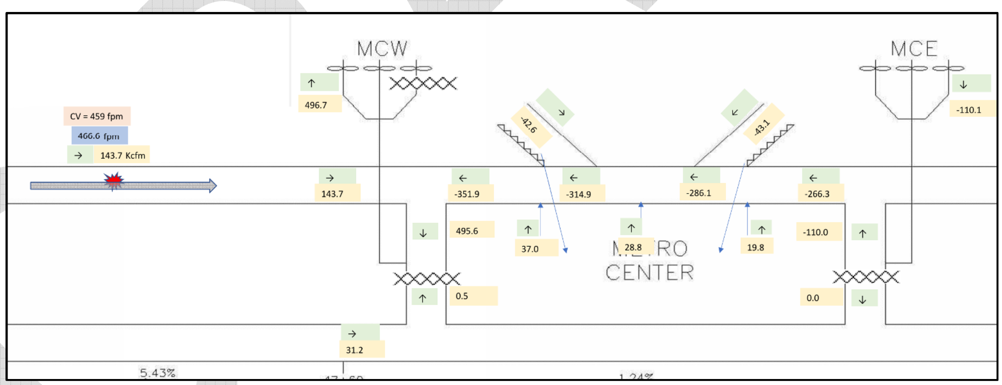


Figure 16: SES Case No. 6 Diagram

- Case no. 7: Tunnel fire in Westbound track between west portal and metro station. For this case the evacuation direction is towards the portal (west) and the smoke extraction direction is towards metro station (east). Fire zone is 100. Two fans in the metro station west plant(MCW) are operating in exhaust mode. Critical velocity is achieved. Non incident tunnel track dampers 901 and 906 are closed.

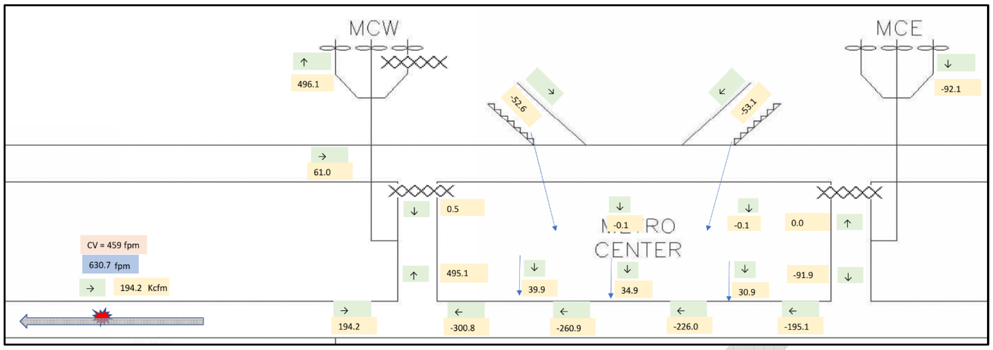


Figure 17: SES Case No. 7 Diagram

- Case no. 10: Tunnel fire in Eastbound track between metro station and commerce station. For this case the evacuation direction is towards the portal (west) and the smoke extraction direction is towards metro station (east). Fire zone is 320. Two fans in the metro station east plant (MCE) are operating in exhaust mode and two fans in commerce station west plant (CSW) in supply mode. Critical velocity is achieved. Non incident tunnel track dampers 907 and 912 are closed.

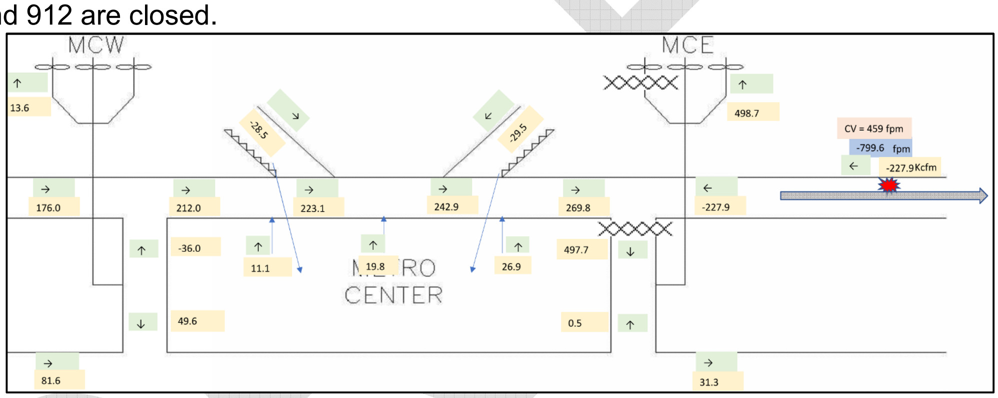


Figure 18: SES Case No. 10 Diagram

- Case no. 11: Tunnel fire in Westbound track between metro station and commerce station. For this case the evacuation direction is towards the portal (west) and the smoke extraction direction is towards metro station (east) Fire zone is 300. Two fans in the metro station east plant (MCE) is operating in exhaust mode and two fans in commerce station west plant (CSW) in supply mode. Critical velocity is achieved. Non incident tunnel track dampers 906 and 911 are closed.

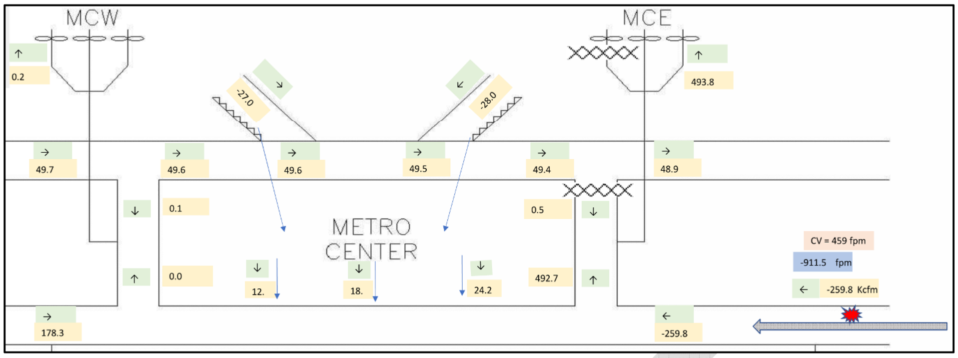


Figure 19: SES Case No. 11 Diagram

- Case no.9: Tunnel fire in Eastbound track near west portal. For this case the evacuation direction is towards the portal (west) and the smoke extraction direction is towards metro station (east). Fire zone is 120. **Three** fans in the metro station west plant (MCW) are operating in exhaust mode. Critical velocity is achieved. Non incident tunnel track dampers 902 and 907 are closed. There fans have to be turned on to achieve critical velocity due to the 6% slope of the tunnel near the west portal.

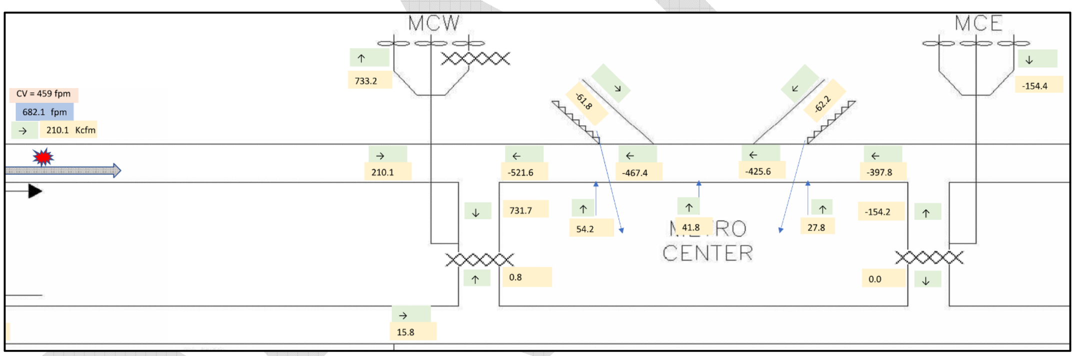


Figure 20: SES Case No. 9 Diagram

4.2 CFD

Results from CFD simulations will be provided in Table 6 upon completion. Further details can be found in Note all simulation train fire events assume fire has

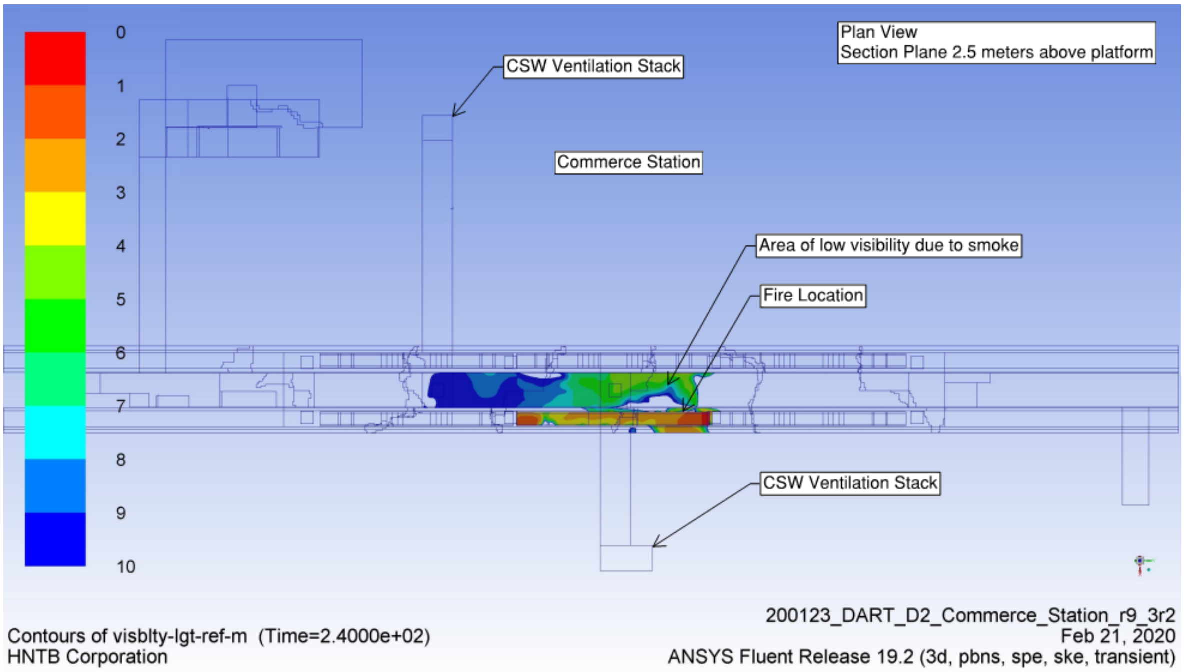
Table 6: CFD Results

CFD Config. ID	(Name)	R9_3r2	R9_4	R9_5
SES Case	(Case #)	3r1	4	5
Fire Scenario		(a)	(b)	(c)
Fire Location		South Track Middle Train	South Track No Train	Center Platform
Exhaust Scheme		Extraction	Extraction	Extraction
Smoke Direction		Extraction	Extraction	Extraction
Input Boundary Conditions (kcfm)	Prtl NW	6.5	10.2	11.7
	Prtl NE	Vent	Vent	Vent
	Prtl SW	153.2	67.2	32.5
	Prtl SE	150.3	39	31.4
	West Vent	-210	-78.8	-79.5
	East Vent	-205.2	-73.1	-79.5
Recorded Boundary Conditions (kcfm)[3]	Prtl NW	6.5		
	Prtl NE	-7.1		
	Prtl SW	153.2		
	Prtl SE	150.3		
	West Vent	-210		
	East Vent	-205.2		
Pass/Fail[1]		Pass		

1. Simulation pass/fail is determined by the system's ability to keep smoke from propagating towards egress walkway paths.
2. A negative value indicates supply from a boundary condition (airflow "into" domain). A positive value indicates exhaust from the domain.
3. Simulation results updated upon completion

4.2.1 Case No.3r1

The CFD configuration represents fire scenario 1 where a center train on the south track is on fire. The ventilation method used for this scenario is the same as SES Case no.3r1 with an extraction ventilation approach. In this case both the west fan plant (CSW) and the east fan plant (CSE) are in exhaust with both the OTE and OPE terminals open. Simulation time is 4 minutes (8 minutes after fire has started). Results indicate that smoke is maintained with the center of the platform when the OPE terminals are.



Appendix A. Fan Pressure Calculation

HNTB

Made By:	jn	Date:	2/10/2020	Job No.:	61144
Checked by	tvt	Date:	2/21/2020	Sheet No.:	
Bkchk by:		Date:	1	File Name:	\\seaw00\jobs2\61144\Redbook\08_TechProd\20%_Cncpt_Dsgn_Rpt\[Dart D2 Duct Minor Losses.xlsx]HV-1 with Fan

PROJECT NAME: DART D2

CALCULATION: Comparison of Duct Section with Abrupt Contraction @ Silencer Outlet To Flex Connection - Study of Airflow At Outlet of Baffle To Flex Connection

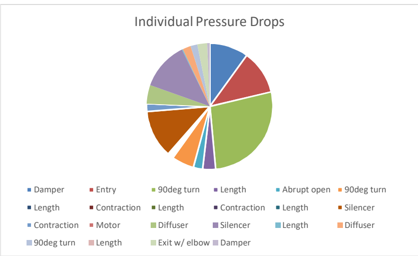
Air density at 70deg F and 14.7 psia: 0.081 lbm/ft^3
Air temperature 32 deg F.

