APPENDIX 13.1 HAZARD TO LIFE ASSESSMENT FOR PROPOSED EFFLUENT POLISHING PLANT (EPP)

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1. INTRODUCTION

1.1 Background

1.1.1.1 This section identifies the hazardous scenarios associated with the generation, storage, utilization, processing and transmission (if applicable) of biogas during operation of the Project, and presents the analysis and findings of the Quantitative Risk Assessment (QRA) undertaken.

1.1.1.2 An organic waste co-digestion facility that processes off-site pre-treated organic wastes (approximately 100 wet tonnes / day) together with sewage sludge and handles the associated wastewater and biogas will be installed at the proposed Effluent Polishing Plant (EPP). The preliminary site layout of the proposed EPP and the location of its biogas related facilities are shown in **Annex A**.

1.1.1.3 In accordance with Section 3.4.14 of the EIA Study Brief (ESB-340/2021), a hazard assessment should be conducted to evaluate the biogas risk to existing, committed and planned off-site population due to operation of the organic waste co-digestion facility.

1.2 Hazard to Life Assessment Objectives and Risk Criteria

1.2.1 Objectives

1.2.1.1 The Hazard to Life Assessment requirements for the proposed EPP, as detailed in Appendix H of the EIA Study Brief, are shown below:

(a) Identify hazardous scenarios associated with the generation, storage, use and on-site transport of biogas at the proposed sewage treatment works and then determine a set of relevant scenarios to be included in a QRA;

(b) Execute a QRA of the set of hazardous scenarios determined in (a), expressing population risks in both individual and societal terms;

(c) Compare individual and societal risks with the criteria for evaluating hazard to life as stipulated in Annex 4 of the TM; and

(d) Identify and assess practicable and cost-effective risk mitigation measures.

1.2.2 EIAO-TM Risk Criteria

1.2.2.1 Annex 4 of the EIAO-TM specifies the Individual and Societal Risk Guidelines. The Hong Kong Risk Guidelines (HKRG) per the EIAO-TM Annex 4 states that the individual risk is the predicted increase in the chance of fatality per year to an individual due to a potential hazard. The individual risk guidelines require that the maximum level of individual risk should not exceed 1 in 100,000 per year i.e. 1×10^{-5} per year. Societal risk expresses the risks to the whole population. It is expressed in terms of lines plotting the cumulative frequency (F) of N or more deaths in the population from incidents at the installation. Two F-N risk lines are used in the HKRG that demark “Acceptable” or “Unacceptable” societal risks. To avoid major disasters, there is a vertical cut-off line at the 1000 fatality level extending down to a frequency of 1 in a billion years. The intermediate region indicates the acceptability of societal risk is borderline and should be reduced to a level which is “as low as reasonably practicable” (ALARP). It seeks to ensure that all practicable and cost-effective measures that can reduce risk are considered. The HKRG is presented graphically in **Plate 1.1**.

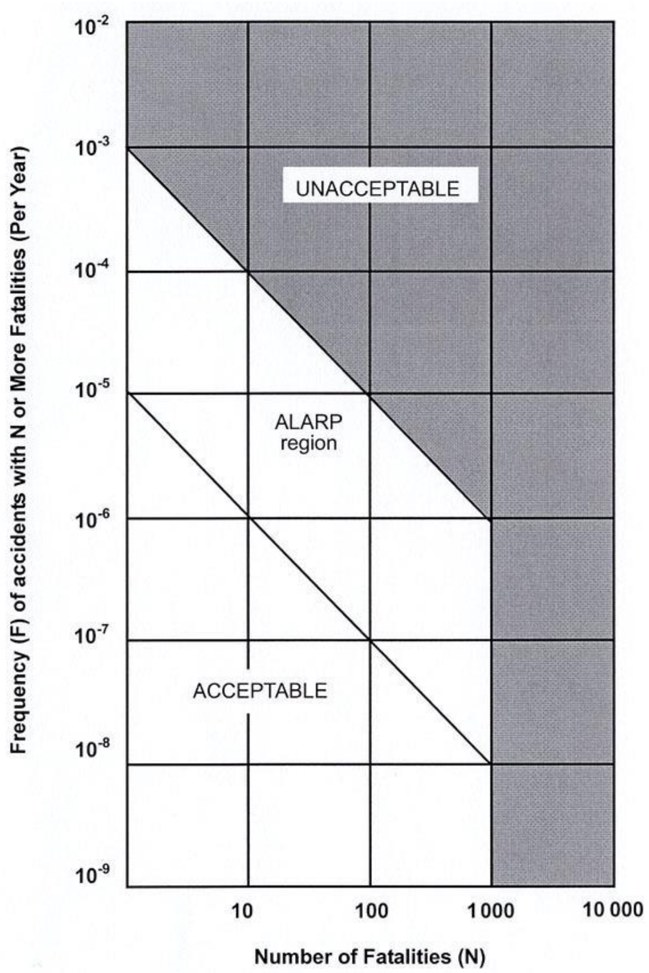

Plate 1.1 Societal Risk Guidelines

1.3 Study Approach

1.3.1.1 This assessment consists of the following six main tasks:

(a) **Data / Information Collection and Update**: Relevant data / information necessary for the hazard assessment, including project design and surroundings of the Project were collected;

(b) **Hazard Identification**: A set of relevant hazardous scenarios associated with the operations of the organic waste co-digestion facility were identified by reviewing relevant literature and studies with similar installations as well as historical accident database, such as Major Hazard Incident Data Service (MHIDAS);

(c) **Frequency Estimation**: Frequencies of each hazardous event leading to fatalities with full justification were estimated by reviewing historical accident data, previous similar projects and using Fault Tree Analysis (FTA) of the identified hazardous scenarios;

(d) **Consequence Analysis**: The consequences of the identified hazardous scenarios were analysed by conducting source term modelling and effect modelling;

(e) **Risk Assessment and Evaluation**: The risks associated with the identified hazardous scenarios were evaluated. The evaluated risks were compared with the HKRG in EIAO-TM to determine their acceptability; and

(f) **Identification of Mitigation Measures**: Where necessary, practicable and cost-effective risk mitigation measures were identified and assessed to ensure compliance with the ALARP principle in the HKRG. Risks of the mitigated case were re-assessed to determine the level of risk reduction as required.

1.3.1.2 The main tasks of the QRA are shown schematically in **Plate 1.2**.

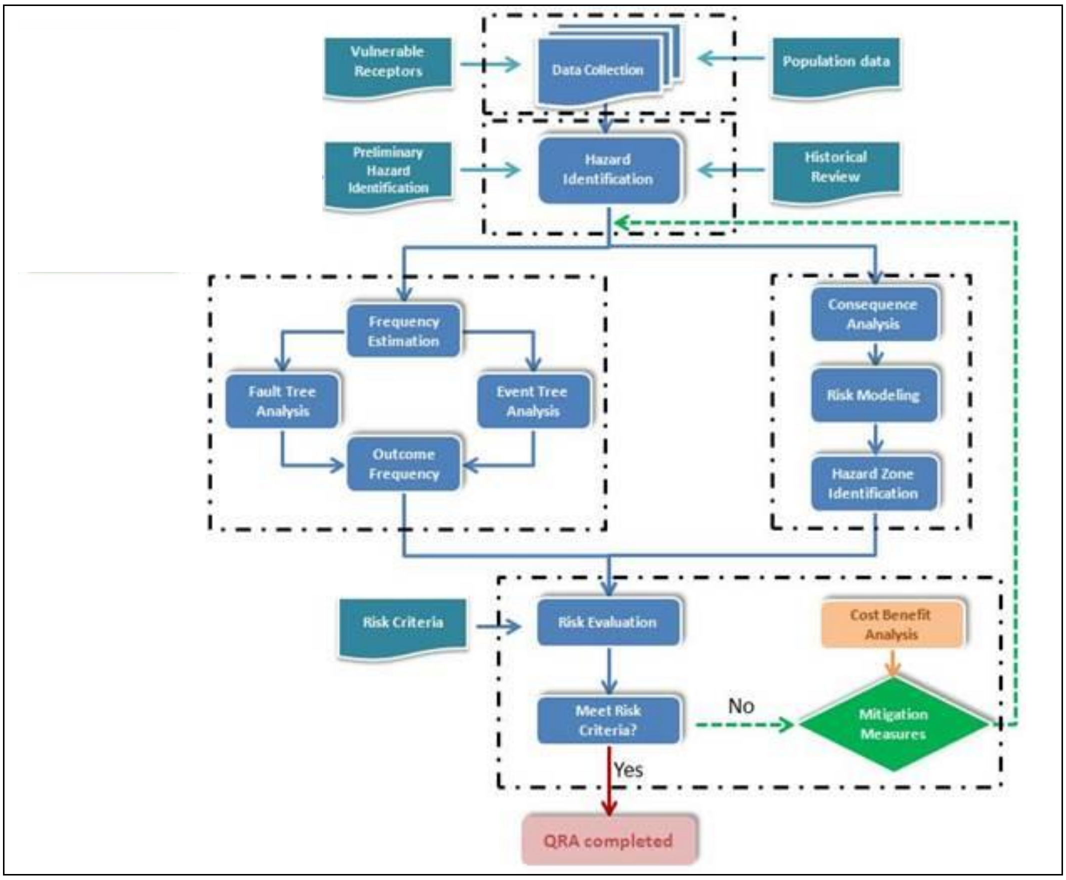

Plate 1.2 Schematic Diagram of QRA Process

1.4 Assessment Scenario

1.4.1.1 Based on the currently envisaged construction programme, the proposed EPP will be commenced in 2031. The hazard assessment covers the following two scenarios:

(a) Year 2032 (Construction phase) – The risk imposed by the operation of the biogas facilities in the proposed EPP and two GFS, and the HP Gas Pipeline to the existing, committed and planned population in 2032. This scenario accounted for the commencement of the EPP and the two GFSs, and also the presence of the construction workers for areas of the proposed development located along the San Tam Road.

(b) Year 2039 (Operation phase) – The risk imposed by the operation of the biogas facilities in the proposed EPP and two GFSs, and the HP Gas Pipeline to the existing, committed and planned population in 2039. This scenario accounted for the ultimate situation with all the planned land users of the proposed development being considered.

2. SITE DESCRIPTION

2.1 Description of Surroundings

2.1.1.1 Societal risk is a measure of the consequence magnitude and the frequency of the hazardous events. To establish the impact of any release (the number of people likely to be affected) in the future, it is necessary to know the future surrounding population levels. These would include residential population, government and institutional population and transport population but exclude staff of the EPP since they are considered as voluntary risk takers.

2.2 On-site Populations

2.2.1.1 The following population is anticipated in the EPP during operation phase of the plant:

(a) Staff: the number of staff of EPP would be around 200, and they are considered as voluntary risk takers and would not be considered in this assessment.

2.3 Surrounding Populations

2.3.1.1 The site of the proposed EPP is located at the western part of STLMC development. The proposed organic waste co-digestion facility is located in the middle portion of the proposed EPP. All population groups included in this assessment are detailed in **Annex B**.

2.3.2 Land and Building Population

2.3.2.1 Population covered in the QRA included residents and workers in the residentials, institutions, government facilities and amenity. Estimation of land and building populations was based on the latest information provided by Civil Engineering and Development Department (CEDD) and are summarized in **Table 2.1**.

2.3.2.2 Residential population of the existing buildings was estimated based on the average household size obtained from the Territory Population and Employment Data Matrix (TPEDM) data, together with the building information (e.g. no. of units and floors) obtained from Centamap.

2.3.2.3 The TPEDM population projections for Planning Data Zones (PDZs) (i.e. PDZ 183 and PDZ332) was obtained from the Planning Department (PlanD) to forecast the population of the existing residential developments in the assessment years. The average domestic household sizes for the respective PDZs in 2031 were adopted to estimate the residential population in 2031. The 2030+ TPEDM data showed negative growth of average domestic household size in all the concerned PDZs from 2031 to 2041. To be conservative, the population of the existing residential developments (i.e. E02 and E05) in 2032 and 2039 were assumed to remain the same as those in 2031.

2.3.2.4 The population groups considered in this QRA are shown in **Plate 2.1** and the numbers of population in each area are listed in **Table 2.1**, while details of the population at different time modes and information sources are provided in **Annex A**. The numbers of population were estimated based on the following assumptions:

(a) According to the 2030+ TPEDM data, the average domestic household size in PDZ 183 and PDZ 332 in 2031 are 3.12 and 3.20 respectively. Since a negative growth of average domestic household size from 2031 to 2041 was observed in all the concerned PDZs, the residential population in existing residential developments in 2032 and 2039 was assumed to remain the same as those in 2031;

(b) The amenity areas were assumed to be unmanned, while population in open areas were estimated based on a density of 100m^2/ person; and

(c) An average of 5% population was considered to be outdoor for residential, institution and industrial population, while 100% population was assumed to be outdoor for construction workers, users in open spaces and open storages area.

Table 2.1 Land and Building Population Data

ID	Description	Population	
		Year 2032 – Construction Phase	Year 2039 – Operation Phase
E02	Scenic Heights	106	106
E05	Mai Po San Tsuen	3164	3164
P01	A.5.1 - Amenity	0	0
P02	OU(ESS).5.12 - Reserve	0	0
P03	G.5.3 - Existing Mai Po ESS	125	84
P04	G.5.1 - Sport Centre	125	1018
P05	RSc.2.1 - Public Housing	9899	9899
P06	RSc.2.2 - Public Housing	7603	7603
P07a	OU(EPP).5.3 - Food Waste Pretreatment Facilities	100	100
P08	OU(GFS).5.1 - Green Fuel Station	10	10
P09	G.5.2 - Reserve	0	0
P10	GB.5.3 - Green Belt	0	0
P11	OU(ESS).5.6 - 132kV ESS	0	0
P12	G.5.5 - Reserve	0	0
P13	E.5.3 - Potential Education Facilities	125	1680
P14	GB.5.4 - Green Belt	0	0
P15	OU(SPS).5.7 - Sewage Pumping Station	30	30
P53	OU(LSW).1.2 - Logistics, Storage and Warehouse	220	220
P54	OU(DSC).1.11 - District Cooling System	25	25
P55	O.1.3 - Open space	410	410
P56	OU(I&T)3.1.9 - Information and Technology - Zone 3	80	5228
P57	OU(WRP).5.2 - Water Reclamation Plant	100	100
P58	E.2.1 - 2 Primary School	129	1678
P59	OU(RCP).5.5 - RCP	0	0
P60	GB.5.1 - Green Belt	0	0
P61	GB.5.2 - Green Belt	0	0
P63	A.1.17 - Amenity	0	0

Plate 2.1 Population Groups Considered

2.3.3 Traffic Population

2.3.3.1 The traffic data was based on the latest Annual Traffic Census (ATC) published by Transport Department (TD) [6] and the Traffic Impact Assessment (TIA) report prepared for this Assignment. The traffic population was predicted based on the following equation:

$$Traffic\ Population = \frac{No.of\ Person\ per\ vehicle \times No.of\ Vehicle\ per\ hour \times Road\ Length}{Speed}$$

2.3.3.2 Based on the latest ATC [6], the occupancies for each vehicle type and vehicle mix were taken at the core station no. 5016 (San Tin Highway, Castle Peak Road and San Tam Road (from Kam Tin Road to Fairview Park Boulevard) were selected to represent the road traffic for this assessment.

2.3.3.3 The traffic population considered in this assessment, which was assumed to be 100% outdoor, is summarized in **Table 2.2** and detailed in **Annex B**. The locations of roads considered for construction and operation phases are presented in **Plate 2.2**.

