Appendix 4.4g **Detailed Calculations of In-Tunnel Air Quality along Tuen Mun Road Town Centre Section near Tsing Sin Playground**

One-way Enclosure - Normal Condition

Tunnel Parameter

Length L	=	112	m	
Height H	=	6	m	
Width W	=	15	m	
Cross-sectional area A_T = H x W =				90 m^2
Perimeter P	=	42	m	

Emission Data

Traffic Breakdown (%)

Tunnel Traffic (Link no.)	Traffic flow (veh/hr)	Motor Cycles	Petrol PC &LGV	Taxi	Non-franchised Buses <6.4t	Non-franchised Buses 6.4-15t	Non-franchised Buses >15t	Private Light Buses <3.5t	Private Light Buses >3.5t	Diesel PC&LGV <2.5t	Diesel LGV 2.5-3.5t	Diesel LGV >3.5t	HGV<15t	HGV>15t	Single Deck Franchised Buses	Double Deck Franchised Buses	Public Light Buses
135	3538	0.02	0.45	0.06	0	0.03	0	0	0.01	0.01	0.09	0.07	0.19	0.01	0	0.02	0.04
137	1178	0.02	0.25	0.02	0	0.03	0	0	0.01	0.01	0.05	0.04	0.39	0.02	0.01	0.06	0.09
Total	4716	0.02	0.40	0.05	0.00	0.03	0.00	0.00	0.01	0.01	0.08	0.06	0.24	0.01	0.00	0.03	0.05
NOx Emission Factor (g/mile)		1.14	0.28	0.28	0.00	7.07	0.00	0.00	0.82	1.07	0.59	3.76	7.89	10.01	5.44	5.81	0.77

Total NO_2 emission rate = total NO_X emission factor x traffic flow x tunnel length x NO_2 conversion factor
where conversion factor = 12.5% (including tailpipe NO_2 emission taken as 7.5% of NO_X and 5% of NO_2/NO_X for tunnel air)

Weighted NOX E.F. (g/km/veh)	=	1.807	g/km/veh
Total NO_2 emission factor (g/s)	=	3.31E-02	g/sec

Vehicle Data

Nominal dimensions of vehicles are given in Transport Planning and Design Manual, Vol. 2 as:

	W /m	H /m	L /m
Motor Cycles	1.7	1.5	4.6
Petrol PC &LGV	1.7	1.5	4.6
Taxi	1.7	1.5	4.6
Non-franchised Buses <6.4t	2.5	3.5	12
Non-franchised Buses 6.4-15t	2.5	3.5	12
Non-franchised Buses >15t	2.5	3.5	12
Private Light Buses <3.5t	2	3	6.5
Private Light Buses >3.5t	2	3	6.5
Diesel PC&LGV <2.5t	2.1	1.6	5.2
Diesel LGV 2.5-3.5t	2.1	1.6	5.2
Diesel LGV >3.5t	2.1	1.6	5.2
HGV<15t	2.5	4.6	16
HGV>15t	2.5	4.6	16
Single Deck Franchised Buses	2.5	3.5	12
Double Deck Franchised Buses	2.5	4.6	12
Public Light Buses	2	3	6.5

* No dimensions for motor cycles and non-franchised buses are provided.
* For the purpose of this study, the dimensions of motor cycles and taxi are assumed to be the same as private car and the dimension of non-franchised buses are assumed to be the same as single deck franchised buses.

Nominal cross-sectional area A_C = (1.7*1.5*0.02)+(1.7*1.5*0.4)+(1.7*1.5*0.05)+(2.5*3.5*0.03)+(2*3*0.01)+(2.1*1.6*0.01)+(2.1*1.6*0.08)+(2.1*1.6*0.06)+(2.5*4.6*0.24)+(2.5*4.6*0.01)+(2.5*4.6*0.03)+(2*3*0.05)

= 5.6185 m^2

Appendix 4.4g **Detailed Calculations of In-Tunnel Air Quality along Tuen Mun Road Town Centre Section near Tsing Sin Playground**

Tunnel Airflow

For Uni-directional Traffic,

Push Force by vehicles: $$F_C = \frac{1}{2}\rho\,(V_C - V_T)^2\,C_d\,A_C\,N$$

Resisting Force by tunnel: $$F_T = \frac{1}{2}\rho\,V_T^2\,(K_{in} + K_{out} + \frac{fL}{D})\,A_T$$

External Wind at the Entrance and Exit Portals: $$F_W = \frac{1}{2}\rho\,C_W(V_W\cos\theta)^2\,A_T$$

where ρ	=	Air density	=	1.2	kg/m^3
V_C	=	Velocity of vehicle, m/s			
V_T	=	Velocity of air flow in tunnel, m/s			
C_d	=	Vehicle drag coefficient	=	0.645	
A_C	=	Vehicle frontal area	=	5.61851285	m^2
N	=	No. of vehicles in tunnel			
K_{in}	=	Inlet loss coefficient	=	0.5	
K_{out}	=	Outlet loss coefficient	=	1.0	
f	=	Tunnel friction factor	=	0.0155	
L	=	Length of tunnel	=	112	m
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	8.57142857	m, P is the Perimeter of tunnel
A_T	=	Cross-sectional area of tunnel	=	90	m^2
C_W	=	External wind coefficient	=	0.3	
$V_{W(ref)}$	=	Velocity of wind at Tuen Mun Station	=	2.36	m/s (Weighted average of 2006 Tuen Mun Station data)
θ	=	Angle of the wind velocity component parallel to the roadway			

For the worst scenario, only external wind at the exit portal is considered and the wind is parallel to the roadway.