HIDE THE ORANGE ROWS FOR PRINTING
1. ENTER RECTANGULAR DUCT SIZE OR ROUND DUCT SIZE, NOT BOTH. FORMULAS WILL IGNORE RECTANGULAR DUCT SIZE IF ROUND DUCT SIZE IS ENTERED INTO CELL.
2. VALUES IN COLUMN "Duct Pressure Drop/100 ft (in. w.ater)" WILL BE RED TEXT WITH RED SHADE BACKGROUND IF PRESSURE DROP EXCEEDS 0.25 IN WATER PER 100 FT

Duct Section	Fitting Name	ASHRAE Fitting(s) No. (Ref 1, 2)	Duct Material e	Duct Roughness, ft.	Terminal/ Branch Airflow (cfm)	Airflow (cfm)	Rectangular Duct Size			Duct Size (Dia., in.)	Duct Area (ft^2)	Room NC/ Max Velcity (fpm)	Velocity (fpm)	Velocity Pressure (in. water)	Duct Length (ft)	Summary of Fitting Loss Coefficients	Reynolds Number Re (Ref 4)	Friction Factor f (Ref 3)	Duct Pressure Drop/100 ft (in. water)	Fitting Pressure Drop (in. water)	Equipment Pressure Drop (in. water)	Total Pressure Drop (in. water)	Notes
							Duct Size (W, in.)	Duct Size (L, in.)	Duct Size (Dh, in.)														
1	Damper	Fig 2.28	Galv. Stl.	0.0005	500000	500000	144	156	149.76		156.00	35/2000	3205	0.6918		0.44	4.69E+06	0.0000	0.0000	0.3044		0.3044	1, 2
2	Entry	Fig 2.28	Galv. Stl.	0.0005	500000	500000	144	156	149.76		156.00	35/2000	3205	0.6918		0.5	4.69E+06	0.0109	0.0602	0.3459		0.3459	1, 2
3	90deg turn	Fig 2.28	Galv. Stl.	0.0005	500000	500000	144	156	149.76		156.00	35/2000	3205	0.6918		1.2	4.69E+06	0.0109	0.0602	0.8302		0.8302	1, 2
4	Length	Fig 2.28	Galv. Stl.	0.0005	500000	500000	144	156	149.76		156.00	35/2000	3205	0.6918	170.00		4.69E+06	0.0109	0.0602	0.0000		0.1024	1, 2
5	Abrupt open	Fig 2.28	Galv. Stl.	0.0005	500000	500000	276	138	184		264.50	35/2000	1890	0.2406		0.3	3.40E+06	0.0109	0.0170	0.0722		0.0722	1, 2
6	90deg turn	Fig 2.28	Galv. Stl.	0.0005	500000	500000	408	120	185.45455		340.00	35/2000	1471	0.1456		1.2	2.67E+06	0.0111	0.0104	0.1748		0.1748	1, 2
7	Length	Fig 2.28	Galv. Stl.	0.0005	500000	500000	408	120	185.45455		340.00	35/2000	1471	0.1456	35.00		2.67E+06	0.0111	0.0104	0.0000		0.0037	1, 2
8	Contraction	Fig 2.28	Galv. Stl.	0.0005	500000	500000	318	120	174.24658		265.00	35/2000	1887	0.2397		0.05	3.22E+06	0.0110	0.0181	0.0120		0.0120	1, 2
9	Length	Fig 2.28	Galv. Stl.	0.0005	500000	500000	228	120	157.24138		190.00	35/2000	2632	0.4664	32.00		4.05E+06	0.0109	0.0388	0.0000		0.0124	1, 2
10	Contraction	Fig 2.28	Galv. Stl.	0.0005	500000	250000	174	120	142.04082		145.00	35/2000	1724	0.2002		0.05	2.40E+06	0.0114	0.0194	0.0100		0.0100	1, 2
10.1	Length	Fig 2.28	Galv. Stl.	0.0005	500000	250000			#DIV/0!	120	78.54	35/2000	3183	0.6823	10.00		3.74E+06	0.0113	0.0771	0.0000		0.0077	1, 2
10.2	Silencer	Fig 2.28	Galv. Stl.	0.0005	500000	250000			#DIV/0!	120	78.54	35/2000	3183	0.6823		0.55	3.74E+06	0.0000	0.0000	0.3753		0.3753	1, 2
10.3	Contraction	Fig 2.28	Galv. Stl.	0.0005	500000	250000			#DIV/0!	104.00	58.99	35/2000	4238	1.2094		0.05	4.31E+06	0.0114	0.1595	0.0605		0.0605	1, 2
10.4	Motor	Fig 2.28	Galv. Stl.	0.0005	500000	250000			#DIV/0!	88	42.24	35/2000	5919	2.3593			5.09E+06	0.0116	0.3739	0.0000		0.0000	1, 2
10.5	Diffuser	Fig 2.28	Galv. Stl.	0.0005	500000	250000			#DIV/0!	104.00	58.99	35/2000	4238	1.2094		0.12	4.31E+06	0.0114	0.1595	0.1451		0.1451	1, 2
10.6	Silencer	Fig 2.28	Galv. Stl.	0.0005	500000	250000			#DIV/0!	120.00	78.54	35/2000	3183	0.6823		0.55	3.74E+06	0.0000	0.0000	0.3753		0.3753	1, 2
10.7	Length	Fig 2.28	Galv. Stl.	0.0005	500000	250000			#DIV/0!	120	78.54	35/2000	3183	0.6823	10.00		3.74E+06	0.0113	0.0771	0.0000		0.0077	1, 2
11	Diffuser	Fig 2.28	Galv. Stl.	0.0005	500000	500000	201	258	225.96078		360.13	35/2000	1388	0.1298		0.5	3.07E+06	0.0108	0.0074	0.0649		0.0649	1, 2
12	90deg turn	Fig 2.28	Galv. Stl.	0.0005	500000	500000	228	396	289.38462		627.00	35/2000	797	0.0428		1.2	2.26E+06	0.0109	0.0019	0.0514		0.0514	1, 2
13	Length	Fig 2.28	Galv. Stl.	0.0005	500000	500000	228	396	289.38462		627.00	35/2000	797	0.0428	90.00		2.26E+06	0.0109	0.0019	0.0000		0.0017	1, 2
14	Exit w/ elbow	Fig 2.29	Galv. Stl.	0.0005	500000	500000	228	396	289.38462		627.00	35/2000	797	0.0428		1.8	2.26E+06	0.0109	0.0019	0.0771		0.0771	1, 2
15	Damper	Fig 2.28	Galv. Stl.	0.0005	500000	500000	228	396	289.38462		627.00	35/2000	797	0.0428		0.44	2.26E+06	0.0109	0.0019	0.0188		0.0188	1, 2
																					Total	3.0534	

References:
1. ASHRAE Duct Fitting Database, Version 2.2.5
2. 1989 Fundamentals, Chapter 32, Fitting Loss Coefficients
3. ASHRAE 1997 Fundamentals, Equation 32.20
4. ASHRAE 1997 Fundamentals, Equation 32.21
4. ASHRAE 1981 Fundamentals, Chapter 33, Duct Design

Notes:
1. Fittings are located at the beginning of a duct section
2. Equipment is located at the end of a duct section
3. Equipment loss is for register
4. Equipment loss is for combination fire/smoke damper



Total Vol	Section Pressure Drop	Area (ft^2)	V (fpm)	K-factor to achieve drop	Resulting Drop
102500.8	1.8298	156	3205.1282	2.645314737	1.830013698
	1.2236	400	1250	11.63033291	1.223765906

F.S. 20% 4.58

Appendix B. SES Simulation Tracker

HNTB Made By: SSP Date: 2/1/2020 Job Number: 61144
Chkd By: Date: Sheet No: 1
File Name: C:\Users\trtran\AppData\Local\Microsoft\Windows\INetCache\Content.MSO\[Copy (1) of APPENDIX_DART SES tracker.xlsx]Dart D2

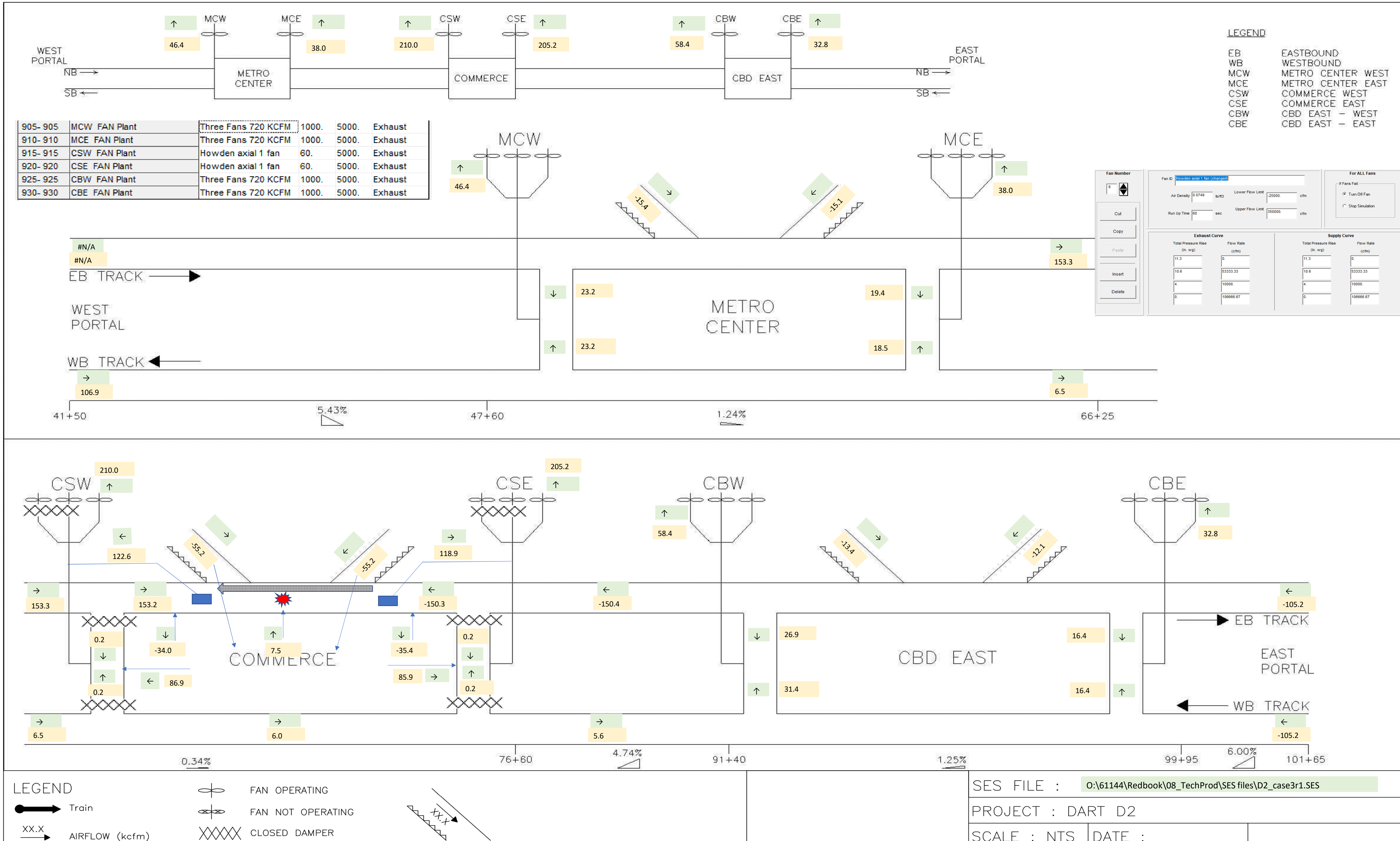
Dart D2 SES Run Log

Link to SES files = SES files
Link to SES results diagram = SES post

No	File Name	Notes	Mode	Fire Segment (Segment)[1]	NON INCIDENT DAMPERS CLOSED[1]	INCIDENT DAMPERS CLOSED	Vent Zone[2]	Evac direction	Smoke Direction	Critical Velocity (fpm)[3]	Critical Airflow (kfpm)[3]	Run Velocity (fpm)	Run Airflow (kcfm)	Pass/Fail[4]	MCW	MCE	CSW	CSE	CBW	CBE	Results diagram	Node network diagram
1	D2_case1	fire in station track, 3 platform doors open, fan curve is adjusted	Extraction	625	912, 917	none	410	N/A	Extraction	N/A	N/A	N/A	N/A	N/A	-	-	1 E	1 E	-	-	D2_case1.pdf	node dart D2.pdf
2	D2_case2	fire in station track, 3 platform doors open, fan curve is adjusted, OPENED PLATFORM DAMPERS	Extraction	625	912, 917	none	410	N/A	Extraction	N/A	N/A	N/A	N/A	N/A	-	-	1 E	1 E	-	-	D2_case2.pdf	node dart D2.pdf
3	D2_case3	fire in station track, 3 platform doors open, fan curve is adjusted, both platfrom dampers are open	Extraction	625	912, 917	none	410	N/A	Extraction	N/A	N/A	N/A	N/A	N/A	-	-	1 E	1 E	-	-	D2_case3.pdf	node dart D2.pdf
3r1	D2_case3r1	Increase fan capacity from case 3	Extraction	625	912, 917	none	410	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-	-	1 E	1 E	-	-	D2_case3r1.pdf	node dart D2.pdf
4	D2_case4	track fire, no train, 3 platform doors open	Extraction	625	912, 917	none	410	N/A	Extraction	N/A	N/A	N/A	N/A	N/A	-	-	1 E	1 E	-	-	D2_case4.pdf	node dart D2.pdf
5	D2_case5	platform fire, no train	Extraction	605	N/A	none	420	N/A	Extraction	N/A	N/A	N/A	N/A	N/A	-	-	1 E	1 E	-	-	D2_case5.pdf	node dart D2.pdf
6	D2_push pul	tunnel fire	Push Pull	106	902,907	none	120	west	east	459	131	467	144	Pass	2E	-	-	-	-	-		Node Dart D2 _with PSE.pdf
7	D2_push pul	tunnel fire	Push Pull	306	901,906	none	100	west	east	459	131	630.7	194.2	Pass	2E	-	-	-	-	-		Node Dart D2 _with PSE.pdf
8	D2_push pul	tunnel fire near the west portal	Push Pull	302	901,906	none	100	west	east	459	131	283.5	87.3	fail	2E	-	-	-	-	-		Node Dart D2 _with PSE.pdf
9	D2_push pul	tunnel fire near the west portal, 3 fans ON at MCW	Push Pull	302	901,906	none	100	west	east	459	131	682.1	210.1	Pass	3E	-	-	-	-	-		Node Dart D2 _with PSE.pdf
10	D2_push pul	tunnel fire	Push Pull	118	907,912	none	320	east	west	459	131	799.6	227.9	Pass	-	2E	2S	-	-	-		Node Dart D2 _with PSE.pdf
11	D2_push pul	tunnel fire	Push Pull	318	906, 911	none	300	east	west	459	131	911.5	259.8	Pass	-	2E	2S	-	-	-		Node Dart D2 _with PSE.pdf