Table 2.2 Estimated Road Population

ID	Traffic Speed (km/hr)	Maximum Population			
		Year 2032		Year 2039	
		Daytime	Night-time	Daytime	Night-time
R1	50	18	12	24	14
R2	50	14	10	17	12
R3	50	9	7	20	11
R4	50	16	12	43	22
R5	50	22	13	24	13
R6	100	158	71	191	85
R7	100	148	66	166	73
R8	100	210	93	252	110
R9	100	115	53	129	60
R10	100	260	116	293	133
R11	50	49	26	58	30
R12	50	113	54	98	47
R13	50	20	13	27	15
R14	50	16	11	25	15
R15	50	13	9	20	12
R16	50	17	11	25	15
R17	50	16	11	13	9
R18	50	8	8	13	10
R19	50	35	21	39	22
R20	50	46	26	54	28
R21	50	40	23	47	25
R22	50	42	24	44	24
R23	50	66	35	67	35
R24	50	153	74	168	80
R25	50	176	85	170	81
R26	50	22	14	74	36
R27	50	21	14	77	38
R28	50	0	0	22	13
R29	50	0	0	21	13
R30	50	43	19	88	42
R31	50	45	21	64	29
R32	50	33	20	36	20
R33	50	36	21	51	26
R34	50	34	18	39	19
R35	50	24	15	27	16
R36	50	89	44	83	41
R37	50	7	7	7	7
R38	50	60	31	58	31
R39	50	119	58	149	71
R40	50	7	7	7	7

ID	Traffic Speed (km/hr)	Maximum Population			
		Year 2032		Year 2039	
		Daytime	Night-time	Daytime	Night-time
R41	50	7	7	7	7
R42	50	10	10	12	12
R43	50	20	20	24	24
R44	50	10	10	13	13
R45	50	9	9	10	10
R46	50	10	10	12	12

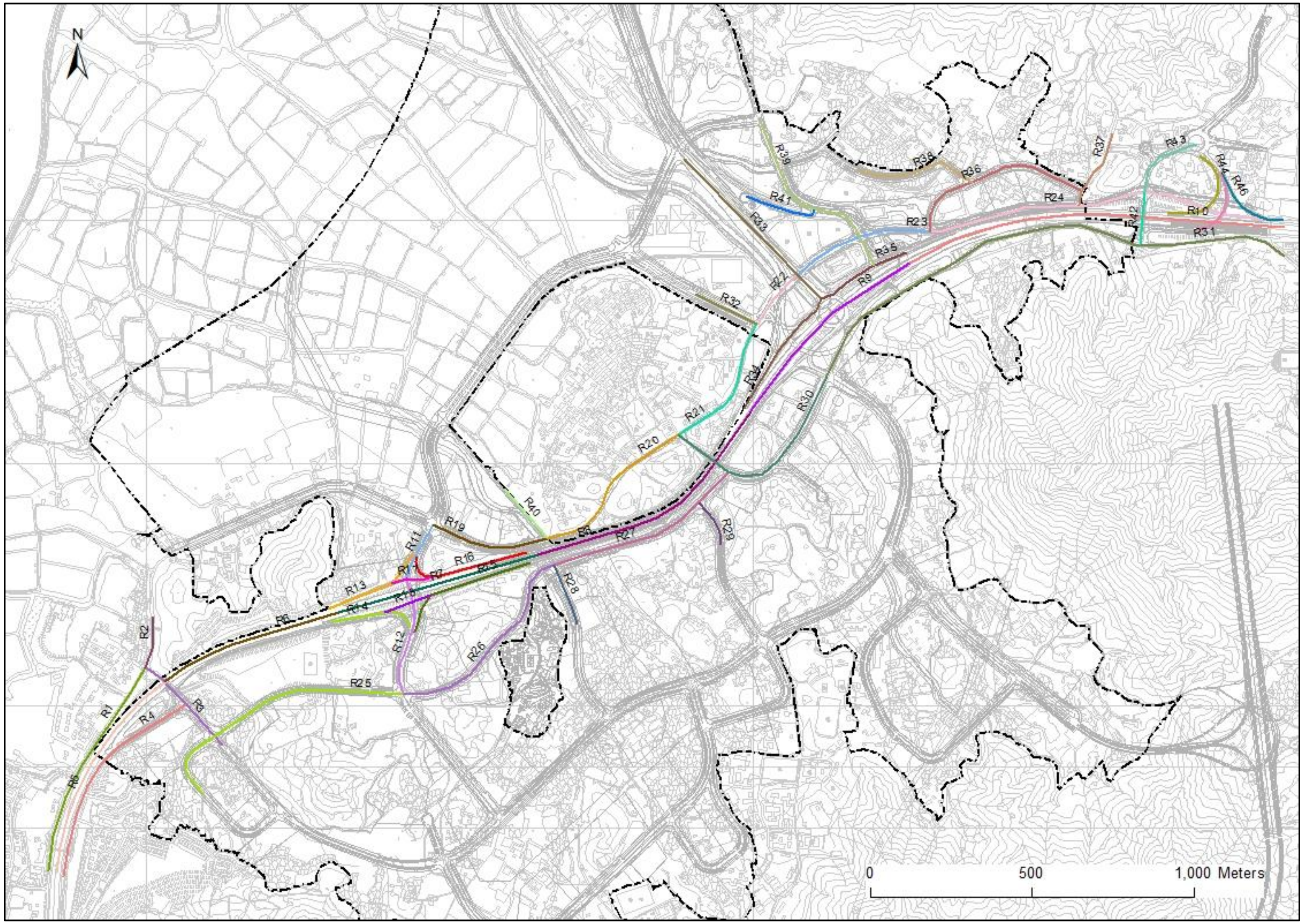

Plate 2.2 **Locations of Road Population Groups**

2.3.4 Time Modes and Occupancies of Population Groups

2.3.4.1 With reference to previous similar studies [1][2][4][5], four time modes as detailed in **Table 2.3** were applied in this hazard assessment to reflect the temporal distribution of population and to address the variation in levels of activities that could lead to a release and the variation in population in the assessment area with time.

Table 2.3 Definitions of Time Modes

Day Category	Time Period		Time Mode
Weekday	Daytime	(07:00 to 19:00)	35.71%
	Night	(19:00 to 07:00)	35.71%
Weekend	Daytime	(07:00 to 19:00)	14.29%
	Night	(19:00 to 07:00)	14.29%

2.4 Meteorology

2.4.1.1 Meteorological data is required for consequence modelling and risk calculation. Consequence modelling (dispersion modelling) requires wind speed and stability class to determine the degree of turbulent mixing potential whereas risk calculation requires wind-rose frequencies for each combination of wind speed and stability class.

2.4.1.2 Meteorological data was obtained from Wetland Park Weather Station (2021) where wind speed, stability class, weather class and wind direction are available. This data represented the weather conditions for the whole year in 2021 and has already taken into account seasonal variations and was therefore considered applicable for the assessment. **Table 2.4** shows the wind speed-stability frequencies.

Table 2.4 Stability Category-Wind Speed Frequencies at Wetland Park Weather Station

Daytime							
Wind Speed (m/s)	**A**	**B**	**C**	**D**	**E**	**F**	**Total (%)**
0.0-1.9	25.55	7.91	0.00	13.77	0.00	14.46	61.69
2.0-3.9	7.62	14.30	6.36	6.34	1.76	0.36	36.74
4.0-5.9	0.00	1.05	0.27	0.18	0.00	0.00	1.50
6.0-7.9	0.00	0.00	0.00	0.05	0.00	0.00	0.05
Over 8.0	0.00	0.00	0.00	0.02	0.00	0.00	0.02
All (%)	33.17	23.26	6.63	20.36	1.76	14.82	100.00
Night-time							
Wind Speed (m/s)	**A**	**B**	**C**	**D**	**E**	**F**	**Total (%)**
0.0-1.9	0.00	0.00	0.00	3.76	0.00	82.06	85.82
2.0-3.9	0.00	0.00	0.00	2.25	8.83	2.44	13.52
4.0-5.9	0.00	0.00	0.00	0.52	0.07	0.00	0.59
6.0-7.9	0.00	0.00	0.00	0.07	0.00	0.00	0.07
Over 8.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All (%)	0.00	0.00	0.00	6.60	8.90	84.50	100.00

2.4.1.3 According to **Table 2.4**, six combinations (2B, 1D, 3D, 6D, 2E and 1F) and five combinations (1D, 3D, 7D, 2E and 1F) of wind speed and stability class were chosen for daytime and night-time meteorological conditions respectively. These combinations were considered adequate to reflect the full range of observed variations in these quantities. It is not necessary and efficient to consider every combination observed. The principle is to group these combinations into representative weather classes that together cover all conditions observed.

2.4.1.4 Once the weather classes have been selected, frequencies for each wind direction for each weather class can then be determined. The frequency distributions for the daytime and night-time meteorological conditions are summarised in **Table 2.5**.

Table 2.5 Weather Class-Wind Direction Frequencies at Wetland Park Weather Station

Daytime							
Direction	**2B**	**1D**	**3D**	**6D**	**2E**	**1F**	**Total (%)**
0 – 30	4.53	1.99	0.82	0.00	0.55	3.21	11.10
30 – 60	6.01	1.30	1.89	0.10	0.60	1.10	11.00
60 – 90	12.03	2.02	3.96	0.02	1.00	1.02	20.05
90 – 120	3.59	1.47	2.69	0.00	0.65	1.49	9.89
120 – 150	2.47	0.50	1.30	0.00	0.42	0.67	5.36
150 – 180	5.58	0.82	2.96	0.00	0.72	1.02	11.10
180 – 210	6.19	0.42	2.59	0.00	0.57	0.62	10.39
210 – 240	3.64	0.12	0.52	0.00	0.07	0.15	4.50
240 – 270	2.07	0.20	0.15	0.00	0.00	0.15	2.57
270 – 300	2.67	0.45	0.17	0.00	0.05	0.20	3.54
300 – 330	4.04	0.32	0.12	0.00	0.00	0.22	4.70
330 – 360	4.11	0.57	0.37	0.00	0.00	0.75	5.80
All (%)	56.93	10.18	17.54	0.12	4.63	10.60	100.00

Night-time						
Direction	**1D**	**3D**	**7D**	**2E**	**1F**	**Total (%)**
0 – 30	0.83	0.32	0.00	1.52	20.93	23.60
30 – 60	0.48	1.47	0.11	2.96	4.32	9.34
60 – 90	0.48	0.37	0.00	2.06	4.46	7.37
90 – 120	0.32	1.15	0.00	4.46	7.98	13.91
120 – 150	0.08	0.27	0.00	1.23	5.37	6.95
150 – 180	0.16	0.03	0.00	7.29	12.01	19.49
180 – 210	0.13	0.21	0.00	6.41	5.47	12.22
210 – 240	0.05	0.05	0.00	0.35	0.43	0.88
240 – 270	0.03	0.00	0.00	0.03	0.27	0.33
270 – 300	0.00	0.00	0.00	0.03	0.29	0.32
300 – 330	0.08	0.03	0.00	0.03	0.72	0.86
330 – 360	0.51	0.19	0.00	0.27	3.76	4.73
All (%)	3.15	4.09	0.11	26.64	66.01	100.00

3. HAZARD IDENIFICATION AND ANALYSIS

3.1 Introduction

3.1.1.1 A hazard is described as the property of a material or activity with the potential to do harm. Potential hazards associated with generation, transfer, storage and use of biogas in the organic waste co-digestion facility within the proposed EPP were identified. All the operation information and parameters have been confirmed with the engineers. This section outlines the hazards preliminarily identified for the facility.

3.1.1.2 Historical incidents and relevant studies of similar facilities were reviewed to identify the possible hazardous scenarios and to ensure that all the relevant hazardous scenarios were incorporated into this assessment.

3.2 Facility Description

3.2.1.1 The organic waste co-digestion facility at the proposed EPP will receive approximately 100 wet tonnes / day of pre-treated organic wastes through pipelines or tankers for co-digestion with sewage sludge and handle the associated wastewater and biogas. Proven biological treatment technologies will be adopted to recover reusable energy, i.e. biogas, from source-separated organic wastes and sewage sludge. Biogas generated will be used onsite heat and power production. The location plan of the facility and the treatment process are illustrated in **Annex A**.

3.2.2 Digesters

3.2.2.1 Five duty and one standby cylindrical anaerobic sludge digesters, each of which is 22m (Dia.) × 28m (H) (internal dimension) in size, will be provided to handle the pre-treated organic waste and sludge. The biogas volume of each digester is $380m^3$. The working temperature and pressure of the digesters will be maintained at 35ºC and 1.03 bar.

3.2.2.2 The digesters consist of concrete, steel or glass enamel holding tanks, with either gas or top mounted mixing systems. Approximately 100 wet tonnes / day of pre-treated organic waste and 70 wet tonnes / day of sewage sludge will enter the digestion tanks along with additional water to reduce the Dissolved Solid (DS) content from an estimated 15% to 5%. The estimated average residence time of the organic waste / sludge within the digesters is assumed to be 20 days. Digested sludge / organic waste will be dewatered for disposal and the wastewater from the dewatered compost will be transferred to the side-stream treatment facilities / inlet works of EPP for treatment.

3.2.2.3 Heating is required for biomass feeding of the digesters and for heat loss compensation from the digesters. The required heating will be provided via heat recovered from the combined heat and power (CHP) unit, or from a boiler.

3.2.2.4 Pressure relief valves will be installed on the digesters to protect against overpressure (50 mbarg). Overflow pipes will be provided on the digesters for protection against overfilling.

3.2.3 Biogas Holders

3.2.3.1 The biogas generated will be stored in the biogas holders. There will be three cylindrical biogas holders, each of which is 19m (Dia.) × 13.7m (H) in size with a maximum biogas storage of $2,300m^3$ per tank. The total storage amount of the biogas will be around 8,860 kg. The quantity does not exceed the lower threshold quantity, i.e. 15 tonnes, for Potentially Hazardous Installations (PHIs) for flammable gas and town gas installations in Hong Kong. Therefore, the proposed waste treatment facilities are not classified as a PHI. The biogas storage would be maintained at a temperature 35 ºC and a pressure of 1.03 bar.

3.2.3.2 Dry seal (Wiggins) type biogas holders with steel containment will be used in the proposed facility for evening out variations in biogas production from the digesters. This type of gas holder typically consists of a cylindrical steel shell and a displacement piston, which is allowed to go up and down with the change of volume of gas. The gas tightness is maintained by a seal between the piston and the inside of the shell. There are pressure relief valves on the biogas holder for protection against the exceedance of designed gas storage pressure and overflow pipes for protection against overfilling.

3.2.3.3 A non-return valve will be installed at the inlet pipe to prevent gas from back-flow. Gas is discharged through the outlet pipe by suction blower. There will be emergency shut-off valves at the inlet and outlet pipes of the gas holder. In case of gas holder failure, the emergency shut-off valves can close the inlet and outlet pipes and the release of biogas to the atmosphere can be minimised.

3.2.4 Sulphur Absorption Vessels

3.2.4.1 The stored biogas will go through the sulphur absorption vessels to remove the hydrogen sulphide (H_2S) before passing to the CHP generator to produce electricity and heat for use onsite.

3.2.4.2 Two duty and one standby sulphur absorption vessels, each of which is 3.5m (Dia.) x 3.7m (H) in size, will be provided downstream of the gasholders for the absorption of H_2S in the biogas. The working temperature and pressure of the sulphur absorption vessels will be maintained at 35 ºC and 1.03 bar. The absorption vessels are made of steel and filled with zinc oxide or iron oxide as absorbents. An explosion proof blower will be used to extract the biogas from gasholder to the sulphur absorption vessels at 400 mbarg.

