Appendix 3.12
In-Tunnel Air Quality Assessment

Appendix 3.12a **Detailed Calculation of In-Tunnel Air Quality**

Deckover along Expo Drive Central

Tunnel Parameter

Length L	= 153	m	
Height H	= 7.5	m	
Width W	= 6	m	
Cross-sectional area $A_T = H \times W$ =			45 m^2
Perimeter P	=	27 m	

Emission Data

Traffic flow = 467 veh/hr

Traffic Breakdown	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
% vehicle	0.04	0.42	0.37	0.00	0.13	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NOx Emission Factor (g/mile)	1.06	0.15	0.26	0.00	4.72	3.66	0.00	0.34	0.42	0.27	2.22	4.60	6.02	2.47	2.82	0.12

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) = 0.516 g/km/veh
Total NO_2 emission factor (g/s) = 1.28E-03 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*0.04)+(1.7*1.5*0.42)+(1.7*1.5*0.37)+(2.5*3.5*0.13)+(2*3*0.04)

= 3.4940 m^2

Appendix 3.12a **Detailed Calculation of In-Tunnel Air Quality**
Deckover along Expo Drive Central

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	=	3.494	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	=	153	m
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	6.666667	m, P is the Perimeter of tunnel
A_T	=	Cross-sectional area of tunnel	=	45	m^2
C_W	=	External wind coefficient	=	0.3	
$V_{W(rel)}$	=	Velocity of wind at Central Station	=	2.1	m/s (Weighted average of 2005 Central Station data)
$V_{W(s)}$	=	Velocity of wind at source	=	1.75	m/s
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 : $$F_C - F_T - F_W = 0 \quad (1)$$

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

where

$$a = C_d A_c N - (K_{in} + K_{out} + \frac{fL}{D})A_T$$
$$b = -2\,C_d A_c N V_c$$
$$c = C_d A_c N V_c^{\,2} - C_w V_w^{\,2} A_T$$

<u>For normal traffic condition</u>

traffic flow Q = 0.12972222 veh/s
Vehicle speed V_C = 50 km/h
= 13.8888889 m/s
Number of vehicles in tunnel N = QL/V_C
= 1.42902

Solving for V_T by equation (1)
a = -80.29
b = -89.46
c = 579.99

tunnel air flow velocity V_T = 2.18776916 m/sec or -3.30199 m/sec (rejected)

Inside tunnel concentration = emission rate / (tunnel air flow x underpass cross-sectional area)
NO_2 = 13 ug/m^3

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Appendix 3.12a **Detailed Calculation of In-Tunnel Air Quality**
Deckover along Expo Drive Central

Tunnel Parameter

Length L	= 153	m	
Height H	= 7.5	m	
Width W	= 6	m	
Cross-sectional area A_T = H x W =			45 m^2
Perimeter P	=	27 m	

Emission Data

Traffic flow = 467 veh/hr

Traffic Breakdown	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
% vehicle	0.04	0.42	0.37	0.00	0.13	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NOx Emission Factor (g/mile)	0.909	0.214	0.382	0.000	6.061	12.404	0.000	0.524	0.639	0.418	3.461	7.111	8.795	4.935	5.573	0.162

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) = 0.669 g/km/veh
Total NO_2 emission factor (g/s) = 1.66E-03 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*0.04)+(1.7*1.5*0.42)+(1.7*1.5*0.37)+(2.5*3.5*0.13)+(2*3*0.04)

= 3.4940 m^2

Appendix 3.12a — **Detailed Calculation of In-Tunnel Air Quality**
Deckover along Expo Drive Central

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	=	3.494 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	=	153 m
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	6.666667 m, P is the Perimeter of tunnel
A_T	=	Cross-sectional area of tunnel	=	45 m^2
C_W	=	External wind coefficient	=	0.3
$V_{W(ref)}$	=	Velocity of wind at Central Station	=	2.1 m/s (Weighted average of 2005 Central Station data)
$V_{W(s)}$	=	Velocity of wind at source	=	1.75 m/s
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
	=	2.77777778 m/s
average length of vehicle	=	(4.6*0.04)+(4.6*0.42)+(4.6*0.37)+(12*0.13)+(6.5*0.04)
	=	5.638 m
distance between vehicle	=	1 m
head to head length	=	6.638 m
Number of vehicles per lane	=	23.0491112
Number of lanes	=	2
Number of vehicles in tunnel N	=	46.0982224