Notes
1 Refer to Node Network Diagram
2 Refer to Ventilation Schematic for Vent Zone identification
3 Critical Velocity refers to the air velocity required to prevent the backlayering of smoke. Critical Velocity is calculated only for longitudinal ventilation configurations and does not apply to extraction ventilation.
4 The pass fail criteria is based on whether or not the simulation run velocity meets or exceeds the calculated critical velocity for logitudinal ventilation configurations, and does not apply to extraction ventilation.

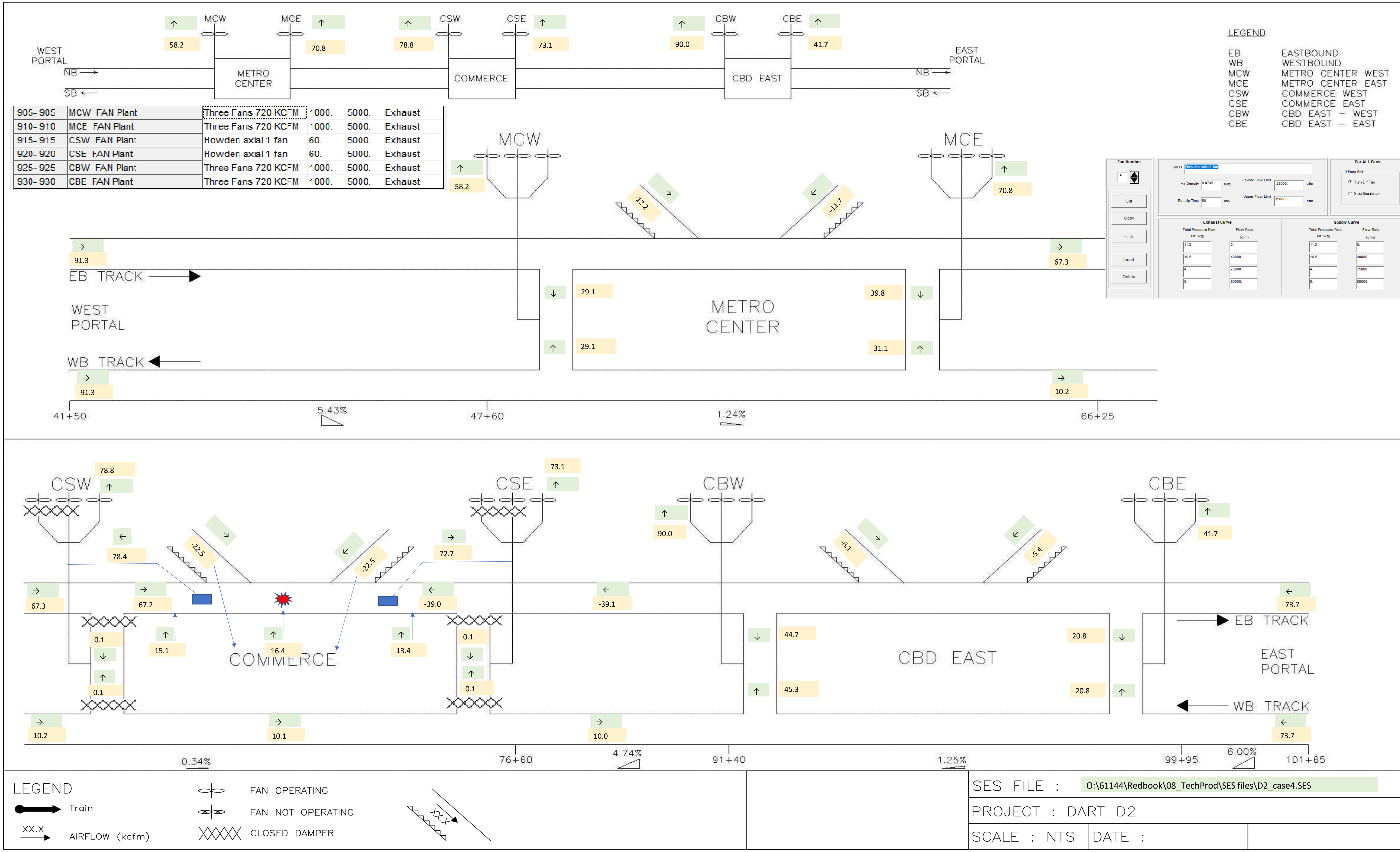
CASE 3r1



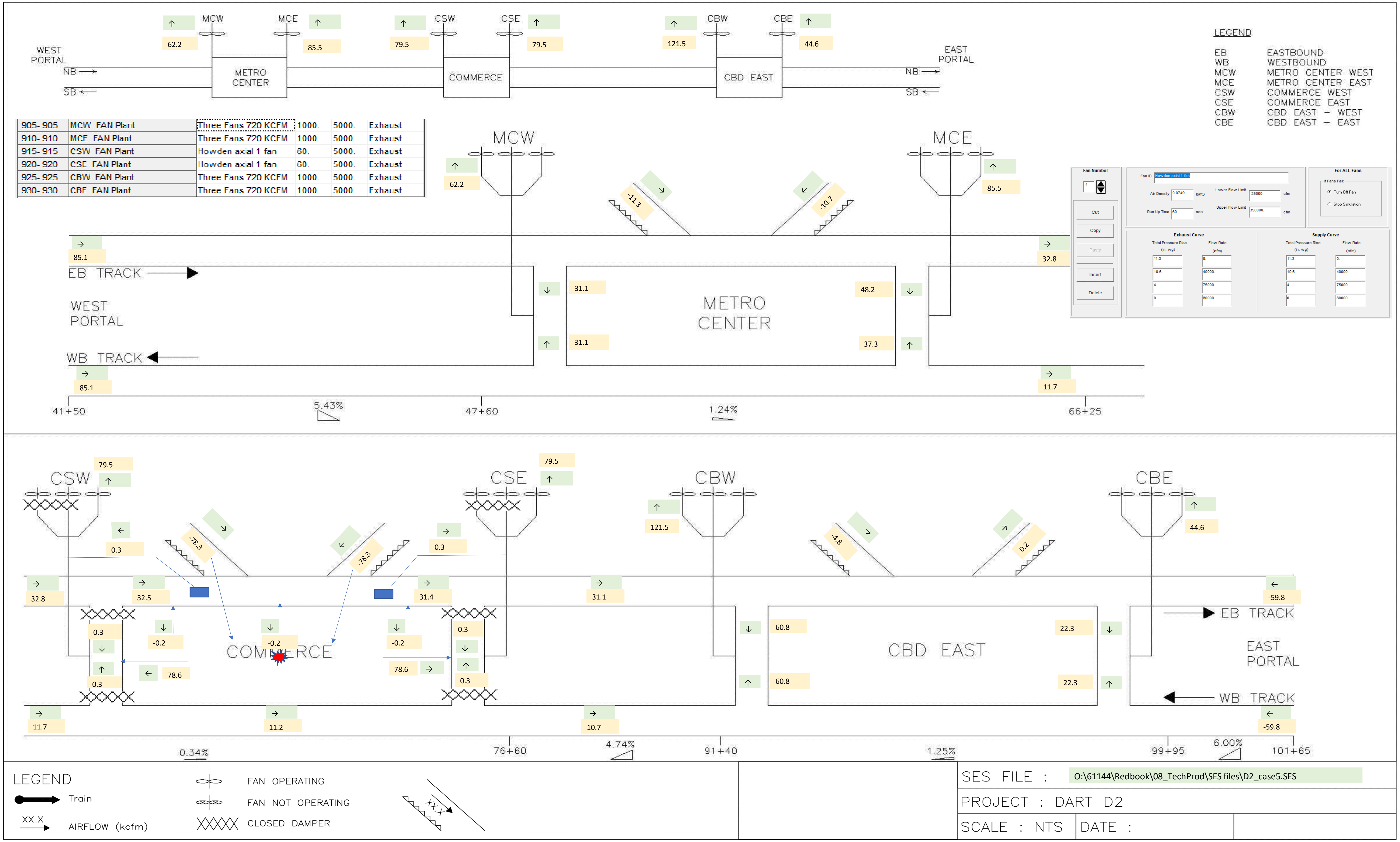
905- 905	MCW FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
910- 910	MCE FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
915- 915	CSW FAN Plant	Howden axial 1 fan	60.	5000.	Exhaust
920- 920	CSE FAN Plant	Howden axial 1 fan	60.	5000.	Exhaust
925- 925	CBW FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
930- 930	CBE FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust

CASE 4

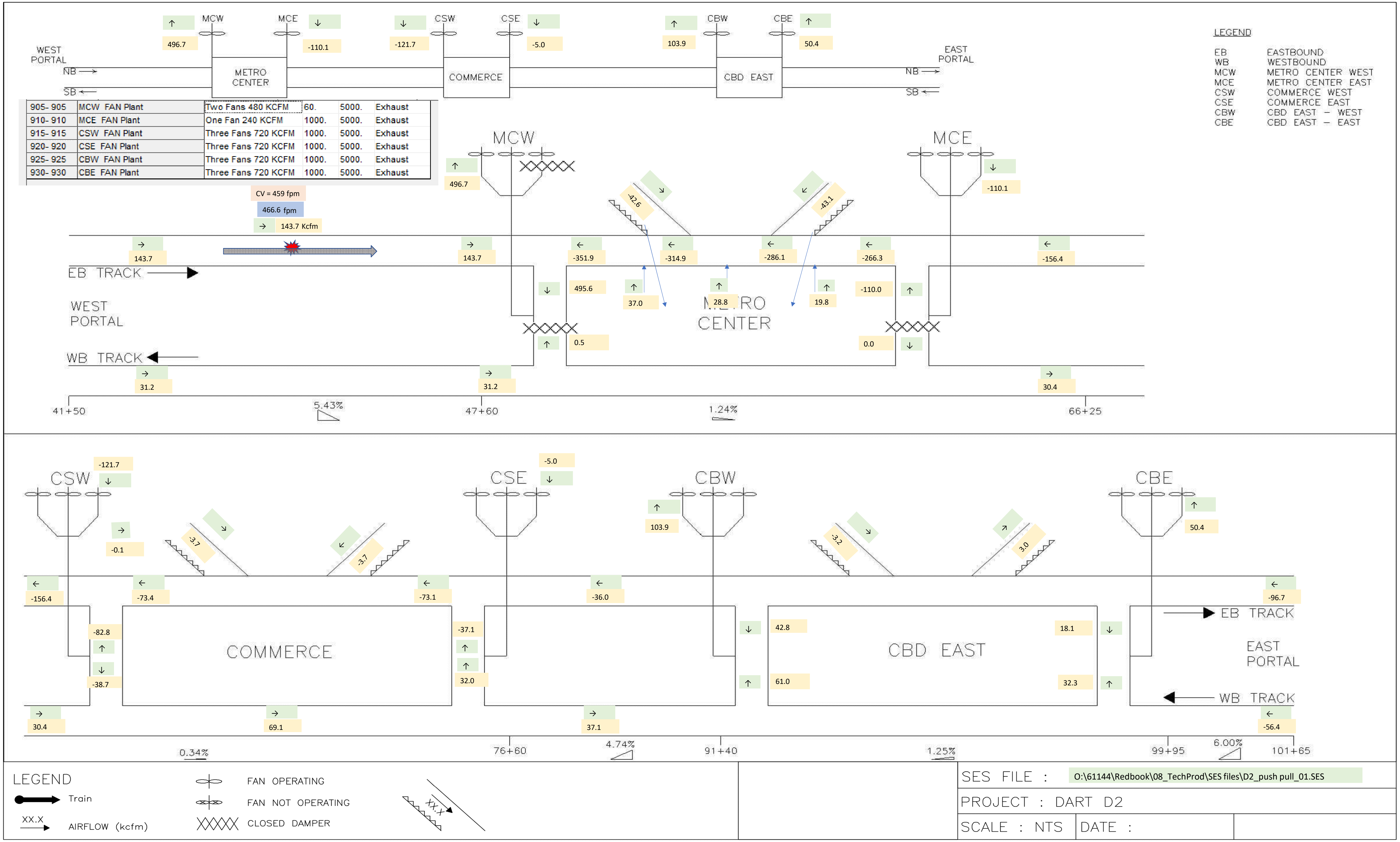
905- 905	MCW FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
910- 910	MCE FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
915- 915	CSW FAN Plant	Howden axial 1 fan	60.	5000.	Exhaust
920- 920	CSE FAN Plant	Howden axial 1 fan	60.	5000.	Exhaust
925- 925	CBW FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
930- 930	CBE FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust



CASE 5

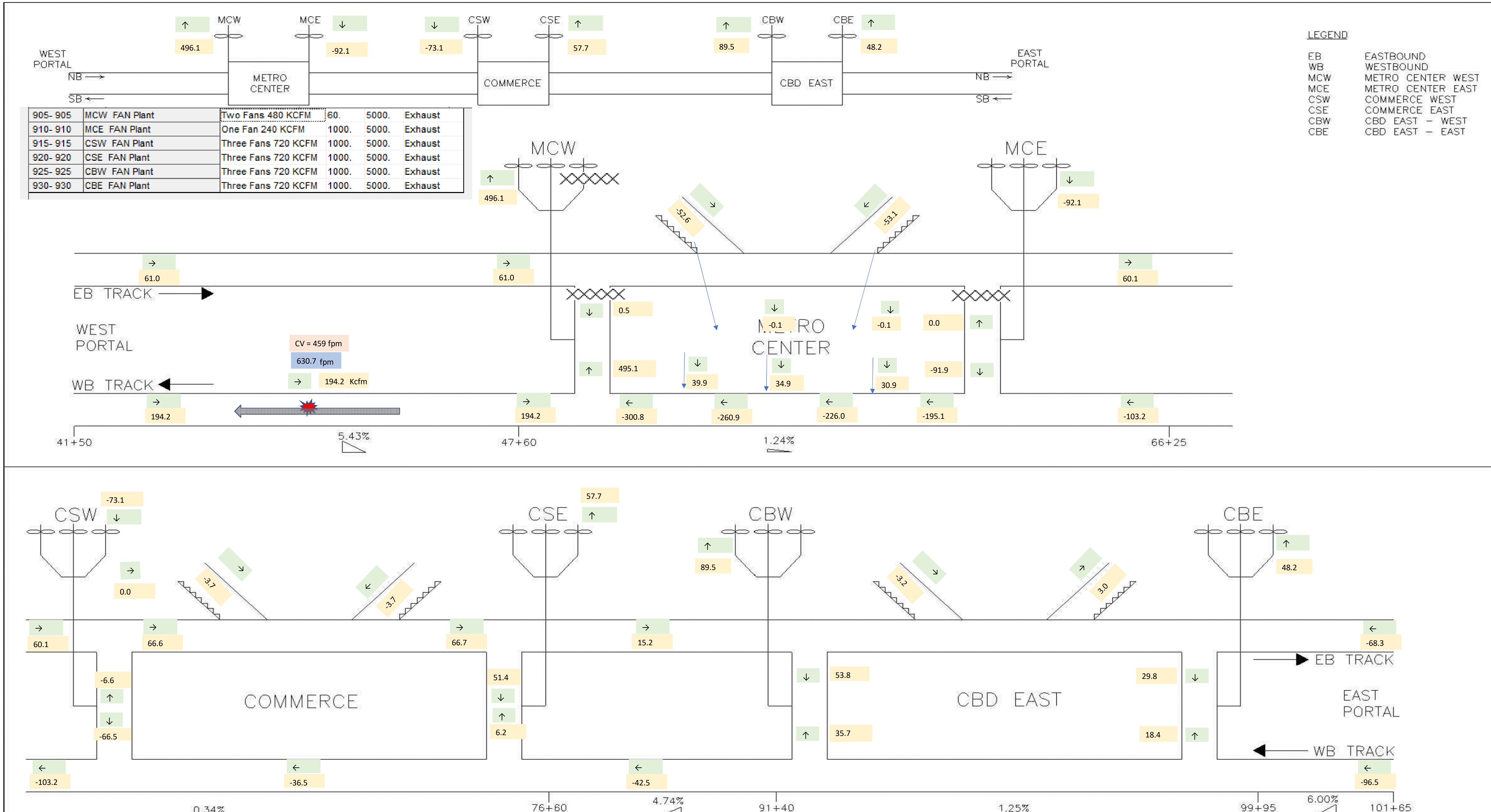

WEST PORTAL
EAST PORTAL
METRO CENTER
COMMERCE
CBD EAST
NB
SB
MCW
MCE
CSW
CSE
CBW
CBE
LEGEND
EB EASTBOUND
WB WESTBOUND
MCW METRO CENTER WEST
MCE METRO CENTER EAST
CSW COMMERCE WEST
CSE COMMERCE EAST
CBW CBD EAST – WEST
CBE CBD EAST – EAST
905- 905 MCW FAN Plant Three Fans 720 KCFM 1000. 5000. Exhaust
910- 910 MCE FAN Plant Three Fans 720 KCFM 1000. 5000. Exhaust
915- 915 CSW FAN Plant Howden axial 1 fan 60. 5000. Exhaust
920- 920 CSE FAN Plant Howden axial 1 fan 60. 5000. Exhaust
925- 925 CBW FAN Plant Three Fans 720 KCFM 1000. 5000. Exhaust
930- 930 CBE FAN Plant Three Fans 720 KCFM 1000. 5000. Exhaust
EB TRACK
WB TRACK
41+50
5.43%
47+60
1.24%
66+25
0.34%
76+60
4.74%
91+40
1.25%
99+95
6.00%
101+65
FAN OPERATING
FAN NOT OPERATING
CLOSED DAMPER
Train
AIRFLOW (kcfm)
SES FILE : O:\61144\Redbook\08_TechProd\SES files\D2_case5.SES
PROJECT : DART D2
SCALE : NTS
DATE :

CASE 6



905- 905	MCW FAN Plant	Two Fans 480 KCFM	60.	5000.	Exhaust
910- 910	MCE FAN Plant	One Fan 240 KCFM	1000.	5000.	Exhaust
915- 915	CSW FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
920- 920	CSE FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
925- 925	CBW FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
930- 930	CBE FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust

CASE 7



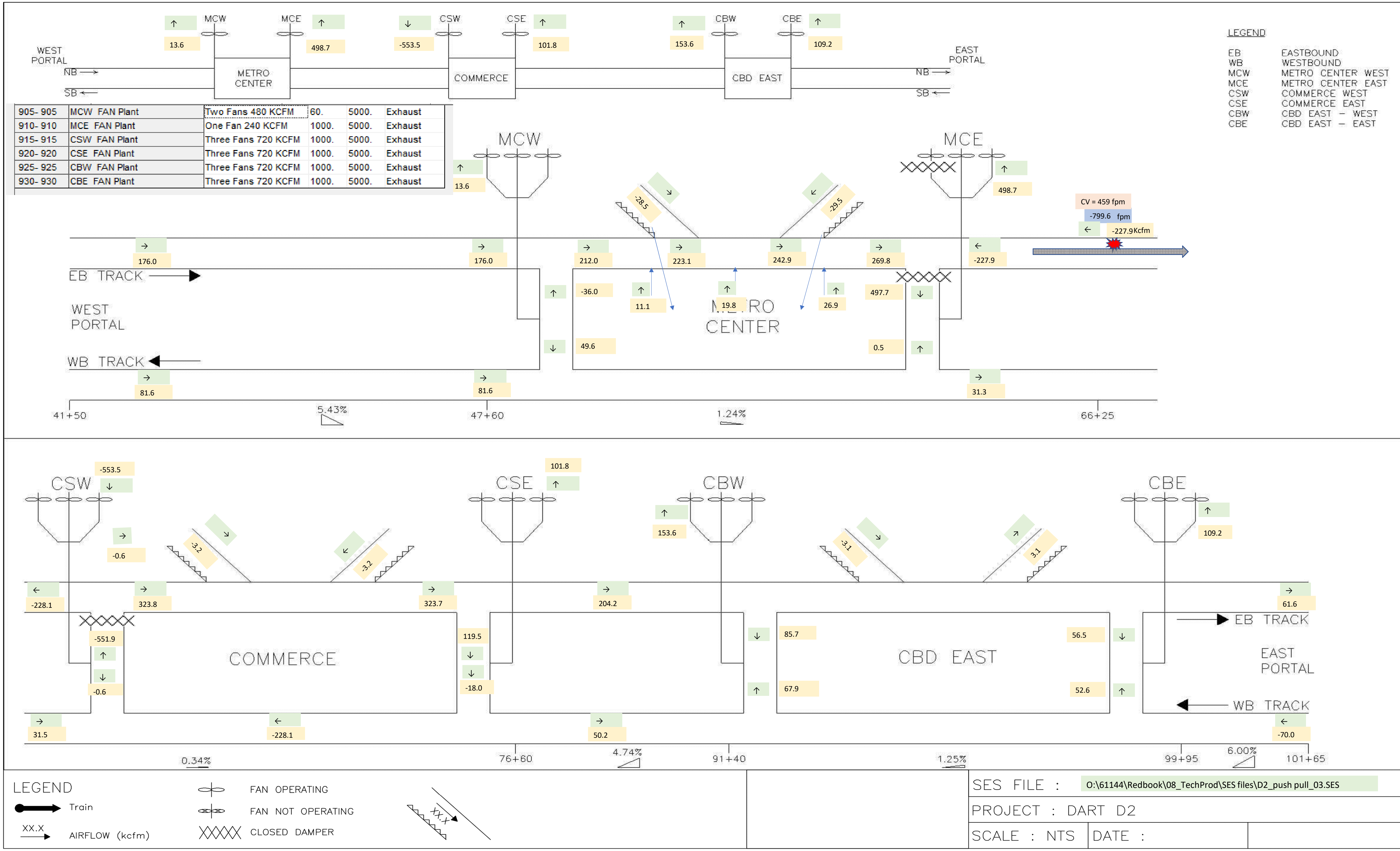
905- 905	MCW FAN Plant	Two Fans 480 KCFM	60.	5000.	Exhaust
910- 910	MCE FAN Plant	One Fan 240 KCFM	1000.	5000.	Exhaust
915- 915	CSW FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
920- 920	CSE FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
925- 925	CBW FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
930- 930	CBE FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust

SES FILE : O:\61144\Redbook\08_TechProd\SES files\D2_push pull_02.SES

PROJECT : DART D2

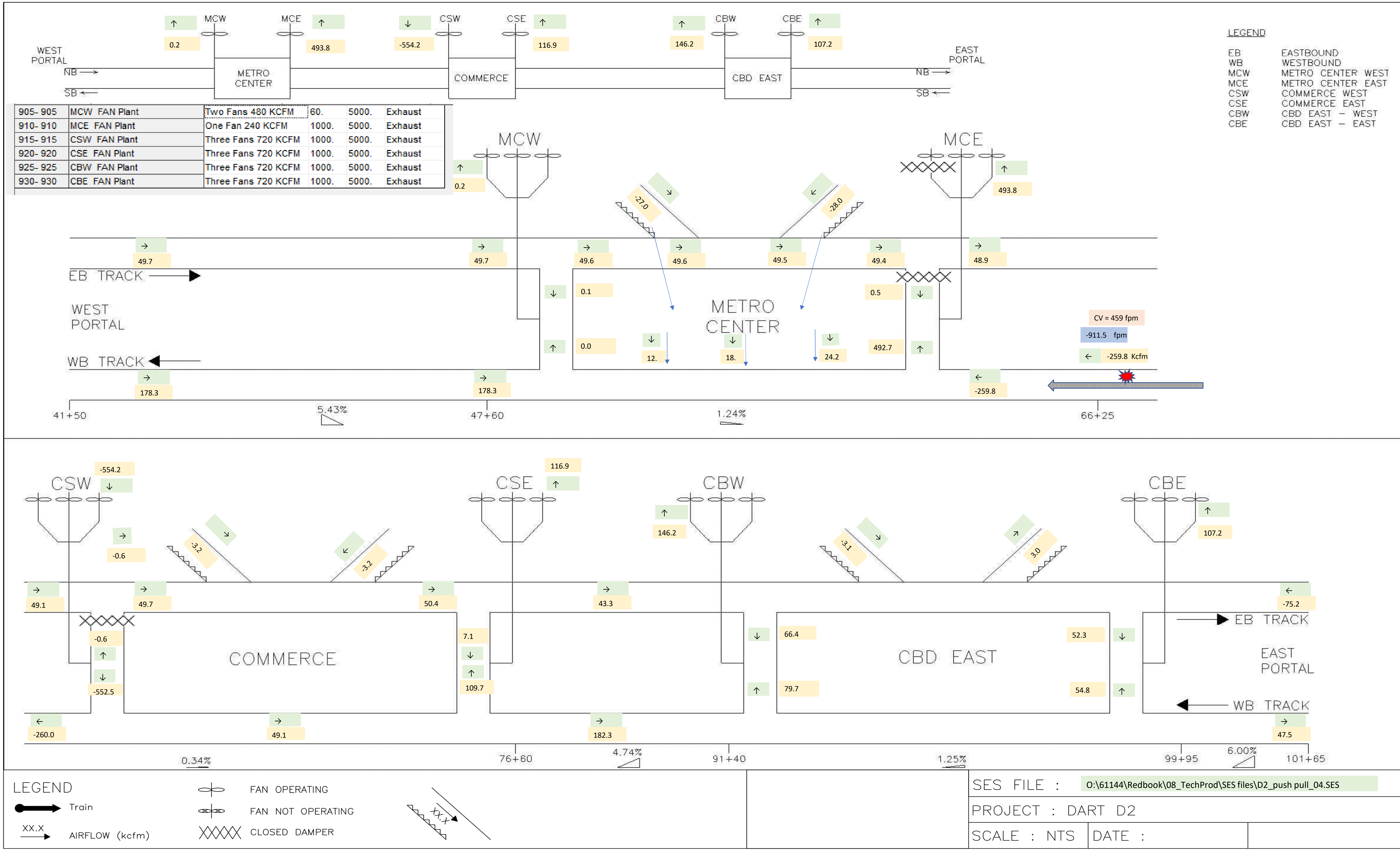
SCALE : NTS | DATE :