Force balance : $$F_C - F_T - F_W = 0 \qquad (1)$$

Solving the equation, $$a\,V_T^2 + b\,V_T + c = 0$$

where

$$a = C_d A_C N - (K_{in} + K_{out} + \frac{fL}{D})A_T$$

$$b = -2\,C_d\,A_c\,N\,V_c$$

$$c = C_d A_C N V_c^2 - C_w V_w^2 A_T$$

For normal traffic condition

traffic flow Q	=	1.31	veh/s	
Vehicle speed V_C	=	50	km/h	
	=	13.88888889	m/s	
Number of vehicles in tunnel N	=	QL/V_C		
	=	10.56384		

Solving for V_T by equation (1)

a = -114.95
b = -1063.41
c = 7234.98

tunnel air flow velocity V_T = 4.557969503 m/sec or -13.809409 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x tunnel cross-sectional area)

NO_2 = 81 ug/m^3

Appendix 4.4g **Detailed Calculations of In-Tunnel Air Quality along Tuen Mun Road Town Centre Section near Tsing Sin Playground**

One-way Enclosure - Worse Condition

Tunnel Parameter

Length L	=	112	m
Height H	=	6	m
Width W	=	15	m
Cross-sectional area A_T = H x W =		90	m^2
Perimeter P	=	42	m

Emission Data

		Traffic Breakdown (%)																
Tunnel Traffic (Link no.)	Traffic flow (veh/hr)	Motor Cycles	Petrol PC &LGV	Taxi	Non-franchised Buses <6.4t	Non-franchised Buses 6.4-15t	Non-franchised Buses >15t	Private Light Buses <3.5t	Private Light Buses >3.5t	Diesel PC&LGV <2.5t	Diesel LGV 2.5-3.5t	Diesel LGV >3.5t	HGV<15t	HGV>15t	Single Deck Franchised Buses	Double Deck Franchised Buses	Public Light Buses
135	3538	0.02	0.45	0.06	0	0.03	0	0	0.01	0.01	0.09	0.07	0.19	0.01	0	0.02	0.04
137	1178	0.02	0.25	0.02	0	0.03	0	0	0.01	0.01	0.05	0.04	0.39	0.02	0.01	0.06	0.09
Total	4716	0.02	0.40	0.05	0.00	0.03	0.00	0.00	0.01	0.01	0.08	0.06	0.24	0.01	0.00	0.03	0.05
NOx Emission Factor (g/mile)		1.02	0.38	0.38	0.00	10.41	0.00	0.00	1.21	1.55	0.86	5.57	11.82	15.06	9.45	10.26	1.14

Total NO_2 emission rate = total NO_X emission factor x traffic flow x tunnel length x NO_2 conversion factor
where conversion factor = 12.5% (including tailpipe NO_2 emission taken as 7.5% of NO_X and 5% of NO_2/NO_X for tunnel air)

Weighted NOX E.F. (g/km/veh)	=	2.712	g/km/veh
Total NO_2 emission factor (g/s)	=	4.97E-02	g/sec

Vehicle Data

Nominal dimensions of vehicles are given in Transport Planning and Design Manual, Vol. 2 as:

	W /m	H /m	L /m
Motor Cycles	1.7	1.5	4.6
Petrol PC &LGV	1.7	1.5	4.6
Taxi	1.7	1.5	4.6
Non-franchised Buses <6.4t	2.5	3.5	12
Non-franchised Buses 6.4-15t	2.5	3.5	12
Non-franchised Buses >15t	2.5	3.5	12
Private Light Buses <3.5t	2	3	6.5
Private Light Buses >3.5t	2	3	6.5
Diesel PC&LGV <2.5t	2.1	1.6	5.2
Diesel LGV 2.5-3.5t	2.1	1.6	5.2
Diesel LGV >3.5t	2.1	1.6	5.2
HGV<15t	2.5	4.6	16
HGV>15t	2.5	4.6	16
Single Deck Franchised Buses	2.5	3.5	12
Double Deck Franchised Buses	2.5	4.6	12
Public Light Buses	2	3	6.5

* No dimensions for motor cycles and non-franchised buses are provided.
* For the purpose of this study, the dimensions of motor cycles and taxi are assumed to be the same as private car and the dimension of non-franchised buses are assumed to be the same as single deck franchised buses.