3.2.5 Inlet / Outlet Piping

3.2.5.1 A total of 140m of aboveground inlet / outlet pipe (150mm Dia.) will be provided to the facility. All other piping will be underground or provided at the basement of concrete buildings. The working temperature and pressure of the inlet and outlet piping will be maintained at 35 ºC and 1.03 bar.

3.3 Biogas Properties

3.3.1.1 Biogas is a colourless flammable a combustible mixture of gases at atmospheric conditions that comprises mainly methane (CH_4) and CO_2. Generally, biogas from anaerobic digestion process has a methane content of 55% to 70% by volume. The exact composition of biogas depends on the substance that is being decomposed. If the material consists of mainly carbohydrates, such as glucose and other simple sugars and high-molecular compounds (polymers) such as cellulose and hemicellulose, the methane production is low. However, if the fat content is high, the methane production is likewise high [3]. In general, the physical properties of biogas are also very similar to those of natural gas. While it is non-toxic, in high concentrations it could lead to asphyxiation. A loss of containment can lead to jet fire (if stored/ transferred under sufficient pressure) or to an explosion if the gas accumulates in a confined space. The properties of biogas from Anaerobic Digestion (AD) process are summarized in **Table 3.1** [1][2].

Table 3.1 Composition and Properties of Biogas from Anaerobic Digestion Process

Property	Biogas from Anaerobic Digestion
Methane Content	55% – 70%
Carbon Dioxide Content	30% – 45%
Density	1.2 Kg/Nm^3
Lower Caloric Value	23 MJ/Nm^3
Flammability#	Extremely Flammable
Auto-Ignition Temperature#	580°C
Flash Points#	-188°C

Property	Biogas from Anaerobic Digestion
Melting Point#	-182.5°C
Boiling Point#	-161.4°C
Flammable Limits#	5% (Lower) – 15% (Upper)
Vapour Density#	0.59-0.72 (air = 1)

Remark:
Physical properties of biogas that are similar to natural gas.

3.3.1.2 Given that flammability increases with increase of methane content, and the exact composition of biogas varies with the substance that is being decomposed, it is conservatively assumed that the biogas is 100% methane in the risk model.

3.4 Review of Historic Incident Database and Relevant Studies

3.4.1.1 Relevant biogas or methane release scenarios from OWTF and YLSEPP (which are facilities of similar nature as the proposed facility at EPP) identified in historical incident databases, such as MHIDAS database, eMARS, FACTS and ARIA, were examined. The recorded hazardous scenarios were mainly associated with leakages from piping, valves and storage vessels and operator error. A total of 11 incidents records related to biogas and methane were identified and these are summarized in **Table 3.2** and detailed in **Annex C**.

Table 3.2 Summary of Biogas or Methane Incidents

Hazardous Scenario	No. of Cases	Country
Methane Storage Tank Failure	3	Turkey, India, Australia
Methane Pipeline Failure	2	UK, USA
Anaerobic Digestion Plant Failure	6	Italy, France, Germany, India

3.4.1.2 The hazardous scenarios of biogas identified in the relevant studies were reviewed and adopted in this hazard assessment where applicable. Failure events and the respective hazardous scenarios associated with the biogas facilities were identified and assessed in the approved EIA studies for OWTF, Phase 2 (AEIAR-180/2013) [1] and YLEPP (AEIAR-220/2019) [2]. The identified hazardous scenarios were mainly associated with leakages from piping, valves and storage vessels due to undetected material defect.

3.5 Spontaneous Failures

3.5.1 Digester Failure

3.5.1.1 Failure of the digesters could be caused by undetected corrosion, fatigue, material or construction defect. Release of biogas could be from various parts of the digesters as well as the associated piping and devices. Possible hazardous outcomes include fireball, jet fire, flash fire and Vapour Cloud Explosion (VCE).

3.5.2 Gasholder Failure

3.5.2.1 Dry seal (Wiggins) type biogas holders will be used for the proposed facility. A dry seal (Wiggins) type gas holder is different from column guided water-sealed gas holder that do not have a gas holder crown. A seal is installed between the piston and the inside of the shell to maintain gas tightness inside the holder and prevent rotation or side movement of the piston. A levelling system consists of wire ropes and balance weights is equipped to prevent tilting of the piston. The seal and the levelling system will be inspected regularly.

3.5.2.2 Failure of the gas holders could be caused by undetected corrosion, fatigue, material or construction defect. Release of biogas could be from various parts of the gas holders or associated piping and devices. Possible hazardous outcomes include fireball, jet fire, flash fire and VCE.

3.5.3 Sulphur Absorption Vessel Failure

3.5.3.1 The absorbents used for removal of H_2S in the sulphur absorption vessels are neither flammable nor explosive that the major hazard will be from the release of biogas. Failure of sulphur absorption vessels could be caused by undetected corrosion, fatigue, material or construction defect. Release of biogas could be from various parts of the process vessels as well as associated piping and devices. Possible hazardous outcomes include fireball, jet fire, flash fire and VCE.

3.5.4 Aboveground Inlet or Outlet Piping Failure

3.5.4.1 Piping will be used to connect process vessels to the gasholder, compressor, and further purification unit and CHP. Failure along the on-site piping may be caused by undetected corrosion, fatigue, material or construction defect, or associated with flange gasket / valve leakage resulting in continuous gas release to the atmosphere. The biogas facilities including the piping are operating with low pressure (~1.03bar), it is considered that any failure of the underground pipelines operating at such low pressure will not cause significant impact to the surrounding as the pipelines are buried under concrete pavement, and thus the underground pipelines was not further considered in the assessment. Failures of gaskets and valve leak only tend to give relatively small-scale leakage and will not contribute to any off-site risk. Nonetheless, gasket and valve leak failure were considered and included into pipework failure in this hazard assessment with reference to previous similar studies [1][2]. Possible hazardous outcomes from the aboveground piping include jet fire, flash fire and VCE.

3.6 External Hazards

3.6.1.1 External hazards that are outside the control of the operating personnel could still pose a threat to the organic waste co-digestion facility at the proposed YLSEPP. Such hazards are termed as 'external hazards' because they are independent of the operations on-site but can lead to major hazard scenarios. This section discusses the credibility of loss of containment due to the external hazards with respect to Hong Kong's geographical location

3.6.2 Aircraft Crash

3.6.2.1 The Project is located around 25 km northeast from the Hong Kong International Airport. The frequency of aircraft crash was estimated using the methodology of the HSE [9] and detailed in **Section 4**.

3.6.3 Earthquake

3.6.3.1 In Hong Kong, buildings and infrastructures are designed to withstand earthquakes up to Modified Mercali Intensity (MMI) VII. It was estimated that MMI VIII is required to provide sufficient intensity to result in damage to specially designed structure. It was assumed that failure in earthquake is possible for storage tank rupture, leakage, pipeline rupture and leakage. Details of frequency analysis are given in **Section 4**.

3.6.4 Vehicle Impact

3.6.4.1 Only authorised vehicles will be permitted to enter the proposed EPP, and speed will be restricted for vehicle movements within the site. Safety markings and marked crash barriers will be provided to the above ground piping, digesters and gasholders near the internal road. Vehicle impact could cause only leak failure to digesters and gas holders as well as both rupture failure and leak failure to aboveground piping [1][2]. The accident rate was estimated based on statistical data for Vehicle/ Object Crash accident involving medium and heavy goods vehicles in recent years and detailed in **Section 4**.

3.6.5 Lightning

3.6.5.1 Lightning sparks could ignite combustible gas in air. The proposed EPP will be equipped with a lightning protection system that can effectively protect the equipment, include the organic waste co-digestion facility, from lightning. Lightning protection installations should be installed following IEC 62305, BS EN 62305, AS/NZS 1768, NFPA 780 or equivalent standards [14]. The installations will be protected with lightning conductors to safely earth direct lightning strikes. The double grounding system will be inspected regularly. Therefore, failures due to lightning strikes are to be covered by generic failure frequencies [1][2].

3.6.6 External Fire

3.6.6.1 External fire means the occurrence of fire event which leads to the failure of the equipment inside the organic waste co-digestion facility. In the proposed EPP, the facilities will be equipped with fire alarm and fire suppression system. In addition, stringent procedures will be implemented to prohibit smoking or naked flames to be used on-site to further lower the probability of initiation due to external fire. Therefore, failures due to external fire was not considered further in this assessment.

3.6.7 Typhoon / Tsunami

3.6.7.1 Loss of containment due to severe environmental event such as typhoon or tsunami (large scale tidal wave) is not possible as the proposed EPP is designed to withstand wind load for local typhoon while Hong Kong is not threatened by tsunami. Subsidence is usually slow in movement and such movement can be observed and remedial action can be taken in time. Thus, typhoon or tsunami causing a release of biogas was not considered further in this assessment.

3.7 Possible Hazardous Scenarios Considered

3.7.1.1 The organic waste co-digestion facility at the proposed EPP will be using organic waste treatment technology, similar to that in the operation of the OWTF Phase 2 and YLEPP, i.e. anaerobic digestion of the organic waste. The sulphur absorption vessels would be structurally similar to anaerobic digestion vessels. Possible hazardous scenarios of the facility are listed in **Table 3.3**.

Table 3.3 Possible Hazardous Scenarios and Hazardous Outcomes of the Organic Waste Co-digestion Facility at the Proposed EPP

Potential Sources	Release Type	Hazardous Outcome
Gasholder	Rupture	Fireball; VCE; and Flash fire
	Leak	Jet fire; VCE; and Flash fire
Digester	Rupture	Fireball; VCE; and Flash fire
	Leak	Jet fire; VCE; and Flash fire
Sulphur Absorption Vessel	Rupture	Fireball; VCE; and Flash fire

Potential Sources	**Release Type**	**Hazardous Outcome**
	Leak	Jet fire; VCE; and Flash fire
Aboveground inlet or outlet piping / pump / non-return valve / flange	Rupture / Leak	Jet fire; VCE; and Flash fire

3.7.1.2 Hazardous outcomes were assessed using PhastRisk 6.7, to determine the risk impact, where the potential risk associated with the operation, layout and facilities threat posed to life and neighbouring property in a hazardous outcome at the Project.

4. FREQUENCY ANALYSIS

4.1 General

4.1.1.1 Frequencies for each of the identified hazardous scenarios were estimated using the best available failure data or historical accident data in the process and gas industry or failure frequencies of similar installations or events. The frequencies documented in the relevant sources were reviewed and justified as necessary to reflect the specific operation and risk reduction practices evident at the organic waste co-digestion facility.

4.2 Spontaneous Failures Frequencies

4.2.1 Digester / Gasholder / Sulphur Absorption Vessel Failure

4.2.1.1 According to Guidelines for Quantitative Risk Assessment: Purple Book, the catastrophic rupture and leak failure frequencies of digester tank / gasholder / sulphur absorption vessel are 1×10^{-5} per year and 1×10^{-4} per year respectively [7].

4.2.2 Aboveground Piping Failure

4.2.2.1 According to Guidelines for Quantitative Risk Assessment: Purple Book, catastrophic rupture and leak failure frequencies of aboveground piping are 3×10^{-7} per metre per year (150 mm dia.) and 2×10^{-6} per metre per year (150 mm dia.) respectively [7].

4.2.2.2 A summary of the base event frequencies is shown in **Table 4.1**.

Table 4.1 Summary of Spontaneous Failures Frequencies

Events	Frequency of Occurrence	
	Rupture / Catastrophic Failure	Leak / Partial Failure
Digester	1.00×10^{-5} per year	1.00×10^{-4} per year
Gasholder	1.00×10^{-5} per year	1.00×10^{-4} per year
Sulphur Absorption Vessel	1.00×10^{-5} per year	1.00×10^{-4} per year
Aboveground Inlet or Outlet Piping	3.00×10^{-7} per metre per year	2.00×10^{-6} per metre per year

4.3 External Event Frequencies

4.3.1 Aircraft Crash

4.3.1.1 The model takes into account specific factors such as the target area of the proposed hazard site and its longitudinal (x) and perpendicular (y) distances from the runway threshold (**Plate 4.1** refers).

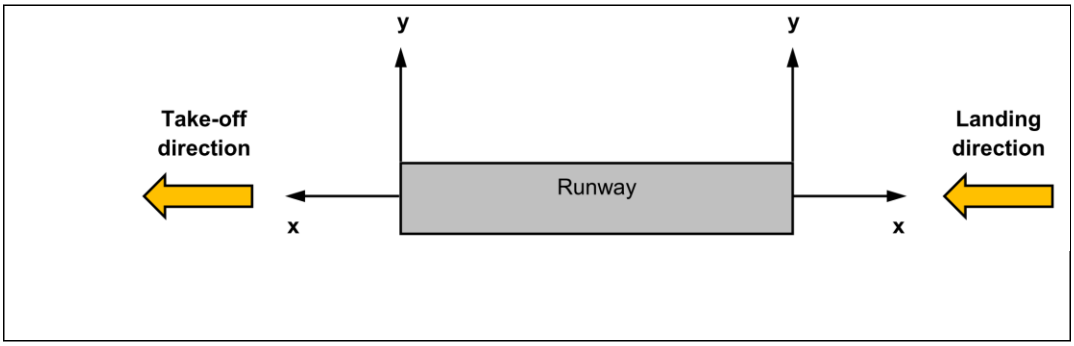

Plate 4.1 Aircraft Crash Coordinate System

4.3.1.2 The crash frequency per unit ground area (per km²) is calculated as:

$$g(x, y) = NRF(x, y) \qquad (1)$$

where *N* is the number of runway movements per year and *R* is the probability of an accident per movement (landing or take-off). *F*(*x*,*y*) gives the spatial distribution of crashes and is given by:

Landings

$$F_L(x,y) = \frac{(x+3.275)}{3.24} e^{\frac{-(x+3.275)}{1.8}} \left[\frac{56.25}{\sqrt{2\pi}} e^{-0.5(125y)^2} + 0.625 e^{-\frac{|y|}{0.4}} + 0.005 e^{-\frac{|y|}{5}} \right] \qquad (2)$$

for $x > -3.275\ km$.

Take-off

$$F_T(x,y) = \frac{(x+0.6)}{1.44} e^{\frac{-(x+0.65)}{12}} \left[\frac{46.25}{\sqrt{2\pi}} e^{-0.5(125y)^2} + 0.9635 e^{-4.1|y|} + 0.08 e^{-|y|} \right] \qquad (3)$$

for $x > -0.6\ km$.

4.3.1.3 Equations (2) and (3) are valid only for the specified range of x values. If x lies outside this range, the impact probability is zero. This case applies for 07L and 07R runways for arrival and 25L and 25R runways for departure flight path.

4.3.1.4 The probability of an accident per movement R is interpreted from NTSB data for fatal accidents in the U.S. involving scheduled airline flights during the period 1986 – 2010. The 10-year moving average suggested a downward trend with recent years showing a rate of about 2×10^{-7} per flight. There were only 13.5% of accidents associated with the approach to landing, 15.8% associated with take-off and 4.2% were related to the climb phase of the flight [15]. The frequency for the approach of landings was therefore taken as 2.7×10^{-8} per flight and for take-off was 4.0×10^{-8} per flight.