CASE 10



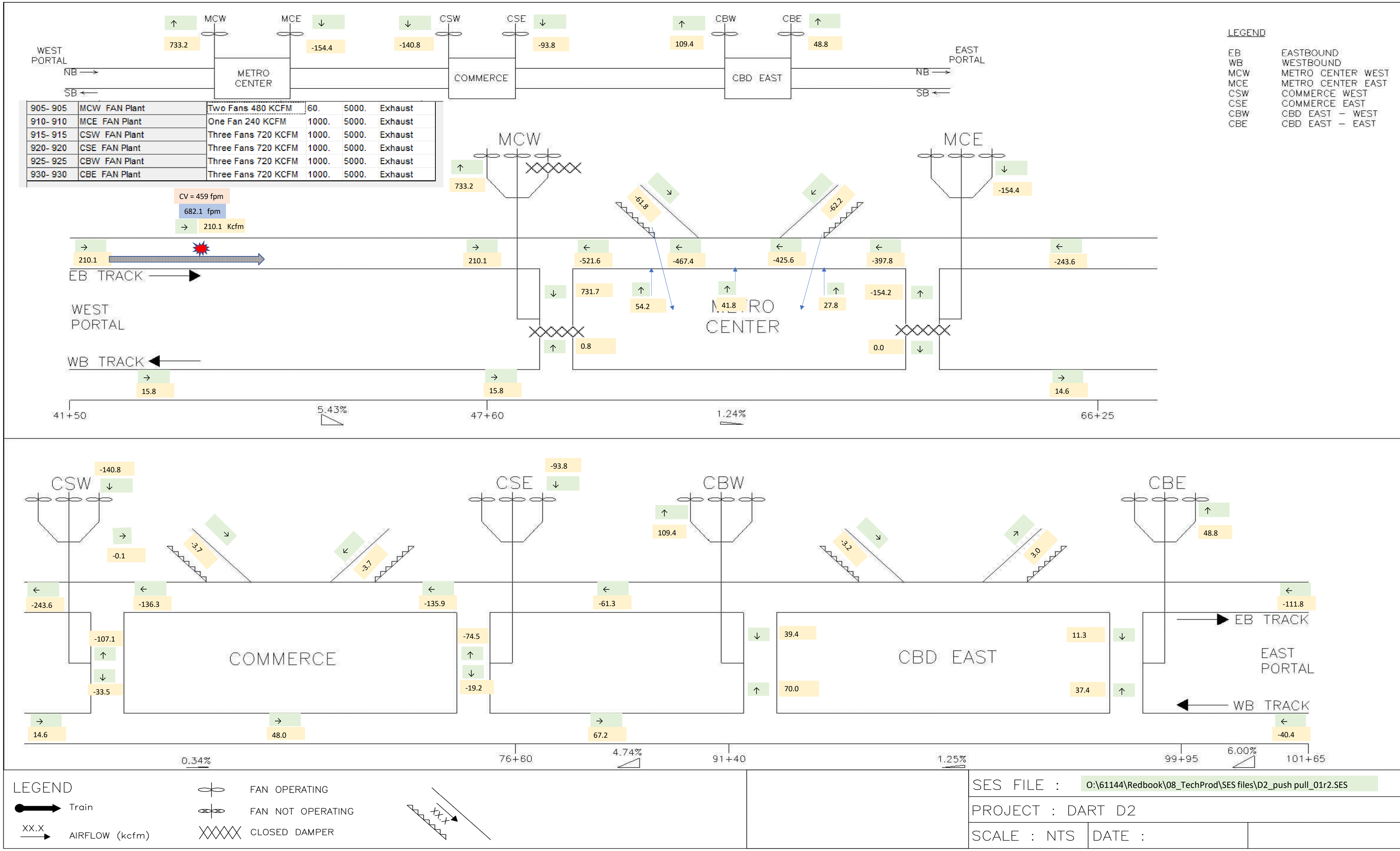
905- 905	MCW FAN Plant	Two Fans 480 KCFM	60.	5000.	Exhaust
910- 910	MCE FAN Plant	One Fan 240 KCFM	1000.	5000.	Exhaust
915- 915	CSW FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
920- 920	CSE FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
925- 925	CBW FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
930- 930	CBE FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust

CASE 11



WEST PORTAL
NB
SB
MCW
MCE
CSW
CSE
CBW
CBE
METRO CENTER
COMMERCE
CBD EAST
EAST PORTAL
0.2
493.8
-554.2
116.9
146.2
107.2
905- 905 MCW FAN Plant Two Fans 480 KCFM 60. 5000. Exhaust
910- 910 MCE FAN Plant One Fan 240 KCFM 1000. 5000. Exhaust
915- 915 CSW FAN Plant Three Fans 720 KCFM 1000. 5000. Exhaust
920- 920 CSE FAN Plant Three Fans 720 KCFM 1000. 5000. Exhaust
925- 925 CBW FAN Plant Three Fans 720 KCFM 1000. 5000. Exhaust
930- 930 CBE FAN Plant Three Fans 720 KCFM 1000. 5000. Exhaust
LEGEND
EB EASTBOUND
WB WESTBOUND
MCW METRO CENTER WEST
MCE METRO CENTER EAST
CSW COMMERCE WEST
CSE COMMERCE EAST
CBW CBD EAST – WEST
CBE CBD EAST – EAST
EB TRACK
WB TRACK
CV = 459 fpm
-911.5 fpm
-259.8 Kcfm
-259.8
41+50
5.43%
47+60
1.24%
66+25
0.34%
76+60
4.74%
91+40
1.25%
99+95
6.00%
101+65
LEGEND
Train
AIRFLOW (kcfm)
XX.X
FAN OPERATING
FAN NOT OPERATING
CLOSED DAMPER
SES FILE : O:\61144\Redbook\08_TechProd\SES files\D2_push pull_04.SES
PROJECT : DART D2
SCALE : NTS
DATE :

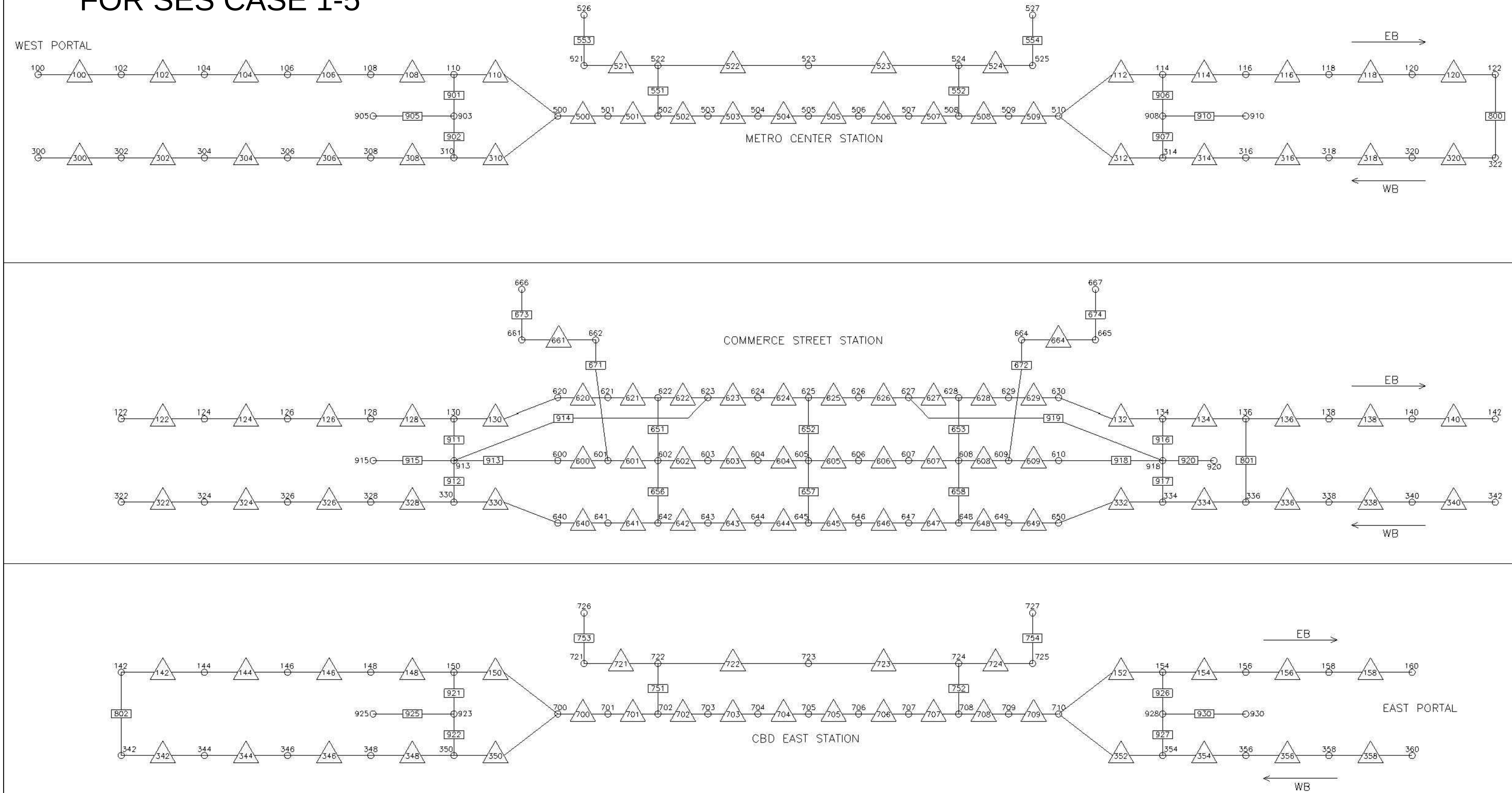
CASE 9



905- 905	MCW FAN Plant	Two Fans 480 KCFM	60.	5000.	Exhaust
910- 910	MCE FAN Plant	One Fan 240 KCFM	1000.	5000.	Exhaust
915- 915	CSW FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
920- 920	CSE FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
925- 925	CBW FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust
930- 930	CBE FAN Plant	Three Fans 720 KCFM	1000.	5000.	Exhaust

