Appendix 4.4h   **Detailed Calculations of In-Tunnel Air Quality**
along Tuen Mun Road Town Centre Section near Kam Fai Garden

One-way Enclosure - Normal Condition
Tunnel Parameter

Length L	=	180	m	
Height H	=	8	m	
Width W	=	15	m	
Cross-sectional area A_T = H x W =			120	m^2
Perimeter P	=	46 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
177	5514	0.02	0.40	0.05	0.00	0.03	0.00	0.00	0.01	0.01	0.08	0.06	0.25	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

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)	=	1.826	g/km/veh
NO_2 emission factor inside tunnel (g/s)	=	6.29E-02	g/sec
NO_2 emission factor transferred from Enclosure I (g/s)	=	20% x IJ	(Note: For the amount of IJ in normal condition, please refer to Appendix 4.4)
	=	1.11E-02	g/sec
Total NO2 emission (g/s)	=	7.40E-02	

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*0.25)+(2.5*4.6*0.01)+(2.5*4.6*0.03)+(2*3*0.05)

= 5.6600 m^2

Appendix 4.4h　　　　　　**Detailed Calculations of In-Tunnel Air Quality**
　　　　　　　　　　　　　　along Tuen Mun Road Town Centre Section near Kam Fai Garden

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/m³
　　　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　　　　　　　=　　　5.66 m²
　　　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　　　　　　　　=　　　180 m
　　　D　=　Hydraulic diameter of tunnel =　　　$4A_T/P$ =　10.4347826 m, P is the Perimeter of tunnel
　　　A_T　=　Cross-sectional area of tunnel　　　=　　　120 m²
　　　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 :　　　　$F_C - F_T - F_W = 0$　　　　　　(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　=　　　1.531666667 veh/s
　　　　　　　Vehicle speed V_C　=　　　　　50 km/h
　　　　　　　　　　　　　=　　　13.88888889 m/s
　　　Number of vehicles in tunnel N　=　　　　QL/V_C
　　　　　　　　　　　　　=　　　　19.8504
　　　　　Solving for V_T by equation (1)
　　　　　　　　　　　a　=　-139.62
　　　　　　　　　　　b　=　-2013.00
　　　　　　　　　　　c　=　13779.40

　　　　tunnel air flow velocity V_T　=　　　5.065527839 m/sec　　　or　　　　　-19.483499 m/sec
　　　　　　　　　　　　　　　　　　　　　　　　　　　　　　　(rejected)

　　　Inside tunnel concentration　=　emission rate / (tunnel air flow x tunnel cross-sectional area)
　　　　　　　　NO_2　=　　　　122 ug/m³

Appendix 4.4h   **Detailed Calculations of In-Tunnel Air Quality**
along Tuen Mun Road Town Centre Section near Kam Fai Garden

One-way Enclosure - Worse Condition
Tunnel Parameter

Length L	=	180	m
Height H	=	8	m
Width W	=	15	m
Cross-sectional area $A_T = H \times W =$		120	m^2
Perimeter P	=	46	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
177	5514	0.02	0.40	0.05	0.00	0.03	0.00	0.00	0.01	0.01	0.08	0.06	0.25	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

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)	=	2.737	g/km/veh
NO_2 emission factor inside tunnel (g/s)	=	9.43E-02	g/sec
NO_2 emission factor transferred from Enclosure I (g/s)	=	20% x IJ	(Note: For the amount of IJ in worse condition, please refer to Appendix 4.4)
	=	1.80E-02	g/sec
Total NO2 emission (g/s)	=	1.12E-01	

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*0.25)+(2.5*4.6*0.01)+(2.5*4.6*0.03)+(2*3*0.05)

= 5.6600 m^2

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		=	5.66 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		=	180 m
D	=	Hydraulic diameter of tunnel =	4A_T/P =	10.4347826 m, P is the Perimeter of tunnel
A_T	=	Cross-sectional area of tunnel		=	120 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 : $F_C - F_T - F_W = 0$ (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*0.25)+(16*0.01)+(12*0.03)+(6.5*0.05)		
=	8.212 m		
distance between vehicle =	1 m		
head to head length =	9.212 m		
Number of vehicles per lane =	19.53973079		
Number of lanes =	4		
Number of vehicles in tunnel N =	78.15892314		

Solving for V_T by equation (1)

a	=	73.25
b	=	-1585.19
c	=	2001.92

tunnel air flow velocity V_T =   1.346691391 m/sec   or   20.2942365 m/sec
                                                                    (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x tunnel cross-sectional area)
NO_2 =   695 ug/m^3

**Appendix 4.4h   Detailed Calculations of In-Tunnel Air Quality
                     along Tuen Mun Road Town Centre Section near Kam Fai Garden**

Overall Concentrations

Four assessment points (ASRs J1-J4) 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	
J1	0.0	392	
	4.0	358	
	8.0	302	
J2	0.0	434	
	4.0	381	
	8.0	316	
J3	0.0	288	
	4.0	308	
	8.0	307	
J4	0.0	236	
	4.0	240	
	8.0	239	

Therefore, the NO2 background concentration inside the enclosure is   434 ug/m^3

Total Maximum NO2 concentration inside enclosure of
Tuen Mun Road near Kam Fai Garden (Normal Speed)   =   122 + 434
                                                          =   556   ug/m3

Total Maximum NO2 concentration inside enclosure of
Tuen Mun Road near Kam Fai Garden (Worse Case)   =   695 + 434
                                                          =   1129   ug/m3