4.3.1.5 The number of runway movement of aircraft N was provided by yearly statistics of the Hong Kong International Airport (HKIA), and the figures from 2009 are presented in **Table 4.2** [16]. Due to the social unrest since mid-2019 and the outbreak of COVID-19, the number of runway movement in 2019 to 2021 was considered to be not representative, as such, the numbers of movements at 2032 and 2039 were estimated by linear regression of the data from 2009 to 2018.

4.3.1.6 The movement numbers for both landing and take-off adopted in the calculation were divided by 4 to take into account that only a quarter of landing or take-off use a specific runway.

Table 4.2 Hong Kong International Airport Civil International Air Transport Movements of Aircraft

Year	Landing	Take-off	Total
2009	139,715	139,686	279,401
2010	153,279	153,260	306,539
2011	166,919	166,887	333,806
2012	175,861	175,823	351,684
2013	186,048	186,032	372,080
2014	195,520	195,488	391,008
2015	203,043	203,005	406,048
2016	205,793	205,773	411,566
2017	210,339	210,320	420,659
2018	213,899	213,867	427,766
2019 Note 1	209,904	209,891	419,795
2020 Note 1	80,330	80,336	160,666
2032	**414,890#**	**414,866#**	**829,756#**
2039	**577,824#**	**577,816#**	**1,155,639#**

Note:
1 The data between 2019 and 2021 were not used to calculate the annual growth rate for linear regression due to the social unrest since mid-2019 and the outbreak of COVID-19.
#: based on an annual growth rate of +4.85% between 2009 and 2018 estimated by linear regression.

4.3.1.7 Only the aircraft arriving from north-east using either 25R or 25L arrival flight path as well as the aircraft departing towards northeast using either 07C or 07R departure flight path would have potential impact to the proposed EPP.

4.3.1.8 For the aircraft arriving from south-west using either 07R or 07L arrival flight path, the longitudinal distance from the runway is more than -17km, which is much smaller than -3.275km and thus the potential impact is considered to be zero. Likewise, for the aircraft departing towards south-west using either 25L or 25C departure flight path, the longitudinal distance from the runway is more than -17km, which is much smaller than -0.6km and thus the potential impact is considered to be zero.

4.3.1.9 The aircraft crash frequency was obtained by multiplying g(x,y) to the target area which was estimated to be 2.36×10^{-2} km^2 as tabulated in **Table 4.3**. The total crash frequency was calculated to be 4.72×10^{-12} per year and 6.57×10^{-12} per year for 2032 and 2039, respectively. The total crash frequencies are much less than 1.0×10^{-9} per year. The risk of aircraft crash at the proposed EPP was therefore not considered further in the analysis.

Table 4.3 Calculation for Aircraft Crash Frequency

Year	Runway	x (km)	y (km)	F(x,y)	N (per year)	R (per flight)	Crash frequency (per unit area)	Target area (km²)	Crash Frequency (per year)
2031	25R Landing	15.2	17.5	3.0E-08	103723	2.7E-08	6.8E-11	2.36E-02	2.0E-12
2031	25L Landing	13.4	20.3	4.2E-08	103723	2.7E-08	9.5E-11	2.36E-02	2.8E-12
2031	07R Landing	x > -3.275km							0.0E+00
2031	07L Landing	x > -3.275km							0.0E+00
2031	07C Landing	No landings at 07C							0.0E+00
2031	25C Landing	No landings at 25C							0.0E+00
2031	07C Take-off	16.1	18.3	9.1E-15	103716	4.0E-08	3.1E-17	2.36E-02	4.0E-18
2031	07R Take-off	14.2	20.6	3.9E-15	103716	4.0E-08	1.3E-17	2.36E-02	9.7E-19
2031	25L Take-off	x > -0.6km							0.0E+00
2031	25C Take-off	x > -0.6km							0.0E+00
2031	07L Take-off	No take-off at 07L							0.0E+00
2031	25R take-off	No take-off at 25R							0.0E+00
2046	25R Landing	15.2	17.5	3.0E-08	144456	2.7E-08	1.2E-10	2.36E-02	2.7E-12
2046	25L Landing	13.4	20.3	4.2E-08	144456	2.7E-08	1.6E-10	2.36E-02	3.8E-12
2046	07R Landing	x > -3.275km							0.0E+00
2046	07L Landing	x > -3.275km							0.0E+00
2046	07C Landing	No landings at 07C							0.0E+00
2046	25C Landing	No landings at 25C							0.0E+00
2046	07C Take-off	16.1	18.3	9.1E-15	144454	4.0E-08	5.2E-17	2.36E-02	5.5E-18
2046	07R Take-off	14.2	20.6	3.9E-15	144454	4.0E-08	2.3E-17	2.36E-02	1.4E-18
2046	25L Take-off	x > -0.6km							0.0E+00
2046	25C Take-off	x > -0.6km							0.0E+00
2046	07L Take-off	No take-off at 07L							0.0E+00
2046	25R take-off	No take-off at 25R							0.0E+00

4.3.2 Earthquake

4.3.2.1 As Hong Kong is situated in a region of low seismicity [11][12] and located rather far away from Circum-Pacific Seismic Belt that runs through Japan, Taiwan and the Philippines [13], the probability of earthquake occurrence at MMI VIII and higher is very low comparing with other places and is estimated to be 1.0×10^{-5} per year [1]. It was assumed that failure in earthquake was possible for storage tank rupture, leakage, pipeline rupture and leakage and the probability of failure in earthquake was assumed to be 0.01 [1][10].

4.3.3 Vehicle Impact

4.3.3.1 The overall numbers of accident involvements of Medium/ Heavy Goods Vehicles (M/HGVs) [17] in Hong Kong are tabulated in **Table 4.4**. The overall accident involvement rate of M/HGVs have been quite steady in recent years. The statistics indicate the overall high and medium impact accident involvement rate per million vehicle kilometre for MGV/HGVs is 0.15. The vehicle crash frequency was therefore estimated to be 1.5×10^{-7} per vehicle kilometre per year.

Table 4.4 Accident Involvements of Medium / Heavy Goods Vehicles in Hong Kong

Serious and Fatal Vehicle involvements of M/HGVs	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average
Invol rate: per million veh-km	0.89	0.87	0.93	0.86	0.96	0.94	0.90	0.95	0.91	1.02	0.92
Total involvements	1 105	1 085	1 125	1 063	1 167	1 162	1 083	1 093	1 008	1 204	1110
Fatal involvements	17	25	23	23	18	26	19	22	17	21	21
Serious injury involvements	175	193	170	250	171	146	134	137	120	109	161
Fatal vehicle involvements ratio	1.5%	2.3%	2.0%	2.2%	1.5%	2.2%	1.8%	2.0%	1.7%	1.7%	1.9%
Serious injury involvements ratio	15.8%	17.8%	15.1%	23.5%	14.7%	12.6%	12.4%	12.5%	11.9%	9.1%	14.5%
High impact accident involvement rate per million vehicle km	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	**0.02**
Medium impact accident involvement rate per million vehicle km	0.14	0.15	0.14	0.20	0.14	0.12	0.11	0.12	0.11	0.09	**0.13**

4.3.3.2 A summary of the base event frequencies is presented in **Table 4.5**.

Table 4.5 Summary of Base Event Frequencies

Events	Frequency of Occurrence
Aircraft Crash	6.6×10^{-12} per year[#]
Earthquake	1.0×10^{-5} per year
Vehicle Impact	1.5×10^{-7} per vehicle-km per year

4.4 Fault Tree Analysis

4.4.1.1 Fault Tree Analysis (FTA) was conducted to evaluate the frequencies of the identified biogas release scenarios. FTA is the use of a combination of simple logic gates, "AND" and "OR" gates, to synthesise a failure model of the biogas facilities. Fault Tree Analyses are shown in **Annex D**. The assumptions used in FTA are summarised in the following **Table 4.6**.

Table 4.6 Assumptions used in Fault Tree Analysis

Items	Assumed Value	Justification
Probability of rupture failure in aircraft crash	1	On conservative approach
Length of internal road close to biogas facilities	0.63 km	Measured from the site plan (**Annex A** refers).
No. vehicle movements per day	95	Included tankers, sludge collectors and staff vehicles
Probability of vehicle running into gasholder / digesters / absorption vessels / pipelines	0.5	With reference to approved EIA report of the OWTF Phase 2 [1], and based on the fact that concerned process vessels are only at one side of the road.
Probability of vehicle causing damage to gasholder / digesters / absorption vessels / pipelines	0.5	With reference to approved EIA report of the OWTF Phase 2 [1].
Probability pipeline rupture failure in car crash	0.1	With reference to approved EIA report of the OWTF Phase 2 [1].
Probability pipeline leak failure in car crash	0.9	With reference to approved EIA report of the OWTF Phase 2 [1].

4.5 Ignition and Explosion Probability

4.5.1.1 In general, the probability of immediate or delayed ignitions depends on the scale of release, the presence and location of ignition sources, and the weather conditions.

4.5.1.2 Possible ignition sources include hot surfaces, static electricity, flame and hot particles from external fire etc. [18]. The ignition probabilities are further split between immediate ignition and delayed ignition in equal proportions [1]. Immediate ignition of biogas could lead to a fireball or jet fire, whereas delayed ignition could cause a flash fire or vapour cloud explosion. **Table 4.7** shows the total ignition probabilities and explosion probabilities according to gas release size [18].

Table 4.7 Ignition and Explosion Probabilities for Gas Releases

Release Size	Ignition Probability	Explosion Probability
Minor (< 1 kg/s)	0.01	0.04
Major (1 – 50 kg/s)	0.07	0.12
Massive (> 50 kg/s)	0.3	0.3

4.5.1.3 Event Tree Analysis (ETA) was developed to determine the possible hazard event outcomes from the identified hazardous events and to estimate the hazard event frequencies from the initiating release frequency. Event Tree Analyses are shown in **Annex E**.

4.6 Estimating Generic Frequencies

4.6.1.1 Generic frequency was estimated based on the historical incidents review identified the accidents involving generation, transfer, storage and use of biogas or methane, anaerobic digesters or facilities of similar nature. The generic accident frequency can be estimated through the information of the number of biogas plants works involved, the operating period and the total number of accidents occurred within the operating period. The objective of the generic frequency estimation is to confirm the appropriateness of adopting generic failure frequencies for this hazard assessment.

4.6.1.2 The generic frequencies estimated based on European experience were 1.73×10^{-4} incident per plant-year [1], whilst the overall failure frequency for organic waste co-digestion facility was 3.97×10^{-3} per year (according to FTA shown in **Annex D**), which was greater than the estimated value from the European historical incidents. The failure frequencies adopted for the facility in this hazard assessment were therefore considered reasonably conservative.

5. CONSEQUENCE AND IMPACT ANALYSIS

5.1 Introduction

5.1.1.1 Consequence and impact analysis were conducted to provide a quantitative estimate of the likelihood and number of deaths associated with the range of possible outcomes (i.e. fireball, jet fire, flash fire etc.) which were resulted from failure cases identified. The consequence assessment consists of two major parts, including:

- Source term modelling – to determine the appropriate discharge models to be used for calculation of the release rate, duration and quantity of the release; and
- Effect modelling – to determine dispersion modelling, fire modelling and explosion modelling from the input of source term modelling.

5.1.1.2 Releases from hazardous sources and their consequences were modelled using PhastRisk 6.7.

5.2 Source Term

5.2.1.1 For instantaneous failure, the whole content release of a tank is modelled. In case of continuous release, release parameters such as release rate and exit velocity are calculated by a discharge model according to storage conditions. Release duration is based on capacity of the storage tank [1]. For piping connecting to the storage tank, release duration is based on the time to empty the whole tank gas content for anaerobic digesters and the response time to completely isolate the gasholder. Release parameters together with release duration are then fed into the dispersion model to calculate the effect. Process vessel, piping and storage vessel would be the major release sources.

5.3 Potential Hazardous Outcomes and Effect Modelling

5.3.1.1 This section gives a brief description of the physical effects models used in the study to assess the effects zones for the following hazardous outcomes in case of loss of containment at the co-digestion facility.

5.3.2 Fireball

5.3.2.1 The release rate following a rupture, if ignition was immediate, would be too high to give a stable flame, and the initial ‘quasi instantaneous’ release is characterised as a fireball. The fireball is limited to a maximum duration of 30 seconds. The combustion would develop into a stable jet fire once the instantaneous release has been burnt and the release rate has become sufficiently steady for a flame to stabilise as stated by Bilo and Kinsman [19]. A release from a hole, if ignited, gives a stable flame close to the hole and produces a jet fire.

5.3.2.2 Due to the large size and intensity of a fireball, its effects are not significantly influenced by weather or wind direction. The principal hazard of fireball arises from thermal radiation. The thermal radiation from a fireball at given distances from the fireball centre are estimated using the PhastRisk’s built-in fireball modelling suite in which TNO model and HSE model are adopted. The modelling suite is set such that it decides the most appropriate one in the effect modelling. Sizes, height, shape, duration, heat flux and radiation are determined in the consequence analysis. A 100% fatality is assumed for anyone within the fireball radius.

5.3.3 Jet Fire

5.3.3.1 A jet fire occurs following the ignition and combustion of a pressurised flammable gas, which burns close to the release source. The jet fire which follows the fire ball is assumed to be directed vertically upwards out of the crater. The jet fire shape is the frustum of a cone and the location and orientation of the frustum are dependent on a number of factors such as release rate and wind speed.

5.3.3.2 Combustion in a jet fire occurs in the form of a strong turbulent diffusion flame that is strongly influenced by the initial momentum of the release. The principal hazards from a jet fire are thermal radiation and the potential for knock-on effects. Jet fires also dissipate thermal radiation and causes casualty and damage to the population and property nearby. The thermal effect to adjacent population is quantified in the consequence model.

5.3.4 Gas Dispersion and Flash Fire

5.3.4.1 Since biogas is lighter than air, its releases will tend to rise rapidly due to the buoyancy nature of the gas under atmospheric conditions. They will propagate and be diluted as a result of air entrainment with the influence of wind. The Unified Dispersion Model (UDM) model is used for the dispersion calculation of biogas for non-immediate ignition scenarios. The model takes into account various transition phases, from dense cloud dispersion to buoyant passive gas dispersion, in both instantaneous and continuous releases.

5.3.4.2 The principal hazard arising from a cloud of dispersing biogas is the delayed ignition of the flammable cloud that cause a flame to flash back to the release location and develop into a stable jet or crater fire. Large scale experiments on the dispersion and ignition of flammable gas clouds show that ignition is unlikely when the average concentration is below the Lower Flammable Limit (LFL) or above the Upper Flammable Limit (UFL).

5.3.4.3 Major hazards from flash fire are thermal radiation and direct flame contact. It is considered that there is no scope for escape within the LFL of a flammable cloud in a flash fire. Therefore, a fatality probability of 100% of persons present within the flammable cloud is assumed for flash fires.

5.3.5 Vapour Cloud Explosion

5.3.5.1 A vapour cloud explosion can occur when a flammable vapour is ignited in a confined or partially confined situation. When there is a large amount of pressurised gas rapidly releasing to the atmosphere from a pressurised tank, a vapour cloud could be formed, dispersed and mixed with the surrounding air. If the vapour cloud is passing through a confined / semi-confined environment and gets ignited, the confinement could limit the degree of expansion of the burning cloud and create an overpressure and explosion.

5.3.5.2 The risk model will be accounted for the VCE hazard according to probabilities for delayed ignition in consequence modelling. The program models the delayed ignition effect by considering the flammable cloud area and location of ignition sources at each time step. Potential damage from a VCE is caused by overpressure.