Appendix C. Node Network Diagram

FOR SES CASE 1-5



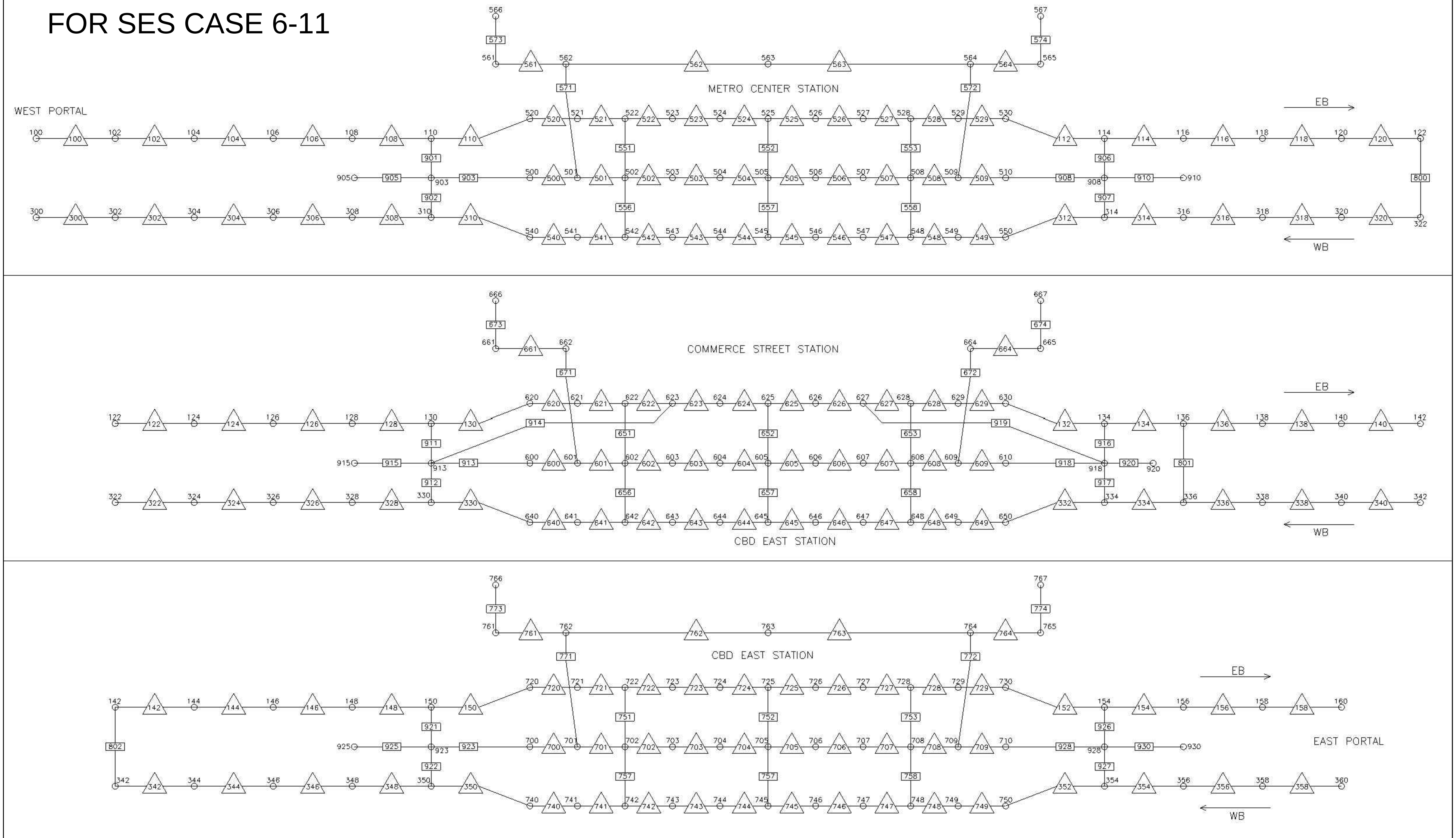
HNTB

SIMULATION RESULTS FLOW DIAGRAM
FIRE SCENARIO AT X

RUN:	DATE	SHEET

SES NODE NETWORK DIAGRAM
DART D2, with PSE only in Commerce Station

FOR SES CASE 6-11



HNTB

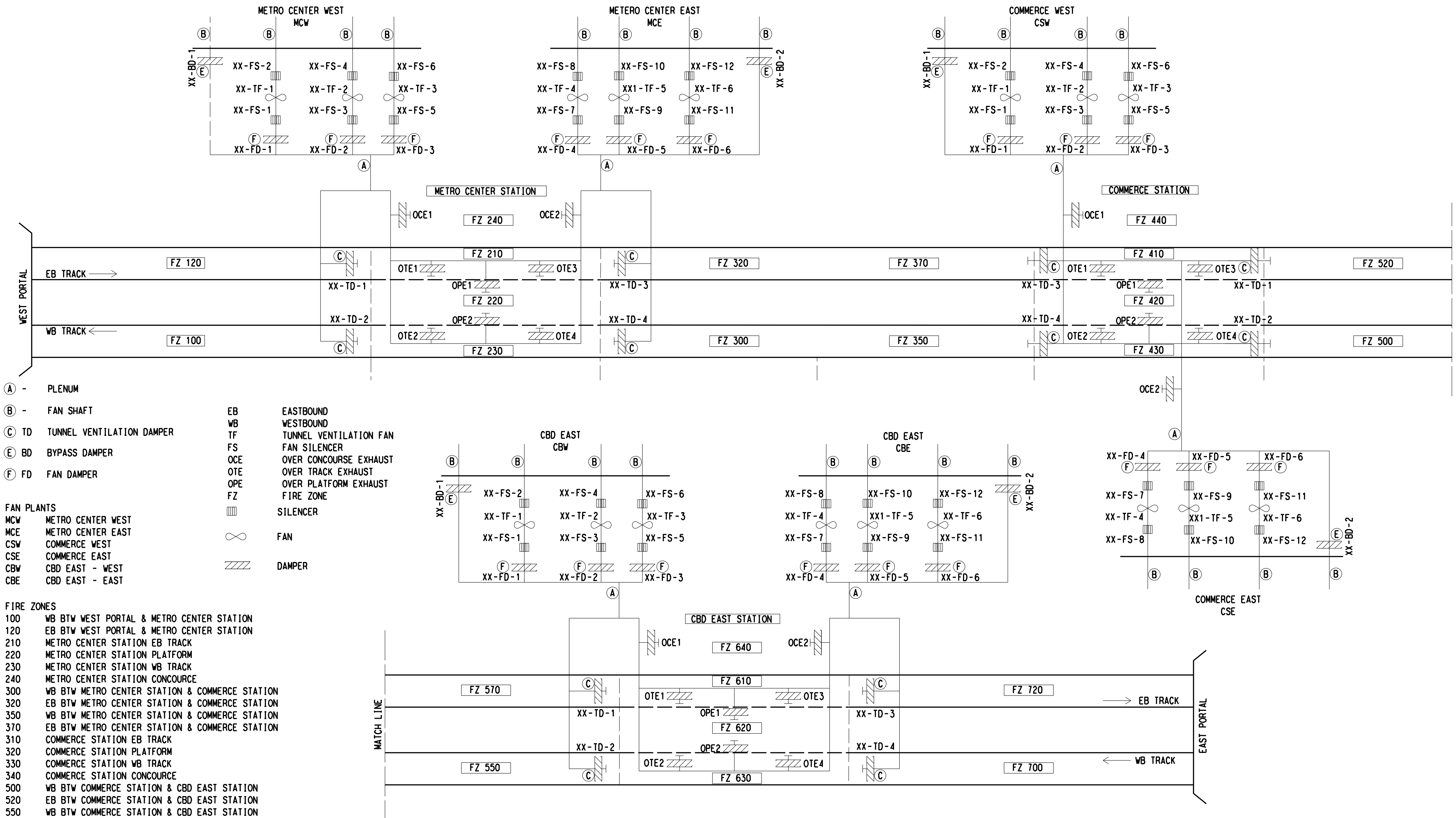
SIMULATION RESULTS FLOW DIAGRAM
FIRE SCENARIO AT X

RUN:	DATE	SHEET

SES NODE NETWORK DIAGRAM
DART D2, with PSE in all stations

Appendix D. Ventilation Schematic

DWG No. MC7-0001



(A) - PLENUM
(B) - FAN SHAFT
(C) TD TUNNEL VENTILATION DAMPER
(E) BD BYPASS DAMPER
(F) FD FAN DAMPER

EB	EASTBOUND
WB	WESTBOUND
TF	TUNNEL VENTILATION FAN
FS	FAN SILENCER
OCE	OVER CONCOURSE EXHAUST
OTE	OVER TRACK EXHAUST
OPE	OVER PLATFORM EXHAUST
FZ	FIRE ZONE

SILENCER
FAN
DAMPER

FAN PLANTS

MCW	METRO CENTER WEST
MCE	METRO CENTER EAST
CSW	COMMERCE WEST
CSE	COMMERCE EAST
CBW	CBD EAST - WEST
CBE	CBD EAST - EAST

FIRE ZONES

100	WB BTW WEST PORTAL & METRO CENTER STATION
120	EB BTW WEST PORTAL & METRO CENTER STATION
210	METRO CENTER STATION EB TRACK
220	METRO CENTER STATION PLATFORM
230	METRO CENTER STATION WB TRACK
240	METRO CENTER STATION CONCOURCE
300	WB BTW METRO CENTER STATION & COMMERCE STATION
320	EB BTW METRO CENTER STATION & COMMERCE STATION
350	WB BTW METRO CENTER STATION & COMMERCE STATION
370	EB BTW METRO CENTER STATION & COMMERCE STATION
310	COMMERCE STATION EB TRACK
320	COMMERCE STATION PLATFORM
330	COMMERCE STATION WB TRACK
340	COMMERCE STATION CONCOURCE
500	WB BTW COMMERCE STATION & CBD EAST STATION
520	EB BTW COMMERCE STATION & CBD EAST STATION
550	WB BTW COMMERCE STATION & CBD EAST STATION
570	EB BTW COMMERCE STATION & CBD EAST STATION
610	CBD EAST STATION EB TRACK
620	CBD EAST STATION PLATFORM
630	CBD EAST STATION WB TRACK
640	CBD EAST STATION CONCOURCE
700	BTW CBD EAST STATION & EAST PORTAL

NOT FOR CONSTRUCTION
NOT AN APPROVED DRAWING
PRELIMINARY 20% DESIGN

CONTRACT SHEET No.

REV	AMEND	CR	DATE	DESCRIPTION	BY	ENG	CHK	APP

IN-PROGRESS

THIS DOCUMENT IS RELEASED FOR THE PURPOSE OF REVIEW UNDER THE AUTHORITY OF: JERRY STEVEN CASEY, P.E. NO. 65588 ON 03/06/2020 HNTB CORPORATION TBPE FIRM NO. F-420 IT IS NOT TO BE USED FOR CONSTRUCTION, BIDDING OR PERMIT PURPOSES.

HNTB

HNTB Corporation
The HNTB Companies
Engineers Architects Planners
TBPE Firm Registration No. 420

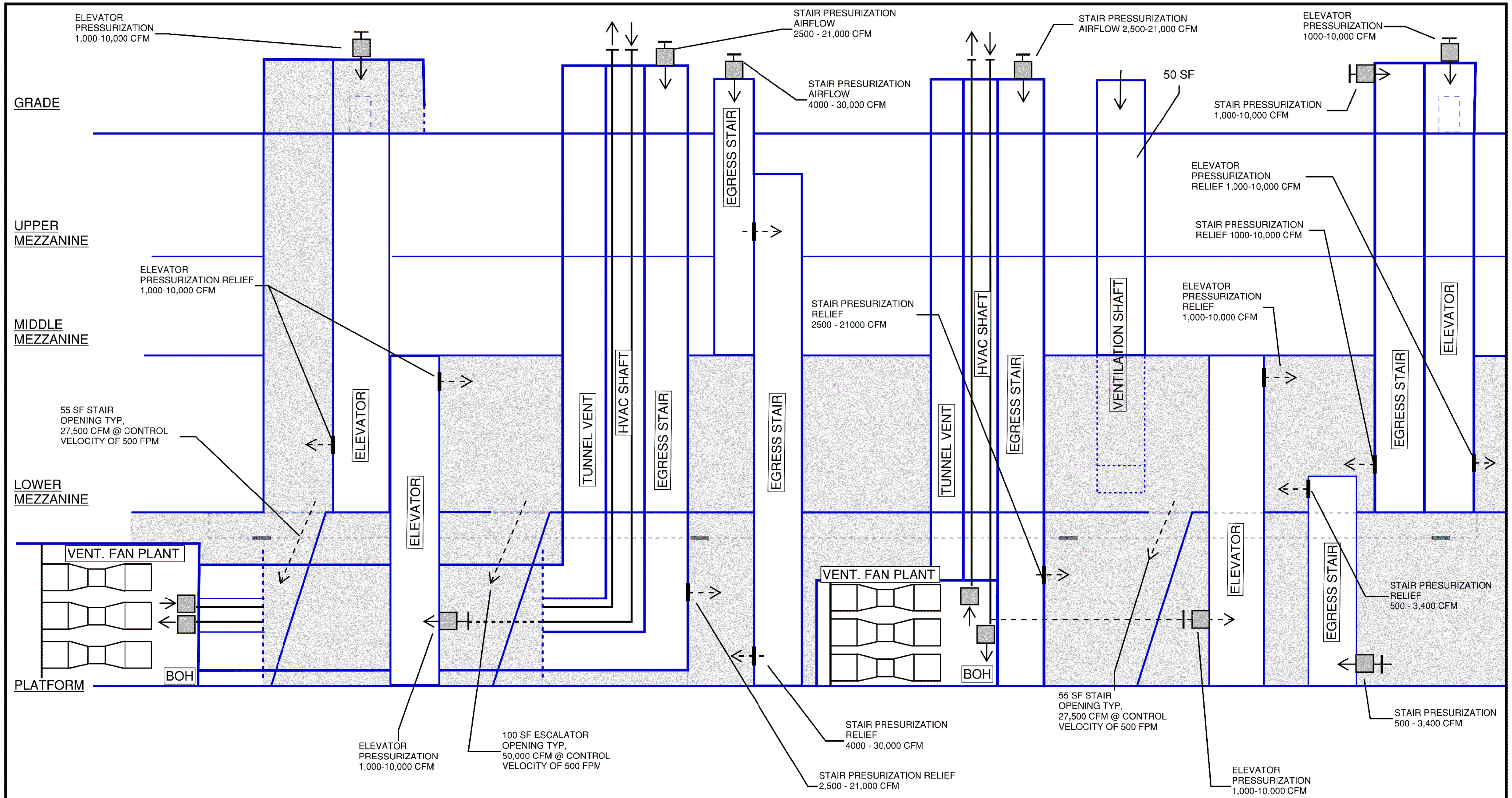
DART PROJECT

SCALE	NTS
DRAWN	S. PARAYIL
DESIGNED	S. PARAYIL
CHECKED	S. CASSADY
IN CHARGE	J. CASEY
DATE	06 MAR 2020

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

SUBWAY SYSTEM
MASTER VENTILATION SCHEMATIC

CONTRACT	DWG No.	REV
	MC7-0001	



COMMERCE STATION AIRFLOW PRESSURIZATION DIAGRAM

Assume Flow Rate 100k CFM

- - -> RELIEF, TRANSFER OR MAKE-UP AIR
—> MECHANICAL VENTILATION
ENVIRONMENTAL VENTILATION FAN
PUBLIC CIRCULATION
BOH BACK OF HOUSE SPACES

NOT FOR CONSTRUCTION
NOT AN APPROVED DRAWING
PRELIMINARY 20% DESIGN

REV	AMEND	CR	DATE	DESCRIPTION	BY	ENG	CHK	APP

IN-PROGRESS

THIS DOCUMENT IS RELEASED FOR THE PURPOSE OF REVIEW UNDER THE AUTHORITY OF: JERRY STEVEN CASEY, P.E. NO. 65588 ON 03/06/2020 HNTB CORPORATION TBPE FIRM NO. F-420 IT IS NOT TO BE USED FOR CONSTRUCTION, BIDDING OR PERMIT PURPOSES.