Detailed Calculation of In-Tunnel Air Quality
Deckover along Expo Drive Central

Solving for V_T by equation (1)

a = 20.38
b = -577.16
c = 760.37

tunnel air flow velocity V_T = 1.38518908 m/sec or 26.93362 m/sec (rejected)

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

NO_2 = 27 ug/m^3

Background Concentration

Two assessment points (ASRs PE1&PE2) at the boundary of the deckover are chosen and shown in Figure A3.12.
Using CALINE4 and ISCST3 model, the air pollutants concentrations at the 2 assessment points at different levels are calculated.
The highest concentration among the two assessment points is assumed to be the background concentration inside the deckover section.

Predicted Concentrations (ug/m^3) at Various Levels

	(mAG)	NO2
PE1	**0**	101
	3.75	94
	7.5	86
PE2	**0**	94
	3.75	90
	7.5	85

Therefore, the NO2 background concentration inside the proposed deckover section is 101 ug/m^3

Total Maximum NO2 concentration inside the proposed deckover section (Normal Speed) = **13 + 101**
= **114** **ug/m^3**

Total Maximum NO2 concentration inside the proposed deckover section (Worse Case) = **27 + 101**
= **128** **ug/m^3**

Appendix 3.12b Detailed Calculation of In-Tunnel Air Quality
Deckover along P2 Road and CWB Tunnel

P2 Road & CWB Tunnel - Normal condition

Tunnel Parameter

Tunnel length (m), L	=	136
Tunnel height (m), H	=	7.5
Tunnel width (m), W	=	48
Tunnel size (m2), At	=	H * W
		360
Equivalent diameter (m), dt	=	(4*At/π)^0.5
		21.4095
Effective length of the tunnel (m), Le	=	L + 2*3*dt
		264.457

Emission Data

Traffic Breakdown (%)

Tunnel traffic	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
CWB to IEC Link	1634	0.06	0.61	0.26	0.00	0.05	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
P2 (EB)	420	0.04	0.37	0.34	0.00	0.12	0.00	0.00	0.03	0.02	0.02	0.02	0.03	0.00	0.00	0.01	0.00
CWB from IEC Link	1490	0.05	0.55	0.30	0.00	0.01	0.00	0.00	0.00	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00
P2 (WB)	1086	0.04	0.44	0.39	0.00	0.05	0.00	0.00	0.01	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0.00
Total	4630	0.05	0.53	0.31	0.00	0.04	0.00	0.00	0.01	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0.00
NOx Emission Factor (g/km)		1.06	0.15	0.26	0.00	4.72	3.66	0.00	0.34	0.42	0.27	2.22	4.60	6.02	2.47	2.82	0.12

Weighted NOX E.F. (g/km/veh)	=	0.3161
NO2 emission factor per unit length (g/m/s)	=	12.5% * Weight NOX E.F. * Traffic flow
	=	5.08E-05

Vehicle Data

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

	W	H	L
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.

Appendix 3.12b Detailed Calculation of In-Tunnel Air Quality Deckover along P2 Road and CWB Tunnel

P2 Road & CWB Tunnel - Normal condition

Nominal cross-sectional area (m2)	= (1.7*1.5*0.05)+(1.7*1.5*0.53)+(1.7*1.5*0.31)+(2.5*3.5*0.04)+(2*3*0.01)+(2.1*1.6*0.02)+(2.1*1.6*0.02)+(2.1*1.6*0.02)+(2.5*4.6*0.01)	
	= 2.964716	
Number of lanes per direction, nl	= 7	
Equivalent cross-sectional area for each direction (m2), Av	=	20.7530095
Equivalent diameter of vehicle (m), dv	= (4*Av/π)^0.5	
	= 5.140387	
Traffic density (traffic flow /s), N	= 1.286111	
Average vehicle speed (m/s), v	= 50 km/hr	
	= 13.88889	
Head to head distance on a lane (m), l	= 2*nl*v/N	
	= 151.1879	

Diffusion Parameters

Reynolds number, Re	= (v*dv)/σ	where σ = 15.6*10^-6
	= 4576555	
According to Figure 16 (Ohashi and Koso)		
Since l / dt	= 7.061721	
D / (N * dt^2 * Re^0.13)	= 0.38	
Longitudinal diffusion coefficient (m2/s), D	= 0.38 * (N * dt^2 * Re^0.13)	
	= 1644.921	