5.4 Impact Assessment

5.4.1 Thermal Radiation

5.4.1.1 Hazardous consequences, such as jet fire, flash fire, etc. were assessed using PHAST's consequence models. Fatality probabilities of various hazardous event outcomes were evaluated at a number of end-point criteria in each type of hazard outcome. The estimation of the fatality/ injury caused by a physical effect such as thermal radiation or overpressure requires the use of probit equations, which describe the probability of fatality as a function of some physical effect. The probit is an alternative way of expressing the probability of fatality and is derived from a statistical transformation of the probability of fatality.

5.4.1.2 The probability of fatality, Pr, due to exposure to heat radiation, i.e. jet fire and fireball is given by the following probit relationship by Eisenberg et al. which provides one of the more conservative estimates [20]:

$$Pr = -14.9 + 2.56\ ln\left(Q^{\frac{4}{3}} \times t\right)$$

Where,
Pr is the probit associated with the probability of fatality;
Q is the heat radiation intensity (kW/m^2);

t is the exposure time (s).

5.4.2 Overpressure

5.4.2.1 The probability of fatality due to overpressure is taken from CIA guidelines [21] as shown in **Table 5.1**. The indoors fatality probability is higher taken into account the increased risk from flying debris such as breaking windows [8].

Table 5.1 End Point Criteria for Vapour Cloud Explosions

Overpressure (psi)	Fatality Probability (Outdoors)	Fatality Probability (Indoors)
5	0.09	0.55
3	0.02	0.15
1	0.00	0.01

6. RISK EVALUATION

6.1 Introduction

6.1.1.1 By combining the population data, meteorological data, results of frequency estimation and consequence analysis, risk levels due to the operation of the organic waste co-digestion facility at the proposed EPP are assessed and evaluated in terms of both individual and societal risks.

6.1.1.2 Individual risk is a measure of the risk to a chosen individual at a particular location. As such, this is evaluated by summing the contributions to that risk across a spectrum of incidents which could occur at a particular location.

6.1.1.3 Societal risk is a measure of the overall impact of an activity upon the surrounding community. As such, the likelihoods and consequences of the range of incidents postulated for that particular activity are combined to create a cumulative picture of the spectrum of the possible consequences and their frequencies. This is usually presented as an F-N curve and the acceptability of the results can be judged against the societal risk criterion under the risk guidelines.

6.2 Individual Risk

Risk Level

6.2.1.1 The individual risk (IR) contours associated with the organic waste co-digestion facility at the proposed EPP are shown in **Plate 6.1**. The risk levels were estimated based on 100% occupancy with no allowance made for shelter or escape, which can be referred from the user manual of PhastRisk.

6.2.1.2 The HKRG criterion for individual risk is that no person off-site should be subject to an additional risk of 1×10^{-5} per year.

Acceptability

6.2.1.3 Individual risk contours down to the level 1×10^{-9} per year are shown in the diagram. The level 1×10^{-5} per year individual risk contour is confined entirely within the boundary of the proposed EPP. The maximum individual risk remains below 1×10^{-5} per year at the site boundary and meets the HKRG requirements.

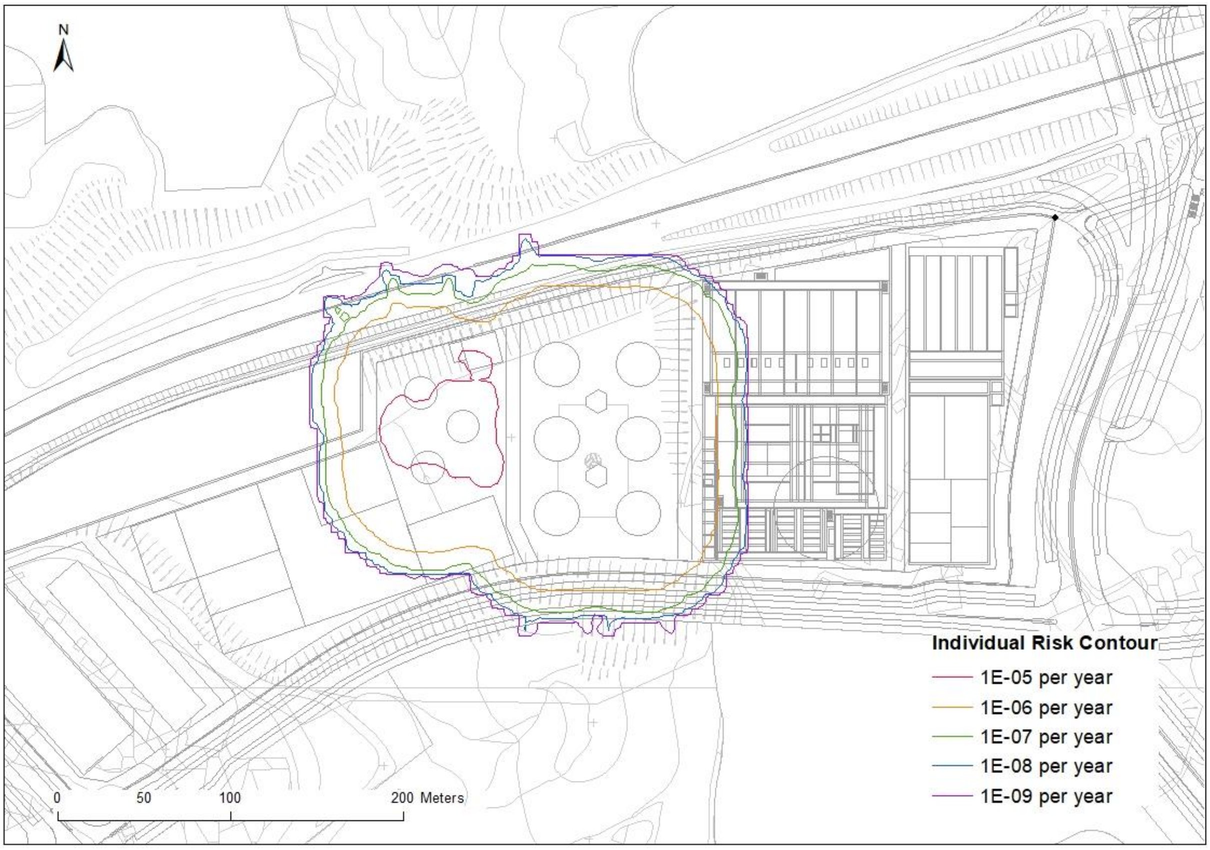

Plate 6.1 Individual Risk Contours for the Proposed EPP

6.3 Societal Risk

6.3.1.1 The societal risk results for the proposed EPP are presented in **Plate 6.2** in form of F-N curves for comparison with the HKRG.

Acceptability

6.3.1.2 The societal risk associated with operation of the biogas facilities in the proposed EPP falls within the "Acceptable" region. The potential loss of life (PLL) for the facility was estimated to be 3.09×10^{-6} per year and 3.57×10^{-6} per year for construction and operation phases respectively.

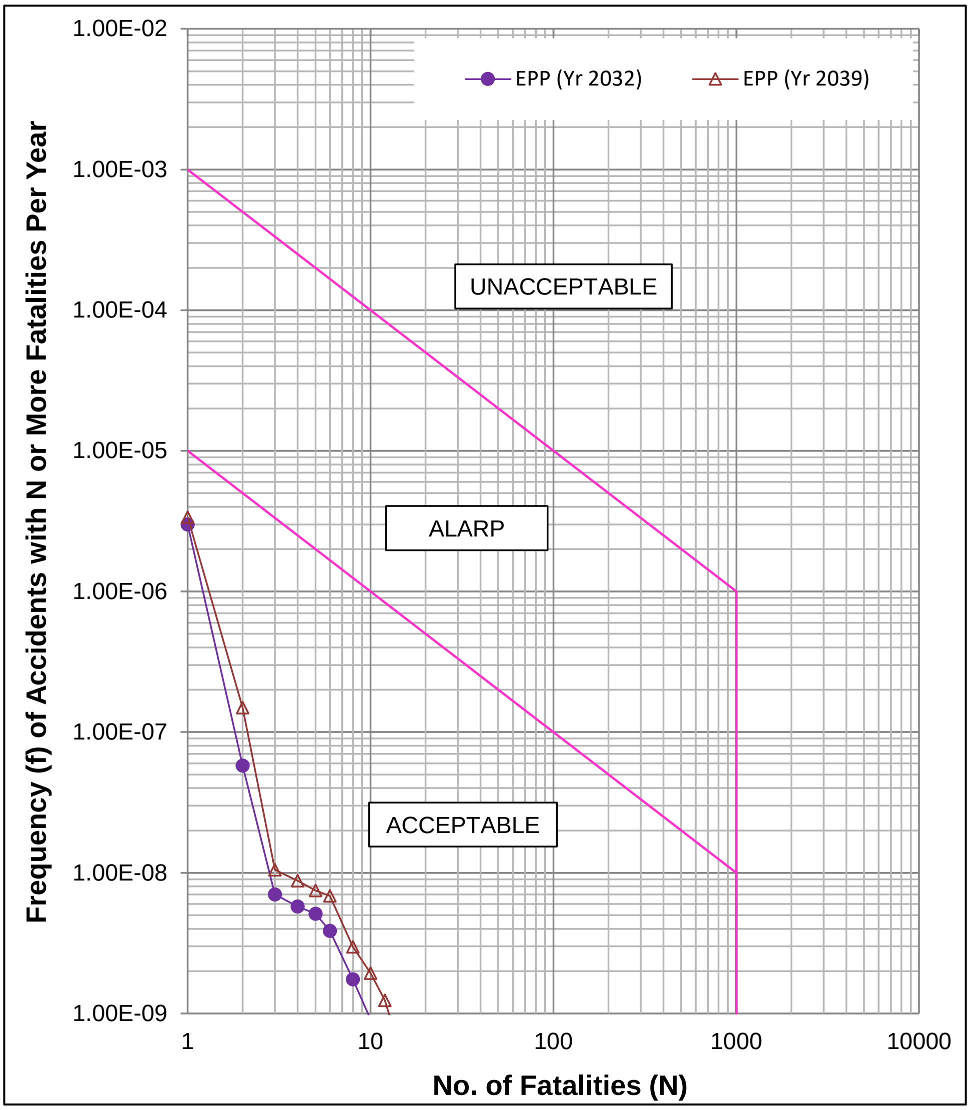

Plate 6.2 Societal Risk Curve in Comparison with HKRG

7. RECOMMENDATIONS

7.1.1.1 While the risks associated with organic waste co-digestion facility are within the acceptable region and no mitigation measures are required, it is still advisable for the following good safety practices and recommended design measures to be followed for the design and operation of the facility as far as practicable:

- the process plant building should be provided with adequate number of gas detectors distributed over various areas of potential leak sources to provide adequate coverage;
- all electrical equipment inside the building should be classified in accordance with the electrical area classification requirements. No unclassified electrical equipment should be used during operations or maintenance;
- all safety valves should be designed to discharge the released fluid to a safe location and stop misdirection of fluid flows in order to avoid hazardous outcome;
- safety markings and crash barriers should be provided to the aboveground piping, digesters and gas holders near the entrance;
- fixed crash barriers should be provided in areas where process equipment is adjacent to the internal roadway to protect against vehicle collision. Adequate warning signage and lighting should also be provided and maximum speed limit should also be in place; and
- lightning protection installations should be installed following *IEC 62305, BS EN 62305, AS/NZS 1768, NFPA 780* or equivalent standards;
- suitable fire extinguishers should be provided within the site. An External Water Spray System (EWSS) should be installed in appropriate areas, such as around the gasholders, digester and sulphur removal vessels. The facilities should also be equipped with fire and gas detection system and fire suppression system; and
- stringent procedures should be implemented to prohibit smoking or naked flames to be used on-site.

8. ENVIRONMENTAL MONITORING AND AUDIT REQUIREMENT

8.1.1.1 The EIA study concluded that no unacceptable risk is anticipated during the operation phase of the Project, no mitigation measures would be required. Good safety practices and recommended design measures are recommended to further manage and minimize the potential risks during operation phase of the Project. No environmental monitoring and audit requirements would be required.

9. CONCLUSION

9.1.1.1 A quantitative hazard assessment was conducted to evaluate the biogas risk to existing, committed and planned off-site population due to operation of the organic waste co-digestion facility at the proposed EPP in accordance with Section 3.4.14 and Appendix H of the EIA Study Brief (ESB-340/2021).

9.1.1.2 Both the individual and societal risk levels were found to meet relevant requirements stipulated in the HKRG, i.e. the off-site individual risk level is far below 1×10^{-5} per year and the societal risk falls into the “Acceptable” region, no mitigation measure is required.

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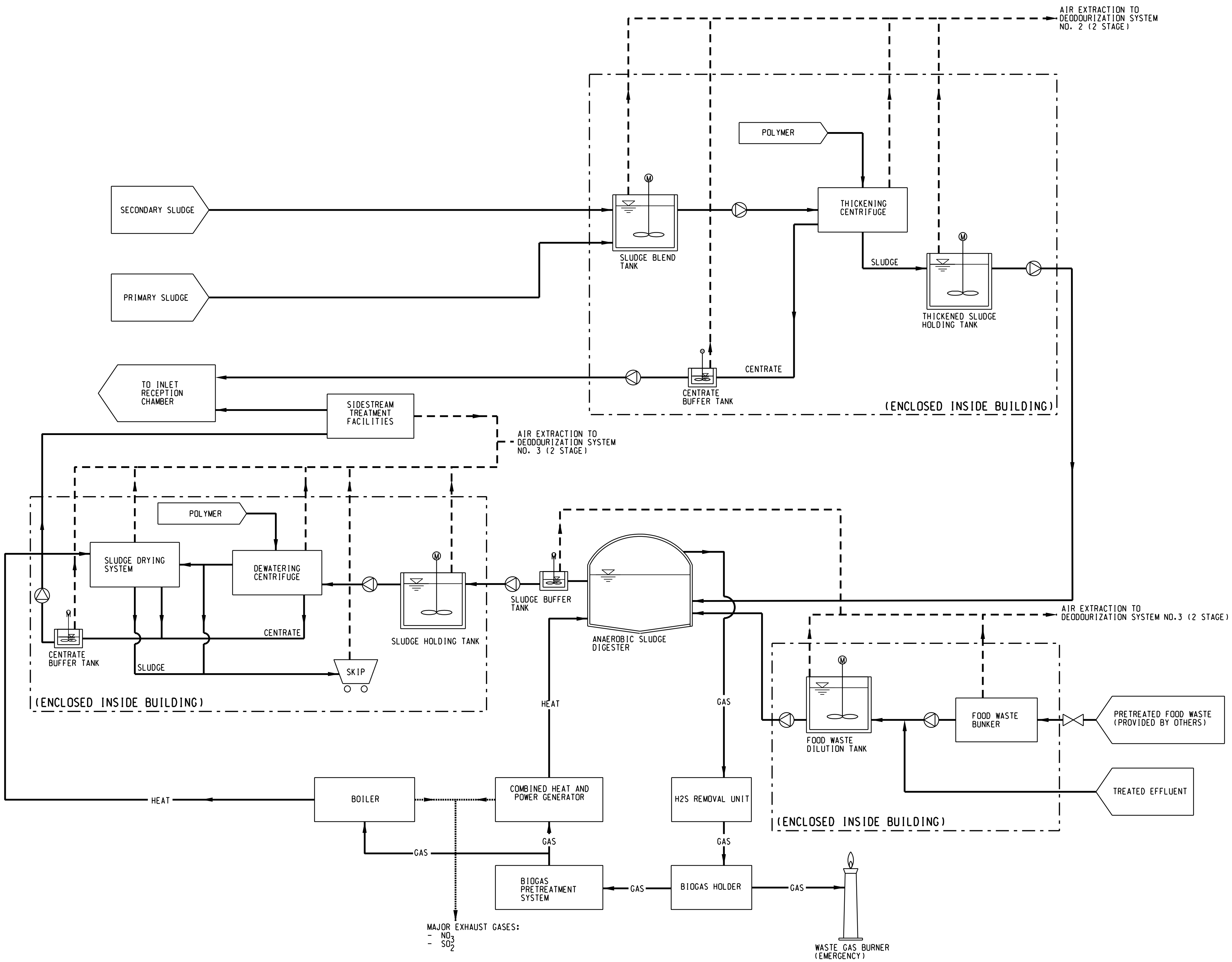
Annex A

Process Flow Description



AECOM

PROJECT 項目

FIRST PHASE DEVELOPMENT OF THE NEW TERRITORIES NORTH – SAN TIN / LOK MA CHAU DEVELOPMENT NODE – INVESTIGATION

CLIENT 業主

土木工程拓展署
CEDD Civil Engineering and Development Department

規劃署
Planning Department

CONSULTANT 工程顧問公司

AECOM Asia Company Ltd.
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ISSUE/REVISION 修訂

I/R 修訂	DATE 日期	DESCRIPTION 內容摘要	CHK. 複核

STATUS 階段

SCALE 比例 N.T.S.