HNTB
HNTB Corporation
The HNTB Companies
Engineers Architects Planners
TBPE Firm Registration No. 420

DART gpc SIX

DART PROJECT

DART

SCALE NTS
DRAWN S. PARAYIL
DESIGNED S. PARAYIL
CHECKED S. CASSADY
IN CHARGE J. CASEY
DATE 06 MAR 2020

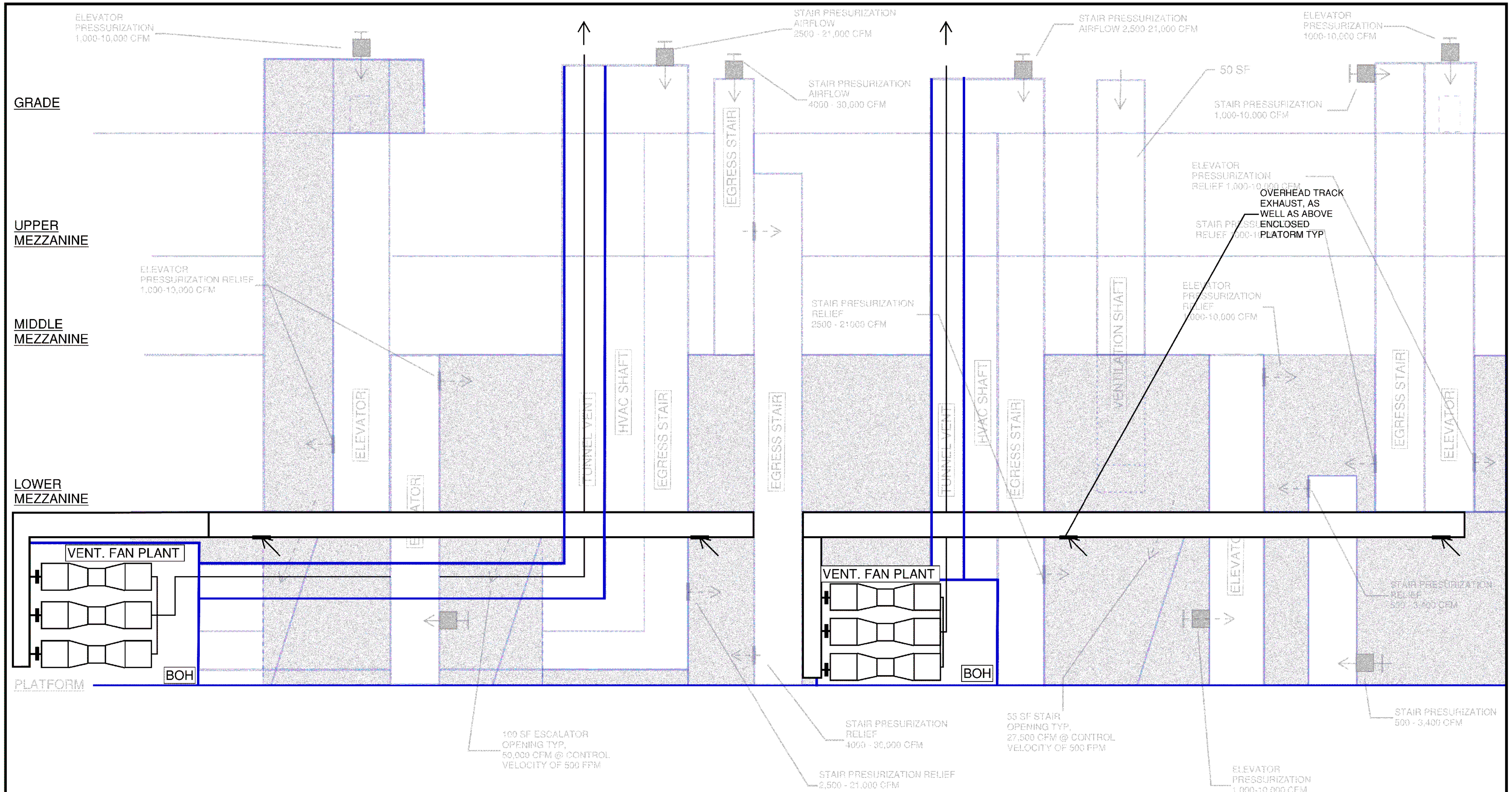
CAES

CONTRACT SHEET No.

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

COMMERCE STATION AIRFLOW PRESSURIZATION DIAGRAM

CONTRACT | DWG No. MC7-0002 | REV



COMMERCE STATION AIRFLOW EMERGENCY VENTILATION DIAGRAM

Assume Flow Rate 100k CFM

RELIEF, TRANSFER OR MAKE-UP AIR
MECHANICAL VENTILATION
ENVIRONMENTAL VENTILATION FAN
PUBLIC CIRCULATION
BOH BACK OF HOUSE SPACES

NOT FOR CONSTRUCTION
NOT AN APPROVED DRAWING
PRELIMINARY 20% DESIGN

REV	AMEND	CR	DATE	DESCRIPTION	BY	ENG	CHK	APP

IN-PROGRESS

THIS DOCUMENT IS RELEASED FOR THE PURPOSE OF REVIEW UNDER THE AUTHORITY OF: JERRY STEVEN CASEY, P.E. NO. 65588 ON 03/06/2020 HNTB CORPORATION TBPE FIRM NO. F-420 IT IS NOT TO BE USED FOR CONSTRUCTION, BIDDING OR PERMIT PURPOSES.

HNTB

HNTB Corporation
The HNTB Companies
Engineers Architects Planners
TBPE Firm Registration No. 420

DART PROJECT

SCALE	NTS
DRAWN	S. PARAYIL
DESIGNED	S. PARAYIL
CHECKED	S. CASSADY
IN CHARGE	J. CASEY
DATE	06 MAR 2020

CONTRACT SHEET No.

LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

COMMERCE STATION AIRFLOW
EMERGENCY VENTILATION DIAGRAM

CONTRACT	DWG No.	REV
	MC7-0003	

Appendix E. CFD Simulation Tracker

DART D2

made by: tvt date: 12/20/2017

File/Simulation Location: \\seaw00\jobs2\62726\Analysis\FLS\CFD Simulations

Key:	
	Yellow highlight indicates a successful and reliable simulation
	Pending Simulations (Antcipated)
	Currently Running Simulation(s)
	Simulations that need to be restarted

		Simulation Data						Fire Characterstic Inputs				Smoke Characterstic Inputs				Boundary/Induced Conditions							
	Submitted Report (Date)	Rev #	Date	Sim. Comp.	#Main Meshes	Cell Ct.(main mesh) $(*10^3)$	Time to Fin (s)	Fire Size (MW)	Fire Curve	Growth Rate (s)	Fire Loc.	CO Yield (kg/kg)	Soot Yield (kg)kg)	Vis. Factor	Max. Vis. (m)	Sth Track Dpr (kCFM)	Nth Track Dpr (kCFM)	Sth OPE (kCFM)	Nth OPE (kCFM)	NW/SW Prtls (kCFM) - Ea	NE/SE Prtls (kCFM) - Ea	West Stair (kcfm)	East Stair (kcfm)
Commerce Station 20%	TBD	rev1	2/12/2020	SEAD909	4	3800	N/a	14.9	14.9 MW/120 sec	120	South Trk Center Train	0.14	0.165	TBD	30 m	TBD	N/a	N/a	-100	N/a	N/a	Open	Open
		rev2	2/13/2020	SEAD909	4	3800	N/a	14.9	14.9 MW/120 sec	120	South Trk Center Train	0.14	0.165	TBD	30 m	TBD	N/a	N/a	-100	(N/a)/(50)	N/a	Open	Open
		rev3	2/13/2020	SEAD909	4	3800	N/a	14.9	14.9 MW/120 sec	120	South Trk Center Train	0.14	0.165	TBD	30 m	TBD	N/a	N/a	-100	N/a	N/a	Open	Open
		rev4	2/13/2020	SEAD909	4	3800	N/a	14.9	14.9 MW/120 sec	120	South Trk Center Train	0.14	0.165	TBD	30 m	TBD	N/a	N/a	-100	N/a	N/a	Open	Open
		rev5	2/13/2020	SEAD909	4	3800	N/a	14.9	14.9 MW/120 sec	120	South Trk Center Train	0.14	0.165	TBD	30 m	TBD	N/a	N/a	-100	N/a	N/a	TBD	TBD
		Case 1	2/18/2020	SEAD909	4	3800	1200	14.9	1.055 MW at 300 sec	T-squared medium growth	South Trk Center Train	0.14	0.165	TBD	30 m	130	CLOSED	CLOSED	CLOSED	12.4/55.4 kcfm	-12.1/42.9 kcfm	Open	Open
		Case 2	2/20/2020	SEAD909	4	try to reduce to <2 mil?	1200	14.9	1.055 MW at 300 sec	T-squared medium growth	South Trk Center Train	0.14	0.165	TBD	30 m	110	CLOSED	45	CLOSED	11.9/57.1 kcfm	-11.6/40.4 kcfm	Open	Open
		Case 3	2/21/2020	SEAD909	4	3800	1200	14.9	1.055 MW at 300 sec	T-squared medium growth	South Trk Center Train	0.14	0.165	TBD	30 m	110	CLOSED	45	45	11.6 /74.7 kcfm	-11.2/66.2 kcfm	Open	Open
		Case 4	2/24/2020	SEAD909	4	try to reduce to <2 mil?	1200	3.5	1.055 MW at 75 sec	T-squared Ultrafast growth	Trackway fire	0.14	0.165	TBD	30 m	130	CLOSED	CLOSED	CLOSED	10.2/67.3 kcfm	-10/39.1 kcfm	Open	Open
		Case 5	2/26/2020	SEAD909	4	try to reduce to <2 mil?	1200	3.5	1.055 MW at 75 sec	T-squared Ultrafast growth	Platform fire	0.14	0.165	TBD	30 m	CLOSED	CLOSED	45	45	11.7/32.8 kcfm	-10.7/-31.1 kcfm	Open	Open