Maximum Concentration of NO2

Cmax (μg/m3)	= w * Le^2 / (8 * D * At)
(without background)	= 1

Appendix 3.12b Detailed Calculation of In-Tunnel Air Quality Deckover along P2 Road and CWB Tunnel

P2 Road & CWB Tunnel - Worse condition

Tunnel Parameter

Tunnel length (m), L	=	136
Tunnel height (m), H	=	7.5
Tunnel width (m), W	=	48
Tunnel size (m2), At	=	H * W
		360
Equivalent diameter (m), dt	=	(4*At/π)^0.5
		21.4095
Effective length of the tunnel (m), Le	=	L + 2*3*dt
		264.457

Emission Data

Traffic Breakdown (%)

Tunnel traffic	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
CWB to IEC Link	1634	0.06	0.61	0.26	0.00	0.05	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
P2 (EB)	420	0.04	0.37	0.34	0.00	0.12	0.00	0.00	0.03	0.02	0.02	0.02	0.03	0.00	0.00	0.01	0.00
CWB from IEC Link	1490	0.05	0.55	0.30	0.00	0.01	0.00	0.00	0.00	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00
P2 (WB)	1086	0.04	0.44	0.39	0.00	0.05	0.00	0.00	0.01	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0.00
Total	4630	0.05	0.53	0.31	0.00	0.04	0.00	0.00	0.01	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0.00
NOx Emission Factor (g/km)		0.91	0.21	0.38	0.00	6.06	12.40	0.00	0.52	0.64	0.42	3.46	7.11	8.80	4.93	5.57	0.16

Weighted NOX E.F. (g/km/veh)	=	0.4221
NO2 emission factor per unit length (g/m/s)	=	12.5% * Weight NOX E.F. * Traffic flow
	=	6.79E-05

Vehicle Data

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

	W	H	L
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.

Appendix 3.12b Detailed Calculation of In-Tunnel Air Quality Deckover along P2 Road and CWB Tunnel

P2 Road & CWB Tunnel - Worse condition

Nominal cross-sectional area (m2)	= (1.7*1.5*0.05)+(1.7*1.5*0.53)+(1.7*1.5*0.31)+(2.5*3.5*0.04)+(2*3*0.01)+(2.1*1.6*0.02)+(2.1*1.6*0.02)+(2.1*1.6*0.02)+(2.5*4.6*0.01)
	= 2.964716
Number of lanes per direction, nl	= 7
Equivalent cross-sectional area for each direction (m2), Av	= 20.75301
Equivalent diameter of vehicle (m), dv	= (4*Av/π)^0.5
	= 5.140387
Equivalent length of each vehicle (m)	= (4.6*0.5)+(4.6+0.53)+(4.6*0.31)+(12*0.04)+(6.5*0.01)+(5.2*0.02)+(5.2*0.02)+(5.2*0.02)+(16*0.01)
	= 5.060929
Distance between vehicle (m)	= 1 (worst case)
Head to head distance on a lane (m), l	= 6.060929
Traffic density (traffic flow /s), N	= 1.286111
Average vehicle speed (m/s), v	= l*N/(2*nl)
	= 0.556788

Diffusion Parameters

Reynolds number, Re	= (v*dv)/σ where σ = 15.6*10^-6
	= 183468.2
According to Figure 16 (Ohashi and Koso)	
Since l / dt	= 0.283095
D / (N * dt^2 * Re^0.13)	= 0.08
Longitudinal diffusion coefficient (m2/s) , D	= 0.08 * (N * dt^2 * Re^0.13)
	= 227.9525

Maximum Concentration of NO2

Cmax (µg/m3)	= w * Le^2 / (8 * D * At)
(without background)	= 7

Appendix 3.12b Detailed Calculation of In-Tunnel Air Quality Deckover along P2 Road and CWB Tunnel

P2 Road & CWB Tunnel - Worse condition

Six assessment points (ASRs PE3-PE5 & PW1-PW3) at the boundary of the deckover are chosen and shown in Figure A3.12. Using CALINE4 and ISCST3 model, the air pollutants concentrations at the 6 assessment points at different levels are calculated. The highest concentration among the six assessment points is assumed to be the background concentration inside the proposed deckover section.