DIMENSION UNIT 尺寸單位 METRES

KEY PLAN 索引圖

PROJECT NO. 項目編號 60670882

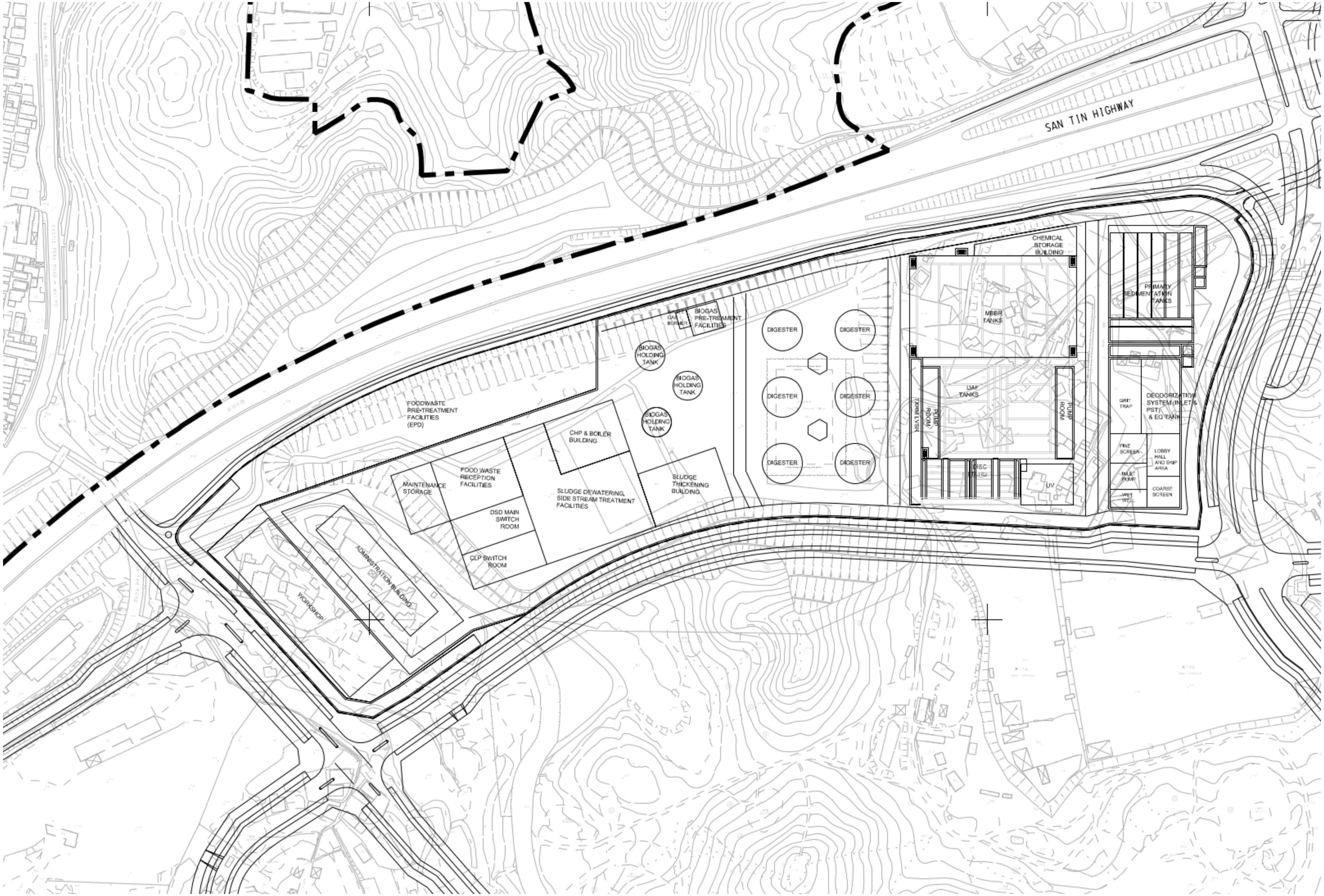
AGREEMENT NO. 協議編號 CE 20/2021

SHEET TITLE 圖紙名稱

SLUDEGE DIAGRAM

SHEET NUMBER 圖紙編號

60670882/A19/431



Proposed Layout of EPP

Annex B

Population Data

Popu_ID	Land_ID	Description	Maximum Population in 2032	Maximum Population in 2039	Indoor Ratio in 2032	% Occupancy in 2032				Population in 2032				Shielding Factor [FB]	Shielded Population in 2032			
						Weekday		Weekend		Weekday		Weekend			Weekday		Weekend	
						Day	Night	Day	Night	Day	Night	Day	Night		Day	Night	Day	Night
E02	-	Scenic Heights	106	106	0.95	0.5	1	0.7	1	53	106	74	106	0.5	27	53	37	53
E05	-	Mai Po San Tsuen	3164	3164	0.95	0.5	1	0.7	1	1582	3164	2215	3164	0.5	791	1582	1108	1582
P01	A.5.1	Amenity	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0
P02	OU(ESS).5.12	Reserve	0	0	0.95	1	0.1	0.5	0.1	0	0	0	0	0.5	0	0	0	0
P03	G.5.3	Existing Mai Po ESS	125	84	0	1	0.1	0.5	0.1	125	13	63	13	0	125	13	63	13
P04	G.5.1	Sport Centre	125	1018	0	1	0.1	0.5	0.1	125	13	63	13	0	125	13	63	13
P05	RSc.2.1	Public Housing	9899	9899	0.95	0.5	1	0.7	1	4950	9899	6929	9899	0.5	2475	4950	3465	4950
P06	RSc.2.2	Public Housing	7603	7603	0.95	0.5	1	0.7	1	3802	7603	5322	7603	0.5	1901	3802	2661	3802
P07a	OU(EPP).5.3	Food Waste Pretreatment Facilities	100	100	0.95	1	0.1	0.5	0.1	100	10	50	10	0.5	50	5	25	5
P08	OU(GFS).5.1	Green Fuel Station	10	10	0	1	1	1	1	10	10	10	10	0	10	10	10	10
P09	G.5.2	Reserve	0	0	0.95	1	0.1	0.5	0.1	0	0	0	0	0.5	0	0	0	0
P10	GB.5.3	Green Belt	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0
P11	OU(ESS).5.6	132kV ESS	0	0	0.95	1	0.1	0.5	0.1	0	0	0	0	0.5	0	0	0	0
P12	G.5.5	Reserve	0	0	0.95	1	0.1	0.5	0.1	0	0	0	0	0.5	0	0	0	0
P13	E.5.3	Reserve (Potential Education Facilities)	125	1680	0	1	0.1	0.5	0.1	125	13	63	13	0	125	13	63	13
P14	GB.5.4	Green Belt	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0
P15	OU(SPS).5.7	Sewage Pumping Station	30	30	0.95	1	0.1	0.5	0.1	30	3	15	3	0.5	15	2	8	2
P53	OU(LSW).1.2	Logistics, Storage and Warehouse	220	220	0.95	1	0.1	0.5	0.1	220	22	110	22	0.5	110	11	55	11
P54	OU(DSC).1.11	District Cooling System	25	25	0.95	1	0.1	0.5	0.1	25	3	13	3	0.5	13	2	7	2
P55	O.1.3	Open space	410	410	0	1	1	1	1	410	410	410	410	0	410	410	410	410
P56	OU(I&T)3.1.9	Information and Technology - Zone 3	80	5228	0	1	0.1	0.5	0.1	80	8	40	8	0	80	8	40	8
P57	OU(WRP).5.2	Water Reclamation Plant	100	100	0.95	1	0.1	0.5	0.1	100	10	50	10	0.5	50	5	25	5
P58	E.2.1	2 Primary School	129	1678	0	1	0.1	0.5	0.1	129	13	65	13	0	129	13	65	13
P59	OU(RCP).5.5	RCP	0	0	0.95	1	0.1	0.5	0.1	0	0	0	0	0.5	0	0	0	0
P60	GB.5.1	Green Belt	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0
P61	GB.5.2	Green Belt	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0
P63	A.1.17	Amenity	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0

Popu_ID	Indoor Ratio in 2039	% Occupancy in 2039				Population in 2039				Shielding Factor [FB]	Shielded Population in 2039			
		Weekday		Weekend		Weekday		Weekend			Weekday		Weekend	
		Day	Night	Day	Night	Day	Night	Day	Night		Day	Night	Day	Night
E02	0.95	0.5	1	0.7	1	53	106	74	106	0.5	27	53	37	53
E05	0.95	0.5	1	0.7	1	1582	3164	2215	3164	0.5	791	1582	1108	1582
P01	0	1	1	1	1	0	0	0	0	0	0	0	0	0
P02	0.95	1	0.1	0.5	0.1	0	0	0	0	0.5	0	0	0	0
P03	0.95	1	0.1	0.5	0.1	84	8	42	8	0.5	42	4	21	4
P04	0.95	1	0.1	0.5	0.1	1018	102	509	102	0.5	509	51	255	51
P05	0.95	0.5	1	0.7	1	4950	9899	6929	9899	0.5	2475	4950	3465	4950
P06	0.95	0.5	1	0.7	1	3802	7603	5322	7603	0.5	1901	3802	2661	3802
P07a	0.95	1	0.1	0.5	0.1	100	10	50	10	0.5	50	5	25	5
P08	0	1	1	1	1	10	10	10	10	0	10	10	10	10
P09	0.95	1	0.1	0.5	0.1	0	0	0	0	0.5	0	0	0	0
P10	0	1	1	1	1	0	0	0	0	0	0	0	0	0
P11	0.95	1	0.1	0.5	0.1	0	0	0	0	0.5	0	0	0	0
P12	0.95	1	0.1	0.5	0.1	0	0	0	0	0.5	0	0	0	0
P13	0.95	1	0	0.5	0	1680	0	840	0	0.5	840	0	420	0
P14	0	1	1	1	1	0	0	0	0	0	0	0	0	0
P15	0.95	1	0.1	0.5	0.1	30	3	15	3	0.5	15	2	8	2
P53	0.95	1	0.1	0.5	0.1	220	22	110	22	0.5	110	11	55	11
P54	0.95	1	0.1	0.5	0.1	25	3	13	3	0.5	13	2	7	2
P55	0	1	1	1	1	410	410	410	410	0	410	410	410	410
P56	0.95	1	0.1	0.5	0.1	5228	523	2614	523	0.5	2614	262	1307	262
P57	0.95	1	0.1	0.5	0.1	100	10	50	10	0.5	50	5	25	5
P58	0.95	1	0	0.5	0	1678	0	839	0	0.5	839	0	420	0
P59	0.95	1	0.1	0.5	0.1	0	0	0	0	0.5	0	0	0	0
P60	0	1	1	1	1	0	0	0	0	0	0	0	0	0
P61	0	1	1	1	1	0	0	0	0	0	0	0	0	0
P63	0	1	1	1	1	0	0	0	0	0	0	0	0	0

Road Population

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2032)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
Road R1													
Total Vehicle per hour	0.7	50	2	73	12	1	26	34	30	4	0	3	186
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	6	1	1	2	0	3	18
Road R2													
Total Vehicle per hour	0.16	50	9	299	50	5	49	115	100	16	0	7	652
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	3	1	1	2	0	2	14
Road R3													
Total Vehicle per hour	0.34	50	5	160	27	3	0	25	21	9	0	0	250
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	0	1	1	2	0	0	9
Road R4													
Total Vehicle per hour	0.69	50	6	183	30	3	3	45	39	11	0	4	323
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	1	1	1	3	0	3	16
Road R5													
Total Vehicle per hour	0.7	50	7	232	39	4	21	73	63	13	0	0	453
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	5	2	1	5	2	2	4	0	0	22
Road R6													
Total Vehicle per hour	0.58	100	106	3416	568	62	134	1266	1081	189	6	224	7051
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	28	7	2	13	10	8	23	0	66	158
Road R7													
Total Vehicle per hour	0.64	100	99	3197	532	58	131	1166	996	176	4	164	6524
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	29	7	2	14	10	8	23	0	54	148
Road R8													
Total Vehicle per hour	0.83	100	106	3440	572	62	131	1244	1064	189	5	192	7007
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	40	10	3	18	14	11	32	0	81	210
Road R9													
Total Vehicle per hour	0.68	100	77	2474	412	45	108	816	698	136	3	105	4872
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	24	6	2	12	8	6	19	0	37	115
Road R10													
Total Vehicle per hour	1.18	100	109	3518	586	64	108	903	772	192	4	147	6402
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		2	59	14	4	21	14	11	46	0	89	260
Road R11													
Total Vehicle per hour	0.19	50	7	238	39	4	3	142	121	14	5	201	774
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	1	1	1	2	0	39	49
Road R12													
Total Vehicle per hour	0.37	50	7	217	36	4	0	34	29	12	7	273	619
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	0	1	1	2	0	103	113
Road R13													
Total Vehicle per hour	0.32	50	3	101	17	2	0	29	25	5	1	38	222
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	13	20
Road R14													
Total Vehicle per hour	0.27	50	4	115	18	2	3	70	59	7	1	26	305
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	1	1	1	1	0	8	16
Road R15													
Total Vehicle per hour	0.45	50	4	133	22	2	0	37	32	7	0	7	246
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	0	1	1	2	0	4	13

Road R16													
Total Vehicle per hour	0.39	50	3	110	18	2	0	41	36	6	1	20	238
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	0	1	1	1	0	9	17

Road R17													
Total Vehicle per hour	0.13	50	2	74	12	1	0	11	10	4	2	62	179
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	9	16

Road R18													
Total Vehicle per hour	0.15	50	3	103	17	2	3	83	70	6	0	0	286
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	1	1	1	1	0	0	8

Road R19													
Total Vehicle per hour	0.37	50	2	56	9	1	52	36	30	3	1	53	244
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	7	1	1	1	0	21	35

Road R20													
Total Vehicle per hour	0.54	50	1	43	7	1	52	28	24	3	1	53	213
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	9	1	1	1	0	30	46

Road R21													
Total Vehicle per hour	0.44	50	2	65	11	1	67	13	11	4	1	51	227
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	10	1	1	1	0	23	40