CFD Supporting File Links					Simulation Notes - Consolidated Changes for simulation
Scheme File	User Defined Function (UDF Files)	Mesh	File Name	SES File Used	
O:\61144\Analysis\CFD\Scheme\DART_master.scm	\\sead909\E$\DATA909_61144_DART_D2\DART_slow_FGR_2.c	O:\61144\Analysis\CFD\Mesh\200123_DART_D2_Commerce_Station_r7_1.msh	\\sead909\E$\DATA909_61144_DART_D2\200123_DART_D2_Commerce_Station_r7_3.cas	N/a	Test Fire Case, Middle train fire. Growth Rate 14.9 MW/ 120 sec, exhaust 100 KCFM split between 2 fan plants. 2 station dampers open. Failed Flow Rates too high
O:\61144\Analysis\CFD\Scheme\DART_master.scm	\\sead909\E$\DATA909_61144_DART_D2\DART_slow_FGR_2.c	O:\61144\Analysis\CFD\Mesh\200123_DART_D2_Commerce_Station_r7_1.msh	\\sead909\E$\DATA909_61144_DART_D2\200123_DART_D2_Commerce_Station_r7_4.cas	N/a	Test Fire Case, Middle train fire. Growth Rate 14.9 MW/ 120 sec, exhaust 100 KCFM split between 2 fan plants. 2 station dampers open. Induced 50kcfm from SW portal. Flow Rates Diverged as soon as fire started
O:\61144\Analysis\CFD\Scheme\DART_master.scm	\\sead909\E$\DATA909_61144_DART_D2\UDF_BSV_VLB_Station_3fire.c	O:\61144\Analysis\CFD\Mesh\200123_DART_D2_Commerce_Station_r7_1.msh	\\sead909\E$\DATA909_61144_DART_D2\200123_DART_D2_Commerce_Station_r7_5.cas	N/a	Test Fire Case, Middle train fire. Growth Rate 14.9 MW/ 120 sec, exhaust 100 KCFM split between 2 fan plants. 2 station dampers open. Using previous UDF from BART Silicon Valley VLB Station. Flow Rates Diverged..
O:\61144\Analysis\CFD\Scheme\DART_master.scm	\\sead909\E$\DATA909_61144_DART_D2\DART_slow_FGR_2.c	O:\61144\Analysis\CFD\Mesh\200123_DART_D2_Commerce_Station_r7_1.msh	\\sead909\E$\DATA909_61144_DART_D2\200123_DART_D2_Commerce_Station_r7_6.cas	N/a	Test Fire Case, Middle train fire. Growth Rate 14.9 MW/ 120 sec, exhaust 100 KCFM split between 2 fan plants. 2 station dampers open. Opened up Platform screen door wall Flow Diverged
O:\61144\Analysis\CFD\Scheme\DART_master.scm	\\sead909\E$\DATA909_61144_DART_D2\DART_slow_FGR_2.c	O:\61144\Analysis\CFD\Mesh\200123_DART_D2_Commerce_Station_r8.msh	\\sead909\E$\DATA909_61144_DART_D2\200123_DART_D2_Commerce_Station_r8_3.cas	N/a	Test Fire Case, Middle train fire. Growth Rate 14.9 MW/ 120 sec, exhaust 100 KCFM split between 2 fan plants. 2 station dampers open. Moved Train away from Platform Edge
O:\61144\Analysis\CFD\Scheme\DART_master.scm	\\sead909\E$\DATA909_61144_DART_D2\DART_slow_FGR_2.c	O:\61144\Analysis\CFD\Mesh\200123_DART_D2_Commerce_Station_r9.msh	\\sead909\E$\DATA909_61144_DART_D2\200123_DART_D2_Commerce_Station_r9_1.cas	\\seaw00\jobs2\61144\Redbook\08_TechProd\20%_Cncpt_Dsgn_Rpt\dart SES\SES post\D2_case1.xlsm	Closed Gap in wall discovered in rev5, added Enclosed Platform Damper to mesh, Closed for this simulation. 130KCFM exhaust split between 2 fan plants, middle train fire, 14.9 MW, Simulation starts 4 minutes after fire has started, fans are on at this point. smoke enters platform simulation fail
O:\61144\Analysis\CFD\Scheme\DART_master.scm	\\sead909\E$\DATA909_61144_DART_D2\DART_slow_FGR_2.c	O:\61144\Analysis\CFD\Mesh\200123_DART_D2_Commerce_Station_r9.msh	\\sead909\E$\DATA909_61144_DART_D2\200123_DART_D2_Commerce_Station_r9_1.cas	\\seaw00\jobs2\61144\Redbook\08_TechProd\20%_Cncpt_Dsgn_Rpt\dart SES\SES post\D2_case1.xlsm	Closed Gap in wall discovered in rev5, added Enclosed Platform Damper to mesh, Closed for this simulation. 130KCFM exhaust split between 2 fan plants, middle train fire, 14.9 MW, Simulation starts 4 minutes after fire has started, fans are on at this point

Appendix F. Critical Velocity Calculation

PROJECT NAME: DART D2

Vehicle Tunnel Smoke Backlayering Calculation Station Area

14.69 MW LOAD

Description	Value	Variable	Units				
Critical Velocity Constant	0.606	K1	none				
Grade Factor	1.0	K2	none				
Acceleration of Gravity	32.2	g	ft/(sec^2)				
Height of the tunnel	16	H	ft				
Fire Energy Load	13941	Q	Btu/sec	949	14.69	MW	
Specific heat of air	0.24	Cp	Btu/(lb*F)				
Perpendicular area of tunnel	230	A	ft^2				
Initial guess Average temp of fire site gases	1200	Tf	R				
Average Temperature of approach air	539.33	Ti	R	459	80.33	DEG F	from CFD model (300K)
Density of air	0.0735	rho	lb/(ft^3)				From engineering toolbox

Iteration constant 2

Units	R	FPS	R			
	Iterative Solution					
	Tf	Vc	Tfit			
	1200	6.881795	1038.628			
	1119.314	7.043169	1027.188			
	1073.251	7.142423	1020.409			
	1046.83	7.201954	1016.432			
	1031.631	7.237115	1014.114			
	1022.872	7.257692	1012.768			
	1017.82	7.269669	1011.988			
	1014.904	7.276618	1011.537			
	1013.22	7.280642	1011.276			
	1012.248	7.282971	1011.125			
	1011.686	7.284317	1011.037			
	1011.362	7.285095	1010.987			
	1011.175	7.285544	1010.958			
	1011.066	7.285804	1010.941			
	1011.004	7.285954	1010.931			
	1010.968	7.286041	1010.926			
	1010.947	7.286091	1010.923			
	1010.935	7.28612	1010.921			
	1010.928	7.286136	1010.92			
	1010.924	7.286146	1010.919			
	1010.921	7.286152	1010.919			
	1010.92	7.286155	1010.918			
	1010.919	7.286157	1010.918			
	1010.919	7.286158	1010.918			
	1010.919	7.286158	1010.918			
	1010.918	7.286159	1010.918	459	551.92	DEG F

Velocity for smoke backlayering	437.17	FPM

REQUIRED AIRFLOW DOWN TUNNEL TO PREVENT SMOKE BACKLAYERING

100,549 CFM

TOTAL REQUIRED SMOKE EVACUATION FLOW

201098

Flow splits to each fan plant 100,549

Considering Fire Site Temperatures Flow Capacity Expansion 6.870637

Assume duct smoke cooling and air mixture cools effective temperature of smoke inlet into ventilation system

Fire Site Temperature Expansion Factor 3 301647

$$V_c = K_1 K_g \left(\frac{gHQ}{\rho C_p A T_f} \right)^{1/3}$$

$$T_f = \left(\frac{Q}{\rho C_p A V_c} \right) + T \quad \textbf{(D.1)}$$

where:

V_c = critical velocity [m/sec (fpm)]
K_1 = 0.606 (Froude number factor, $Fr^{-1/3}$)
K_g = grade factor *(see Figure D.1)*
g = acceleration caused by gravity [m/sec^2 (ft/sec^2)]
H = height of duct or tunnel at the fire site [m (ft)]
Q = heat fire is adding directly to air at the fire site [MW (Btu/sec)]
ρ = average density of the approach (upstream) air [kg/m^3 (lb/ft^3)]
C_p = specific heat of air [kJ/kg K (Btu/lb°R)]
A = area perpendicular to the flow [m^2 (ft^2)]
T_f = average temperature of the fire site gases [K (°R)]
T = temperature of the approach air [K (°R)]

Figure D.1 provides the grade factor for (K_g) in equation D.1.

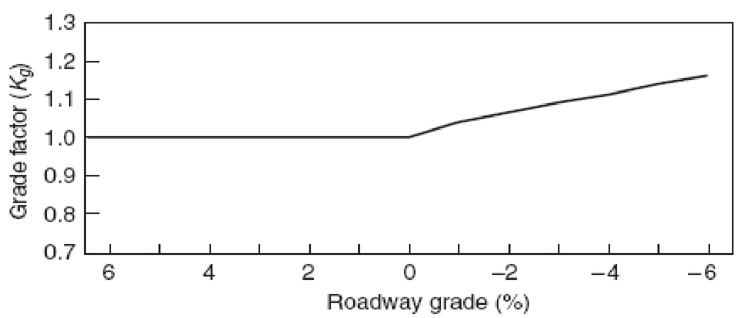


FIGURE D.1 Grade Factor for Determining Critical Velocity.

HNTB	Made By: SSP	Date: 2/14/2020	Job Number: 61144			
			Sheet No.: 1	1		
			File Name:			

\\seaw00\jobs2\61144\Redbook\08_TechProd\20%_Cncpt_Dsgn_Rpt\dart SES\[cr_vel_ for DART D

PROJECT NAME: DART D2

Vehicle Tunnel Smoke Backlayering Calculation — Tunnel Area

14.69 MW LOAD

Description	Value	Variable	Units			
Critical Velocity Constant	0.606	K1	none			
Grade Factor	1.0	K2	none			
Acceleration of Gravity	32.2	g	ft/(sec^2)			
Height of the tunnel	16	H	ft			
Fire Energy Load	13941	Q	Btu/sec	949	14.69 MW	
Specific heat of air	0.24	Cp	Btu/(lb*F)			
Perpendicular area of tunnel	285	A	ft^2			
Initial guess Average temp of fire site gases	1200	Tf	R			
Average Temperature of approach air	539.33	Ti	R	459	80.33 DEG F	from CFD model (300K)
Density of air	0.0735	rho	lb/(ft^3)			From engineering toolbox

Iteration constant 2

Units R	FPS	R		
Iterative Solution				
Tf	Vc	Tfit		
1200	6.407576	972.0937		
1086.047	6.624049	957.951		
1021.999	6.759493	949.5629		
985.7809	6.841199	944.6633		
965.2221	6.889382	941.8286		
953.5253	6.91741	940.1977		
946.8615	6.933583	939.2626		
943.0621	6.942873	938.7275		
940.8948	6.948194	938.4216		
939.6582	6.951238	938.2469		
938.9525	6.952977	938.1471		
938.5498	6.95397	938.0901		
938.32	6.954538	938.0576		
938.1888	6.954861	938.0391		
938.1139	6.955046	938.0285		
938.0712	6.955152	938.0224		
938.0468	6.955212	938.019		
938.0329	6.955246	938.017		
938.0249	6.955266	938.0159		
938.0204	6.955277	938.0152		
938.0178	6.955283	938.0149		
938.0163	6.955287	938.0146		
938.0155	6.955289	938.0145		
938.015	6.95529	938.0145		
938.0147	6.955291	938.0144		
938.0146	6.955291	938.0144	459	479.01 DEG F

Velocity for smoke backlayering	417.32 FPM

REQUIRED AIRFLOW DOWN TUNNEL TO PREVENT SMOKE BACKLAYERING

118,935 CFM

TOTAL REQUIRED SMOKE EVACUATION FLOW

237871

Flow splits to each fan plant 118,935

Considering Fire Site Temperatures Flow Capacity Expansion 5.963082

Assume duct smoke cooling and air mixture cools effective temperature of smoke inlet into ventilation system

Fire Site Temperature Expansion Factor 3 356806.5

$$V_c = K_1 K_g \left(\frac{gHQ}{\rho C_p A T_f} \right)^{1/3}$$
$$T_f = \left(\frac{Q}{\rho C_p A V_c} \right) + T \qquad \textbf{(D.1)}$$

where:

V_c = critical velocity [m/sec (fpm)]
K_1 = 0.606 (Froude number factor, Fr $^{-1/3}$)
K_g = grade factor *(see Figure D.1)*
g = acceleration caused by gravity [m/sec^2 (ft/sec^2)]
H = height of duct or tunnel at the fire site [m (ft)]
Q = heat fire is adding directly to air at the fire site [MW (Btu/sec)]
ρ = average density of the approach (upstream) air [kg/m^3 (lb/ft^3)]
C_p = specific heat of air [kJ/kg K (Btu/lb°R)]
A = area perpendicular to the flow [m^2 (ft^2)]
T_f = average temperature of the fire site gases [K (°R)]
T = temperature of the approach air [K (°R)]

Figure D.1 provides the grade factor for (K_g) in equation D.1.

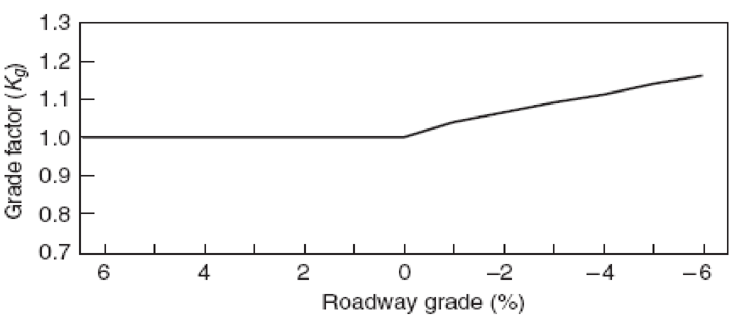


FIGURE D.1 Grade Factor for Determining Critical Velocity.

Pass Fail Criteria

Case No	Tunnel Configuration	Height of Tunnel	Tunnel Cross Sectional Area	Fire load	Derived Values [4] Critical Vel. [1]	Critical Vel. + 10% F.S. [2]	Critical Airflow	Notes
		(ft)	(sq. Ft)	(MW)	(fpm)	(fpm)	(kcfm)	
1	Tunnel track	16	285	14.9	417	459	131	1
2	Station Track	16	230	14.9	437	481	111	1
1	Tunnel track	16	175	14.9	417	459	80	5
2	Station Track	16	120	14.9	437	481	58	5

Notes:

[1] Critical velocity for full area is used

[2] Added 10% factor of safety per BFS Criteria - Mechanical Line Sections, page 12 of 18

[3] Fourde number used for critical velocity calculation is 0.85 per interpolation based on a fire load of 15 MW.

[4] Fourde number used for critical velocity calculation is 0.606 per interpolation based on a fire load of 15 MW.

[5] Annular area = tunnel area minus train area