NO2 Concentrations (ug/m3) at Various Levels

	Elevation (mAG)	NO_2
PE3	0.0	101
	3.75	93
	7.5	85
PE4	0.0	110
	3.75	99
	7.5	89
PE5	0.0	106
	3.75	98
	7.5	89
PW1	0.0	94
	3.75	88
	7.5	80
PW2	0.0	95
	3.75	87
	7.5	79
PW3	0.0	85
	3.75	80
	7.5	77

Therefore, the NO2 background concentration inside the proposed deckover section is 110 ug/m^3

Total Maximum NO2 concentration inside the proposed deckover section (Normal Speed) = **1 + 110**
= **111** **ug/m3**

Total Maximum NO2 concentration inside the proposed deckover section (Worse Case) = **7 + 110**
= **117** **ug/m3**

Appendix 3.12c

Detailed Calculation of In-Tunnel Air Quality
Deckover along Convention Avenue

Tunnel Parameter

Length L	= 132	m	
Height H	= 7.5	m	
Width W	= 7	m	
Cross-sectional area $A_T = H \times W$ =			52.5 m^2
Perimeter P	=	29 m	

Emission Data

Traffic flow = 1044 veh/hr

Traffic Breakdown	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
% vehicle	0.05	0.49	0.33	0.00	0.04	0.00	0.00	0.01	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.00
NOx Emission Factor (g/mile)	1.06	0.15	0.26	0.00	4.72	3.66	0.00	0.34	0.42	0.27	2.22	4.60	6.02	2.47	2.82	0.12

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) = 0.399 g/km/veh
Total NO_2 emission factor (g/s) = 1.91E-03 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*0.05)+(1.7*1.5*0.49)+(1.7*1.5*0.33)+(2.5*3.5*0.04)+(2*3*0.01)+(2.1*1.6*0.01)+(2.1*1.6*0.01)+(2.1*1.6*0.02)+(2.5*4.6*0.04)

= 3.2229 m^2

Appendix 3.12c **Detailed Calculation of In-Tunnel Air Quality**
Deckover along Convention Avenue

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	=	3.2229 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	=	132 m
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	7.241379 m, P is the Perimeter of tunnel
A_T	=	Cross-sectional area of tunnel	=	52.5 m^2
C_W	=	External wind coefficient	=	0.3
$V_{W(ref)}$	=	Velocity of wind at Central Station	=	2.1 m/s (Weighted average of 2005 Central Station data)
$V_{W(s)}$	=	Velocity of wind at source	=	1.75 m/s
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

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

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

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

<u>**For normal traffic condition**</u>

traffic flow Q = 0.29 veh/s

Vehicle speed V_C = 50 km/h

= 13.8888889 m/s

Number of vehicles in tunnel N = QL/V_C

= 2.75616

Solving for V_T by equation (1)

a = -87.85

b = -159.15

c = 1057.10

tunnel air flow velocity V_T = 2.67932025 m/sec or -4.49085 m/sec (rejected)

Appendix 3.12c **Detailed Calculation of In-Tunnel Air Quality**
Deckover along Convention Avenue

Inside tunnel concentration	=	emission rate / (tunnel air flow x underpass cross-sectional area)
NO_2	=	14 ug/m^3

Appendix 3.12c **Detailed Calculation of In-Tunnel Air Quality**
Deckover along Convention Avenue

Tunnel Parameter

Length L	= 132	m	
Height H	= 7.5	m	
Width W	= 7	m	
Cross-sectional area $A_T = H \times W$ =			52.5 m^2
Perimeter P	=	29 m	

Emission Data

Traffic flow = 1044 veh/hr

Traffic Breakdown	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
% vehicle	0.05	0.49	0.33	0.00	0.04	0.00	0.00	0.01	0.01	0.01	0.02	0.04	0.00	0.00	0.00	0.00
NOx Emission Factor (g/mile)	0.91	0.21	0.38	0.00	6.06	12.40	0.00	0.52	0.64	0.42	3.46	7.11	8.80	4.93	5.57	0.16

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) = 0.552 g/km/veh
Total NO_2 emission factor (g/s) = 2.64E-03 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*0.05)+(1.7*1.5*0.49)+(1.7*1.5*0.33)+(2.5*3.5*0.04)+(2*3*0.01)+(2.1*1.6*0.01)+(2.1*1.6*0.01)+(2.1*1.6*0.02)+(2.5*4.6*0.04)