Road R22													
Total Vehicle per hour	0.2	50	3	110	18	2	89	78	66	6	4	139	516
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	6	1	1	1	0	29	42

Road R23													
Total Vehicle per hour	0.45	50	9	281	47	5	17	86	73	16	3	109	645
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	3	2	1	3	0	50	66

Road R24													
Total Vehicle per hour	1.11	50	7	226	38	4	17	55	47	12	3	109	519
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	8	2	1	7	2	2	6	0	124	153

Road R25													
Total Vehicle per hour	0.86	50	5	161	27	3	0	31	27	9	5	185	453
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	1	1	4	0	163	176

Road R26													
Total Vehicle per hour	0.67	50	1	27	4	0	0	4	3	2	1	21	61
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	15	22

Road R27													
Total Vehicle per hour	0.63	50	0	7	1	0	0	4	3	0	1	21	36
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	14	21

Road R28													
Total Vehicle per hour	0.2	50	0	0	0	0	0	0	0	0	0	0	0
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		0	0	0	0	0	0	0	0	0	0	0

Road R29													
Total Vehicle per hour	0.15	50	0	0	0	0	0	0	0	0	0	0	0
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		0	0	0	0	0	0	0	0	0	0	0

Road R30													
Total Vehicle per hour	0.67	50	1	22	4	0	0	8	6	1	1	52	95
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	36	43

Road R31													
Total Vehicle per hour	1.62	50	7	219	36	4	5	125	107	12	0	4	519
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	10	3	1	3	6	5	9	0	7	45

Road R32													
Total Vehicle per hour	0.21	50	4	130	21	2	0	56	49	7	3	121	394
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	26	33

Road R33													
Total Vehicle per hour	0.6	50	28	918	154	17	0	38	32	49	0	0	1237
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	16	4	1	0	1	1	12	0	0	36

Road R34													
Total Vehicle per hour	0.42	50	7	238	39	4	12	127	108	14	1	42	593
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	2	2	2	3	0	19	34

Road R35													
Total Vehicle per hour	0.31	50	23	730	123	13	0	73	63	38	0	19	1082
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	7	2	1	0	1	1	5	0	6	24

Road R36													
Total Vehicle per hour	0.59	50	4	125	21	2	0	37	32	7	3	131	362
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	0	1	1	2	0	79	89

Road R37													
Total Vehicle per hour	0.25	50	0	12	2	0	0	3	3	1	0	0	21
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7

Road R38													
Total Vehicle per hour	0.38	50	4	139	23	3	0	41	35	8	3	131	388
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	0	1	1	2	0	51	60

Road R39													
Total Vehicle per hour	0.6	50	19	603	101	11	45	182	155	32	3	130	1281
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	11	3	1	9	3	3	8	0	80	119

Road R40													
Total Vehicle per hour	0.2	50	0	0	0	0	0	0	0	0	0	0	0
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7

Road R41													
Total Vehicle per hour	0.23	50	0	14	2	0	0	14	12	1	0	0	44
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7

Road R42													
Total Vehicle per hour	0.16	50	16	516	85	9	0	168	143	30	0	0	968
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	0	1	1	2	0	0	10

Road 43													
Total Vehicle per hour	0.24	50	16	531	88	10	0	170	145	30	1	25	1015
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	2	1	3	0	7	20

Road 44													
Total Vehicle per hour	0.32	50	8	259	43	5	0	61	52	14	0	0	442
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	0	1	1	2	0	0	10

Road 45													
Total Vehicle per hour	0.23	50	7	210	34	4	0	69	58	13	0	0	395
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	0	1	1	2	0	0	9

Road 46													
Total Vehicle per hour	0.25	50	11	358	60	6	0	75	64	20	0	0	594
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	0	1	1	2	0	0	10

[1] Person per vehicle is based on the average occupancy at core stations 5016 in Year 2019 from Transport Department - The Annual Traffic Census 2019

Road Population

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2032)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
Road R1													
Total Vehicle per hour	0.7	50	1	32	6	0	13	7	6	2	0	1	69
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	3	1	1	1	0	2	12
Road R2													
Total Vehicle per hour	0.16	50	5	149	29	1	24	23	21	6	0	3	261
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	2	1	1	1	0	1	10
Road R3													
Total Vehicle per hour	0.34	50	2	76	15	0	0	5	4	3	0	0	106
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Road R4													
Total Vehicle per hour	0.69	50	3	83	16	1	1	9	8	4	0	2	126
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	1	1	1	2	0	2	12
Road R5													
Total Vehicle per hour	0.7	50	4	115	22	1	10	14	13	5	0	0	184
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	3	1	1	2	0	0	13
Road R6													
Total Vehicle per hour	0.58	100	52	1673	322	8	66	242	216	73	4	102	2758
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	14	4	1	7	2	2	9	0	31	71
Road R7													
Total Vehicle per hour	0.64	100	49	1583	304	7	64	224	200	69	3	75	2579
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	15	4	1	7	2	2	9	0	25	66
Road R8													
Total Vehicle per hour	0.83	100	53	1704	328	8	64	239	214	74	3	88	2776
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	20	6	1	9	3	3	13	0	37	93
Road R9													
Total Vehicle per hour	0.68	100	38	1239	238	5	53	158	142	54	2	48	1977
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	12	4	1	6	2	2	8	0	17	53
Road R10													
Total Vehicle per hour	1.18	100	55	1778	341	8	53	175	157	77	3	67	2713
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	30	8	1	10	3	3	19	0	41	116
Road R11													
Total Vehicle per hour	0.19	50	4	112	22	1	1	27	24	5	4	93	292
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	1	1	1	1	0	18	26
Road R12													
Total Vehicle per hour	0.37	50	3	98	19	1	0	6	5	4	5	121	262
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	0	1	1	1	0	46	54
Road R13													
Total Vehicle per hour	0.32	50	2	52	10	0	0	5	5	2	1	17	94
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	6	13
Road R14													
Total Vehicle per hour	0.27	50	2	38	8	0	1	13	10	2	0	10	85
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	1	1	1	1	0	3	11
Road R15													
Total Vehicle per hour	0.45	50	2	65	12	0	0	7	7	3	0	3	100
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	2	9

Road R16													
Total Vehicle per hour	0.39	50	2	56	11	0	0	8	8	2	0	10	97
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	4	11

Road R17													
Total Vehicle per hour	0.13	50	1	38	7	0	0	2	2	2	1	26	79
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	4	11

Road R18													
Total Vehicle per hour	0.15	50	2	41	8	0	1	16	13	2	0	0	83
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	1	1	1	1	0	0	8

Road R19													
Total Vehicle per hour	0.37	50	1	25	5	0	26	7	6	1	1	25	96
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	4	1	1	1	0	10	21

Road R20													
Total Vehicle per hour	0.54	50	1	19	4	0	26	5	5	1	1	25	85
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	5	1	1	1	0	14	26

Road R21													
Total Vehicle per hour	0.44	50	1	27	5	0	33	3	2	1	1	24	97
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	5	1	1	1	0	11	23

Road R22													
Total Vehicle per hour	0.2	50	2	54	10	0	44	15	13	2	3	64	208
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	3	1	1	1	0	14	24

Road R23													
Total Vehicle per hour	0.45	50	4	134	26	1	9	17	15	6	2	51	264
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	2	1	1	2	0	24	35

Road R24													
Total Vehicle per hour	1.11	50	4	113	22	0	9	11	10	5	2	51	226
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	4	1	1	3	0	58	74

Road R25													
Total Vehicle per hour	0.86	50	2	80	15	0	0	6	5	3	3	86	202
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	0	1	1	2	0	76	85

Road R26													
Total Vehicle per hour	0.67	50	0	12	2	0	0	1	1	1	0	10	27
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	7	14

Road R27													
Total Vehicle per hour	0.63	50	0	3	1	0	0	1	1	0	0	10	14
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	7	14

Road R28													
Total Vehicle per hour	0.2	50	0	0	0	0	0	0	0	0	0	0	0
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		0	0	0	0	0	0	0	0	0	0	0

Road R29													
Total Vehicle per hour	0.15	50	0	0	0	0	0	0	0	0	0	0	0
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		0	0	0	0	0	0	0	0	0	0	0

Road R30													
Total Vehicle per hour	0.67	50	0	8	2	0	0	1	1	0	1	17	29
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	12	19

Road R31													
Total Vehicle per hour	1.62	50	3	108	21	1	3	24	21	5	0	2	187
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	5	2	1	2	2	1	4	0	3	21

Road R32													
Total Vehicle per hour	0.21	50	2	62	12	0	0	11	10	3	2	56	159
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	13	20

Road R33													
Total Vehicle per hour	0.6	50	14	480	92	2	0	7	6	20	0	0	622
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	9	3	1	0	1	1	5	0	0	21

Road R34													
Total Vehicle per hour	0.42	50	4	102	20	1	6	24	21	5	1	19	202
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	1	1	1	1	0	9	18

Road R35													
Total Vehicle per hour	0.31	50	12	394	75	1	0	14	13	16	0	9	534
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	1	1	3	0	3	15

Road R36													
Total Vehicle per hour	0.59	50	2	60	12	0	0	7	6	3	2	61	153
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	37	44

Road R37													
Total Vehicle per hour	0.25	50	0	6	1	0	0	1	1	0	0	0	9
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7

Road R38													
Total Vehicle per hour	0.38	50	2	69	13	0	0	8	7	3	2	61	166
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	24	31

Road R39													
Total Vehicle per hour	0.6	50	9	320	61	1	22	35	31	13	2	60	556
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	6	2	1	5	1	1	4	0	37	58

Road R40													
Total Vehicle per hour	0.2	50	0	0	0	0	0	0	0	0	0	0	0
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7

Road R41													
Total Vehicle per hour	0.23	50	1	43	7	1	0	32	28	2	0	0	114
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7

Road R42													
Total Vehicle per hour	0.16	50	16	516	85	9	0	168	143	30	0	0	968
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	0	1	1	2	0	0	10

Road 43													
Total Vehicle per hour	0.24	50	16	531	88	10	0	170	145	30	1	25	1015
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	2	1	3	0	7	20

Road 44													
Total Vehicle per hour	0.32	50	8	259	43	5	0	61	52	14	0	0	442
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	0	1	1	2	0	0	10

Road 45													
Total Vehicle per hour	0.23	50	7	210	34	4	0	69	58	13	0	0	395
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	0	1	1	2	0	0	9

Road 46													
Total Vehicle per hour	0.25	50	11	358	60	6	0	75	64	20	0	0	594
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	0	1	1	2	0	0	10

Note:
[1] Person per vehicle is based on the average occupancy at core stations 5016 in Year 2019 from Transport Department - The Annual Traffic Census 2019

Road Population

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2039)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
Road R1													
Total Vehicle per hour	0.7	50	6	185	30	3	26	86	74	11	0	3	425
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	6	2	2	4	0	3	24
Road R2													
Total Vehicle per hour	0.16	50	22	725	120	13	49	238	203	40	0	7	1419
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	3	1	1	3	0	2	17
Road R3													
Total Vehicle per hour	0.34	50	20	661	110	12	0	124	107	37	0	0	1071
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	7	2	1	0	2	1	6	0	0	20
Road R4													
Total Vehicle per hour	0.69	50	23	733	122	13	3	148	126	40	0	4	1212
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	15	4	1	1	3	3	12	0	3	43
Road R5													
Total Vehicle per hour	0.7	50	9	287	48	5	21	106	91	15	0	0	582
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	6	2	1	5	2	2	5	0	0	24
Road R6													
Total Vehicle per hour	0.58	100	152	4909	816	89	133	1785	1522	270	6	228	9910
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	40	9	3	13	14	11	32	0	68	191
Road R7													
Total Vehicle per hour	0.64	100	124	4007	667	73	131	1416	1210	220	4	159	8011
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	36	9	3	14	12	10	29	0	52	166
Road R8													
Total Vehicle per hour	0.83	100	154	4969	827	90	131	1557	1330	272	5	185	9520
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		2	58	14	4	18	17	14	46	0	79	252
Road R9													
Total Vehicle per hour	0.68	100	94	3046	508	55	108	748	640	166	3	116	5485
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	30	7	2	12	7	6	23	0	41	129
Road R10													
Total Vehicle per hour	1.18	100	136	4409	736	80	108	853	730	238	4	153	7448
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		2	73	17	5	21	14	11	58	0	92	293
Road R11													
Total Vehicle per hour	0.19	50	17	560	93	10	3	269	229	32	6	225	1443
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	1	2	2	3	0	44	58
Road R12													
Total Vehicle per hour	0.37	50	43	1389	231	25	0	262	223	77	4	157	2410
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	15	4	1	0	3	2	12	0	60	98
Road R13													
Total Vehicle per hour	0.32	50	10	336	55	6	0	136	116	20	1	41	721
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	2	1	3	0	14	27
Road R14													
Total Vehicle per hour	0.27	50	18	566	94	10	3	232	197	31	1	28	1179
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	5	1	1	1	2	2	4	0	8	25
Road R15													
Total Vehicle per hour	0.45	50	17	561	93	10	0	66	56	31	0	0	835
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	8	2	1	0	1	1	6	0	0	20

Road R16													
Total Vehicle per hour	0.39	50	12	401	67	7	0	75	64	22	1	25	674
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	5	1	1	0	1	1	4	0	11	25

Road R17													
Total Vehicle per hour	0.13	50	13	424	70	8	0	88	75	24	1	26	729
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	0	1	1	2	0	4	13

Road R18													
Total Vehicle per hour	0.15	50	6	204	34	4	3	136	115	11	1	28	540
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	1	1	1	1	0	5	13

Road R19													
Total Vehicle per hour	0.37	50	9	275	45	5	52	84	71	16	1	53	612
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	7	1	1	3	0	21	39

Road R20													
Total Vehicle per hour	0.54	50	8	266	44	5	52	87	74	15	1	53	607
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	5	1	1	9	2	1	4	0	30	54

Road R21													
Total Vehicle per hour	0.44	50	10	315	52	6	67	95	82	17	1	51	696
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	10	2	1	4	0	23	47

Road R22													
Total Vehicle per hour	0.2	50	10	329	54	6	89	149	127	19	4	139	925
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	6	1	1	2	0	29	44

Road R23													
Total Vehicle per hour	0.45	50	9	295	49	5	17	97	83	16	3	109	684
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	3	2	1	4	0	50	67

Road R24													
Total Vehicle per hour	1.11	50	8	244	41	4	17	62	53	13	3	121	567
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	8	2	1	7	2	2	7	0	138	168

Road R25													
Total Vehicle per hour	0.86	50	14	459	76	8	0	72	62	25	4	159	880
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	12	3	1	0	2	2	9	0	140	170

Road R26													
Total Vehicle per hour	0.67	50	15	478	80	9	0	121	103	26	2	68	901
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	9	3	1	0	3	2	8	0	47	74

Road R27													
Total Vehicle per hour	0.63	50	11	346	58	6	0	75	64	19	2	89	671
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	7	2	1	0	2	1	5	0	58	77

Road R28													
Total Vehicle per hour	0.2	50	15	491	81	9	0	127	108	28	1	52	913
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	0	1	1	3	0	11	22

Road R29													
Total Vehicle per hour	0.15	50	17	542	90	10	0	136	116	30	2	68	1011
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	0	1	1	2	0	11	21

Road R30													
Total Vehicle per hour	0.67	50	11	340	56	6	0	78	66	19	3	98	676
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	7	2	1	0	2	2	6	0	67	88