Nominal cross-sectional area A_C = (1.7*1.5*0.02)+(1.7*1.5*0.4)+(1.7*1.5*0.05)+(2.5*3.5*0.03)+(2*3*0.01)+(2.1*1.6*0.01)+(2.1*1.6*0.08)+(2.1*1.6*0.06)+(2.5*4.6*0.24)+(2.5*4.6*0.01)+(2.5*4.6*0.03)+(2*3*0.05)

= 5.6185 m^2

Appendix 4.4g **Detailed Calculations of In-Tunnel Air Quality along Tuen Mun Road Town Centre Section near Tsing Sin Playground**

Tunnel Airflow

For Uni-directional Traffic,

Push Force by vehicles: $$F_C = \frac{1}{2}\rho\ (V_C - V_T)^2\ C_d\ A_C\ N$$

Resisting Force by tunnel: $$F_T = \frac{1}{2}\rho\ V_T^2\ (K_{in} + K_{out} + \frac{fL}{D})\ A_T$$

External Wind at the Entrance and Exit Portals: $$F_W = \frac{1}{2}\rho\ C_W (V_W \cos\theta)^2\ A_T$$

where ρ	=	Air density	=	1.2	kg/m^3
V_C	=	Velocity of vehicle, m/s			
V_T	=	Velocity of air flow in tunnel, m/s			
C_d	=	Vehicle drag coefficient	=	0.645	
A_C	=	Vehicle frontal area	=	5.61851285	m^2
N	=	No. of vehicles in tunnel			
K_{in}	=	Inlet loss coefficient	=	0.5	
K_{out}	=	Outlet loss coefficient	=	1.0	
f	=	Tunnel friction factor	=	0.0155	
L	=	Length of tunnel	=	112	m
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	8.57142857	m, P is the Perimeter of tunnel
A_T	=	Cross-sectional area of tunnel	=	90	m^2
C_W	=	External wind coefficient	=	0.3	
$V_{W(ref)}$	=	Velocity of wind at Tuen Mun Station	=	2.36	m/s (Weighted average of 2006 Tuen Mun Station data)
θ	=	Angle of the wind velocity component parallel to the roadway			

For the worst scenario, only external wind at the exit portal is considered and the wind is parallel to the roadway.

Force balance : $$F_C - F_T - F_W = 0 \qquad (1)$$

Solving the equation, $$a\ V_T^2 + b\ V_T + c = 0$$

where

$$a = C_d A_c N - (K_{in} + K_{out} + \frac{fL}{D}) A_T$$

$$b = -2\ C_d\ A_c\ N\ V_c$$

$$c = C_d A_c N V_c^2 - C_w V_w^2 A_T$$

For congested traffic condition

Vehicle speed Vc	=	10	km/h
	=	2.777777778	m/s
average length of vehicle	=	(4.6*0.02)+(4.6*0.4)+(4.6*0.05)+(12*0.03)+(6.5*0.01)+(5.2*0.01)+(5.2*0.08)+(5.2*0.06)+(16*0.24)+(16*0.01)+(12*0.03)+(6.5*0.05)	
	=	8.150652672	m
distance between vehicle	=	1	m
head to head length	=	9.150652672	m
Number of vehicles per lane	=	12.23956411	
Number of lanes	=	4	
Number of vehicles in tunnel N	=	48.95825643	

Solving for V_T by equation (1)

a	=	24.19
b	=	-985.68
c	=	1219.19

tunnel air flow velocity V_T = 1.27693325 m/sec or 39.4639127 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x tunnel cross-sectional area)

NO_2 = 433 ug/m^3

Appendix 4.4g Detailed Calculations of In-Tunnel Air Quality along Tuen Mun Road Town Centre S along Tuen Mun Road Town Centre Section near Tsing Sin Playground

Overall Concentrations

Four assessment points (ASRs I1-I4) at the boundary of the enclosure are chosen.
Using CALINE4 and ISCST3 model, the air pollutants concentrations at the 4 assessment points at different levels are calculated.
The highest concentration among the four assessment points is assumed to be the background concentration inside the proposed enclosure section.

Elevation	NO2 Concentrations (ug/m3) at Various Levels	
	(mAG)	NO_2
I1	0.0	238
	3.0	252
	6.0	269
I2	0.0	262
	3.0	274
	6.0	285
I3	0.0	377
	3.0	342
	6.0	310
I4	0.0	243
	3.0	246
	6.0	248

Therefore, the NO2 background concentration inside the enclosure is 377 ug/m^3

Total Maximum NO2 concentration inside enclosure of Tuen Mun Road near Tsing Sin Playground (Normal Speed) = **81 + 377**
= **458** **ug/m3**

Total Maximum NO2 concentration inside enclosure of Tuen Mun Road near Tsing Sin Playground (Worse Case) = **433 + 377**
= **810** **ug/m3**