= 3.2229 m^2

Appendix 3.12c

Detailed Calculation of In-Tunnel Air Quality
Deckover along Convention Avenue

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	=	3.2229 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	=	132 m
D	=	Hydraulic diameter of tunnel =	$4A_T/P$ =	7.241379 m, P is the Perimeter of tunnel
A_T	=	Cross-sectional area of tunnel	=	52.5 m^2
C_W	=	External wind coefficient	=	0.3
$V_{W(ref)}$	=	Velocity of wind at Central Station	=	2.1 m/s (Weighted average of 2005 Central Station data)
$V_{W(s)}$	=	Velocity of wind at source	=	1.75 m/s
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

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

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

$$c = C_d A_c N V_c^{\,2} - C_w V_w^{\,2} A_T$$

<u>For congested traffic condition</u>

Vehicle speed Vc =		10 km/h
	=	2.77777778 m/s
average length of vehicle	=	(4.6*0.05)+(4.6*0.49)+(4.6*0.33)+(12*0.04)+(6.5*0.01)+(5.2*0.01)+(5.2*0.01)+(5.2*0.02)+(16*0.04)
	=	5.395 m
distance between vehicle	=	1 m
head to head length	=	6.395 m
Number of vehicles per lane	=	20.6411259
Number of lanes	=	2
Number of vehicles in tunnel N	=	41.2822518

Solving for V_T by equation (1)

Appendix 3.12c

Detailed Calculation of In-Tunnel Air Quality
Deckover along Convention Avenue

a = -7.77
b = -476.76
c = 614.05

tunnel air flow velocity V_T = 1.26202128 m/sec or -62.6431 m/sec (rejected)

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

NO_2 = 40 ug/m^3

Background Concentration

Two assessment points (ASRs PW4&PW5) at the boundary of the deckover are chosen and shown in Figure A3.12.
Using CALINE4 and ISCST3 model, the air pollutants concentrations at the 2 assessment points at different levels are calculated.
The highest concentration among the two assessment points is assumed to be the background concentration inside the deckover section.

Predicted Concentrations (ug/m^3) at Various Levels

	(mAG)	NO2
PW4	0	90
	3.75	84
	7.5	78
PW5	0	87
	3.75	81
	7.5	76

Therefore, the NO2 background concentration inside the proposed deckover section is 90 ug/m^3

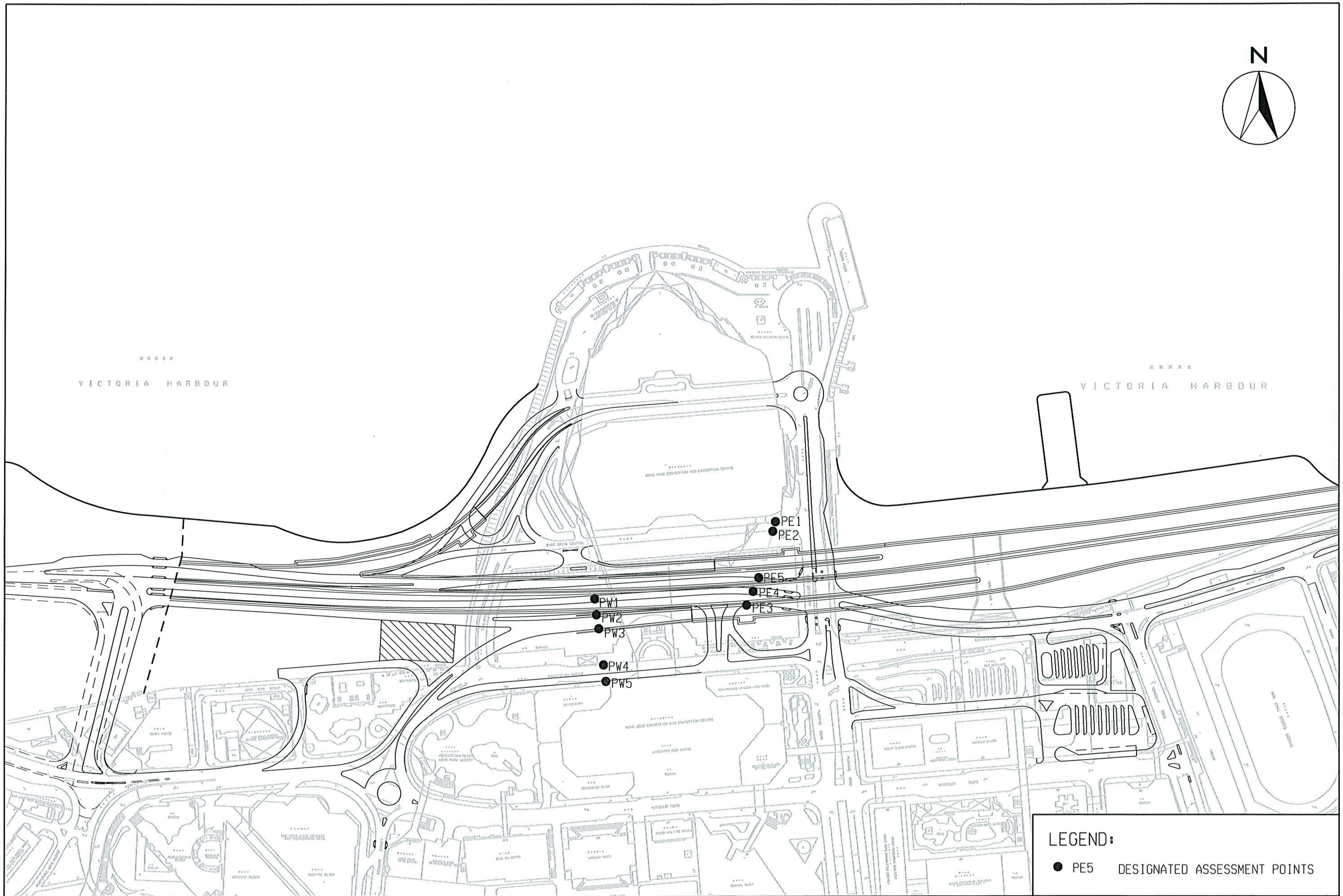
Total Maximum NO2 concentration Inside the proposed deckover section (Normal Speed) = 14 + 90
= 104 ug/m^3

Total Maximum NO2 concentration Inside the proposed deckover section (Worse Case) = 40 + 90
= 130 ug/m^3

Appendix 3.12d Emission Factors for Year 2016 for Different Vehicle Classes (10kph)

Using constant traffic speed at 10kph

Vehicle Class	Emission Factor in g/mile-veh			
	NOX		RSP	
	Trunk Roads	Other Roads	Trunk Roads	Other Roads
Petrol Private Cars & Light Goods Vehicles	0.2139	0.2141	0.0202	0.0201
Diesel Private Cars & Light Goods Vehicles<2.5t	0.6420	0.6390	0.3130	0.3103
Diesel Private Cars & Light Goods Vehicles 2.5-3.5t	0.4179	0.4184	0.1897	0.1859
Public Light Buses	0.1620	0.1618	0.1774	0.1699
Light Goods Vehicles>3.5t	3.4616	3.4607	0.3912	0.3880
Medium & Heavy Goods Vehicles with GVW 5.5-15t	7.1101	7.1112	0.6462	0.6484
Medium & Heavy Goods Vehicles with GVW >=15t	8.8818	8.7954	0.7270	0.6663
Double Deck Franchised Buses	5.5736	5.5730	0.2615	0.2558
Motor Cycles	0.9094	0.9087	0.0801	0.0789
Taxi	0.3823	0.3822	0.0878	0.0874
Private Light Buses<3.5t	0.0000	0.0000	0.0000	0.0000
Private Light Buses>3.5t	0.5250	0.5243	0.5159	0.5155
Non-franchised Buses<6.4t	0.0000	0.0000	0.0000	0.0000
Non-franchised Buses 6.4-15t	6.0610	6.0615	0.3832	0.3806
Non-franchised Buses >15t	12.1939	12.4044	0.2454	0.5228
Single Deck Franchised Buses	4.9380	4.9348	0.3387	0.3136
Note: * - Since the VMT of non-franchised buses >15t is too small, the calculated RSP emission factor for this vehicle class is zero. As a conservative approach, the RSP emission factor of non-franchised buses 6.4-15t would be adopted for non-franchised buses >15t.				



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WAN CHAI DEVELOPMENT PHASE II - PLANNING AND ENGINEERING REVIEW

DESIGNATED ASSESSMENT POINTS FOR FUTURE HKCEC ATRIUM LINK DECKOVER AIR QUALITY

FIGURE A3.12

K:/A01604/DRAWING/REPORT/MAY07/FIGURE A3.12.DGN

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