Road R31													
Total Vehicle per hour	1.62	50	12	376	62	7	5	182	156	21	0	4	826
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	18	4	1	3	8	7	15	0	7	64

Road R32													
Total Vehicle per hour	0.21	50	9	297	49	5	0	211	181	17	3	121	894
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	0	2	1	2	0	26	36

Road R33													
Total Vehicle per hour	0.6	50	39	1265	212	23	0	118	100	67	0	0	1825
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	22	5	2	0	2	2	17	0	0	51

Road R34													
Total Vehicle per hour	0.42	50	15	481	78	9	12	251	215	29	1	36	1127
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	6	2	1	2	3	3	5	0	16	39

Road R35													
Total Vehicle per hour	0.31	50	30	965	163	17	0	71	61	49	0	13	1370
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	9	2	1	0	1	1	7	0	5	27

Road R36													
Total Vehicle per hour	0.59	50	5	164	27	3	0	50	42	9	3	118	422
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	0	1	1	3	0	72	83

Road R37													
Total Vehicle per hour	0.25	50	0	12	2	0	0	3	3	1	0	0	21
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7

Road R38													
Total Vehicle per hour	0.38	50	2	69	11	1	0	33	28	4	3	131	282
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	51	58

Road R39													
Total Vehicle per hour	0.6	50	31	991	166	18	45	268	229	52	4	154	1958
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	17	4	1	9	5	4	13	0	95	149

Road R40													
Total Vehicle per hour	0.2	50	4	129	21	2	0	23	19	7	0	0	206
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7

Road R41													
Total Vehicle per hour	0.23	50	0	14	2	0	0	14	12	1	0	0	44
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7

Road R42													
Total Vehicle per hour	0.16	50	21	674	111	12	0	225	192	38	0	0	1274
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	1	1	3	0	0	12

Road 43													
Total Vehicle per hour	0.24	50	22	722	120	13	0	227	194	41	1	25	1364
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	5	2	1	0	2	2	4	0	7	24

Road 44													
Total Vehicle per hour	0.32	50	14	442	73	8	0	79	67	25	0	0	708
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	1	1	4	0	0	13

Road 45													
Total Vehicle per hour	0.23	50	10	330	54	6	0	89	75	19	0	0	583
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	0	1	1	2	0	0	10

Road 46													
Total Vehicle per hour	0.25	50	14	452	75	8	0	94	80	25	0	0	748
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	1	1	3	0	0	12

[1] Person per vehicle is based on the average occupancy at core stations 5016 in Year 2019 from Transport Department - The Annual Traffic Census 2019

Road Population

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2039)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
Road R1													
Total Vehicle per hour	0.7	50	3	76	15	1	13	17	16	4	0	1	145
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	3	1	1	2	0	2	14
Road R2													
Total Vehicle per hour	0.16	50	11	358	69	2	24	46	41	16	0	3	570
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	2	1	1	2	0	1	12
Road R3													
Total Vehicle per hour	0.34	50	10	327	63	2	0	24	22	14	0	0	462
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	1	1	2	0	0	11
Road R4													
Total Vehicle per hour	0.69	50	11	364	70	2	1	28	25	16	0	2	520
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	8	2	1	1	1	1	5	0	2	22
Road R5													
Total Vehicle per hour	0.7	50	5	151	29	1	10	21	19	6	0	0	241
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	3	1	1	2	0	0	13
Road R6													
Total Vehicle per hour	0.58	100	76	2439	469	11	66	343	304	107	4	105	3923
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	20	6	1	7	3	3	13	0	31	85
Road R7													
Total Vehicle per hour	0.64	100	62	2005	385	9	64	273	243	87	3	73	3205
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	18	5	1	7	3	2	12	0	24	73
Road R8													
Total Vehicle per hour	0.83	100	77	2489	478	11	64	300	268	108	3	85	3884
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	29	8	1	9	4	3	19	0	36	110
Road R9													
Total Vehicle per hour	0.68	100	47	1548	297	6	53	145	131	67	2	53	2350
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	15	4	1	6	2	2	10	0	19	60
Road R10													
Total Vehicle per hour	1.18	100	69	2263	434	9	53	165	149	97	3	70	3312
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	38	10	1	10	3	3	24	0	43	133
Road R11													
Total Vehicle per hour	0.19	50	9	265	51	1	1	51	45	12	4	104	545
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	1	1	1	1	0	21	30
Road R12													
Total Vehicle per hour	0.37	50	21	690	133	3	0	50	44	30	3	73	1048
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	8	2	1	0	1	1	5	0	28	47
Road R13													
Total Vehicle per hour	0.32	50	5	146	28	1	0	26	23	7	1	19	256
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	0	1	1	1	0	7	15
Road R14													
Total Vehicle per hour	0.27	50	9	288	55	1	1	44	38	12	1	13	462
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	1	1	1	2	0	4	15
Road R15													
Total Vehicle per hour	0.45	50	9	278	54	1	0	13	12	12	0	0	378
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	1	1	3	0	0	12

Road R16													
Total Vehicle per hour	0.39	50	6	206	39	1	0	15	13	9	0	12	301
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	0	1	1	2	0	5	15
Road R17													
Total Vehicle per hour	0.13	50	7	208	40	1	0	17	15	9	1	13	309
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	2	9
Road R18													
Total Vehicle per hour	0.15	50	3	102	20	0	1	26	22	4	1	13	192
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	1	1	1	1	0	2	10
Road R19													
Total Vehicle per hour	0.37	50	4	130	25	1	26	16	14	6	1	25	247
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	4	1	1	1	0	10	22
Road R20													
Total Vehicle per hour	0.54	50	4	123	24	1	26	17	15	6	1	25	240
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	5	1	1	2	0	14	28
Road R21													
Total Vehicle per hour	0.44	50	5	157	30	1	33	18	17	7	1	24	292
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	5	1	1	2	0	11	25
Road R22													
Total Vehicle per hour	0.2	50	5	150	29	1	44	29	26	7	3	64	357
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	3	1	1	1	0	14	24
Road R23													
Total Vehicle per hour	0.45	50	5	144	28	1	9	19	17	6	2	51	280
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	2	1	1	2	0	24	35
Road R24													
Total Vehicle per hour	1.11	50	4	123	24	1	9	12	11	5	2	56	246
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	4	1	1	3	0	64	80
Road R25													
Total Vehicle per hour	0.86	50	7	226	44	1	0	14	13	10	3	74	392
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	6	2	1	0	1	1	4	0	65	81
Road R26													
Total Vehicle per hour	0.67	50	7	239	46	1	0	23	21	10	1	31	381
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	5	2	1	0	1	1	3	0	22	36
Road R27													
Total Vehicle per hour	0.63	50	5	171	33	1	0	15	13	8	2	41	289
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	1	1	2	0	27	38
Road R28													
Total Vehicle per hour	0.2	50	8	231	45	1	0	24	22	11	1	24	366
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	0	1	1	1	0	5	13
Road R29													
Total Vehicle per hour	0.15	50	8	274	53	1	0	26	23	12	1	31	430
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	0	1	1	1	0	5	13
Road R30													
Total Vehicle per hour	0.67	50	5	164	32	1	0	15	13	7	2	45	285
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	1	1	2	0	31	42
Road R31													
Total Vehicle per hour	1.62	50	6	178	34	1	3	35	32	8	0	2	299
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	9	3	1	2	2	2	6	0	3	29
Road R32													
Total Vehicle per hour	0.21	50	5	139	27	1	0	41	37	6	2	56	313
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	13	20

Road R33													
Total Vehicle per hour	0.6	50	20	673	129	2	0	23	20	28	0	0	894
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	12	3	1	0	1	1	7	0	0	26
Road R34													
Total Vehicle per hour	0.42	50	7	198	39	2	6	49	44	10	1	17	371
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	1	1	1	2	0	8	19
Road R35													
Total Vehicle per hour	0.31	50	15	540	103	1	0	14	13	22	0	6	715
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	5	2	1	0	1	1	3	0	2	16
Road R36													
Total Vehicle per hour	0.59	50	3	84	16	0	0	10	8	4	2	55	181
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	2	1	1	0	1	1	1	0	33	41
Road R37													
Total Vehicle per hour	0.25	50	0	6	1	0	0	1	1	0	0	0	9
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Road R38													
Total Vehicle per hour	0.38	50	1	32	6	0	0	6	6	1	2	61	115
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	24	31
Road R39													
Total Vehicle per hour	0.6	50	16	526	101	2	22	52	46	22	3	71	860
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	9	3	1	5	1	1	6	0	44	71
Road R40													
Total Vehicle per hour	0.2	50	2	61	12	0	0	4	4	3	0	0	85
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Road R41													
Total Vehicle per hour	0.23	50	1	43	7	1	0	33	28	2	0	0	115
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Road R42													
Total Vehicle per hour	0.16	50	21	674	111	12	0	225	192	38	0	0	1274
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	1	1	3	0	0	12
Road 43													
Total Vehicle per hour	0.24	50	22	722	120	13	0	227	194	41	1	25	1364
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	5	2	1	0	2	2	4	0	7	24
Road 44													
Total Vehicle per hour	0.32	50	14	442	73	8	0	79	67	25	0	0	708
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	1	1	4	0	0	13
Road 45													
Total Vehicle per hour	0.23	50	10	330	54	6	0	89	75	19	0	0	583
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	3	1	1	0	1	1	2	0	0	10
Road 46													
Total Vehicle per hour	0.25	50	14	452	75	8	0	94	80	25	0	0	748
Person per vehicle [1]	-		1.0	1.4	1.9	4.5	15.9	1.3	1.2	20.3	0.0	50.9	-
No. of Person	-		1	4	1	1	0	1	1	3	0	0	12

Note:
[1] Person per vehicle is based on the average occupancy at core stations 5016 in Year 2019 from Transport Department - The Annual Traffic Census 2019

Annex C

Review of Historic Incidents Database

Annex C Review of Historical Incidents Database

Year	Location	Injury	Death	Description	Reference	Source of Accident
1988	US	0	0	2 underground pipelines, one carrying methane and the other propane, ruptured causing an explosion leaving 25ft deep, 30ft diameter crater. Flames were sent 300ft into the air. Firefighter could not apprach the fire because of the heat.	MHIDAS	Methane Transportation Pipeline
1989	UK	2	0	Pipework being cooled down prior to export of gas. Gas drained into burner and flashed back igniting gas in the vicinity.	MHIDAS	Methane Transportation Pipeline
1992	Turkey	64	32	Explosion in 1000m3 storage tank under factory canteen. Suspected methane being pumped in with water. 32 killed due to blast and drowning. 64 injured.	MHIDAS	Methane Storage Tank
1996	India		3	Tank of methane gas exploded at effluent treatment plant while welding work was being complete on tank's roofs. Three workers killed and 1 seriously injured. Workers were trying to prevent gas leaks upon orders of state pollution control officers.	MHIDAS	Methane Storage Tank
1997	Italy	1	2	In a municipal sewage plant (wastewater), an explosion occurred during repair work in a concrete silo of a biogas plant. Residue gas and welding operations are the cause of the accident. Two workers were thrown out and killed, and a third one falls to the bottom of the building and was seriously injured. The roof of the silo has been blown.	(i), (ii), (iii)	Biogas in Anaerobic Digestion Plant
1999	France	0	0	In a recycling unit of biogas from the anaerobic treatment plant of a paper mill, an explosion (5kg of TNT) buffer destoryed a ballon of flexible material 10m and their associated piping supplying a boiler or stream flare safety. The ballon exploded, the railings are bent in a radius of 3m, the tiles are destoryed within a radius of 20m, claddding and windows on the unit up to 130m fly into pieces away. There has been no victim. The balloon will be blocked and downhill into depression. Air would be entered by Telfon joints rubbing on the central axis. The biogas has come back and then has formed the explosive mixture which has been ignited by the pilot flame of the flare. An accidental production of hydrogen in the digester and an act of malice were also discussed. Expertise was made. Safety devices were then installed (analyzers, valves, etc.	(i), (ii), (iii)	Biogas in Anaerobic Digestion Plant
2002	Australia	0	0	Gas started leaking from gasometer after tank top tilted. Situation worsened as gas was still being pumped into tank. 2km safety zone imposed.	MHIDAS	Methane Storage Tank
2006	Germany	0	0	At a biogas plant for the treatment of household waste in the vicinity of Göttingen, two fermentation tanks burst, causing around seven million litres of fermentation sludge and rainwater to spread over adjacent fields. A third 20-m-high tank was at risk of collapsing. The mixture ran down from the plateau on which the plant had been built and polluted not only the site but also two bodies of water. There was no risk to the population. However, the bursting force of the standing fermenters caused damage to an adjacent building and a fuel oil tank, from which about 1,000 litres of fuel oil leaked. The amount of the loss was approximately €10m. To date, it has not been possible to clearly ascertain the cause of the loss – it was probably due to a tank failure.	(iv)	Biogas in Anaerobic Digestion Plant
2007	Germany	0	0	An accident also occurred at a biogas plant in Daugendorf, near Riedlingen in Southern Germany. The cause of the accident, in which the plant's 20-m-high and 17-m-wide fermenter ruptured, leaving behind a scene of devastation, is still unknown. The biomass in the fermenter spread up to 200 m around the plant. Several items of construction equipment were badly damaged, while the	(iv)	Biogas in Anaerobic Digestion Plant

Year	Location	Injury	Death	Description	Reference	Source of Accident
				buildings in the immediate vicinity were partially destroyed. Several hundred litres of fuel oil poured out of an overturned tank. The plant had only begun operating two days before. The property damage came to around €1.5m and the business interruption loss to around €1m.		
2009	Germany	2	1	An explosion occurred at a biogas plant and killed a worker and injured two others.	(v)	Biogas in Anaerobic Digestion Plant
2009	India	3	4	A large biogas reactor built in masonry and RCC in Edathala Panchayat Ernakulam District exploded during the commissioning stage, killing four persons and injuring three. The tragedy occurred at 11.30 Hrs on 19th August 2009. The explosion happened when some outlet steel pipe was getting welded or heated by a welder. During the week before the accident, the reactor was partially charged for trial operations with animal dung and other wastes. Gas was getting accumulated and an explosive mixture was naturally building up in the upper spaces of the reactor which could measure a several hundreds of cubic meters. The spark or naked flame from the welding equipment could instantly trigger the explosion of such a large mass of gas-air mix and explosion was severely felt and heard even thousands of feet away. More than a dozen of people were standing on the roof of the reactor or working nearby, when the roof structures caved in as the result of the explosion. Three workers fell into the thick slurry, and one of them was extricated safe with great difficulty and two died, whose dead bodies were recovered later. Workers, standing nearby including the welder, were thrown away by the explosion and two of them died instantly. It was clear that the rule book was violated on several counts. The plant was built unlawfully by the Arabic College Trust.	(vi), (vii)	Biogas in Anaerobic Digestion Plant

Note:

(i) FACTS, http://www.factsonline.nl/

(ii) ARIA, http://www.aria.developpement-durable.gouv.fr/

(iii) Biogas Production - Safety & Regulation, Discussion document for the workshop organized on 24 November 2010 in Paris, Version 09, compiled by Samuel Delsinne, November 2010

(iv) Renewable Energies, German Insurance Association, Berlin: 2008

(v) Industrial Fire World, http://www.fireworld.com/incident_logs/incident_log.php

(vi) Gas Plant Tragedy at Edathala, Visit Report By Er K Vijayachandran FIE And Dr. TV Jacob FIE, Cochin Centre For Policy Initiatives

(vii) "Four killed in explosion at Aluva biogas plant", The Hindu, 27 August, 2009

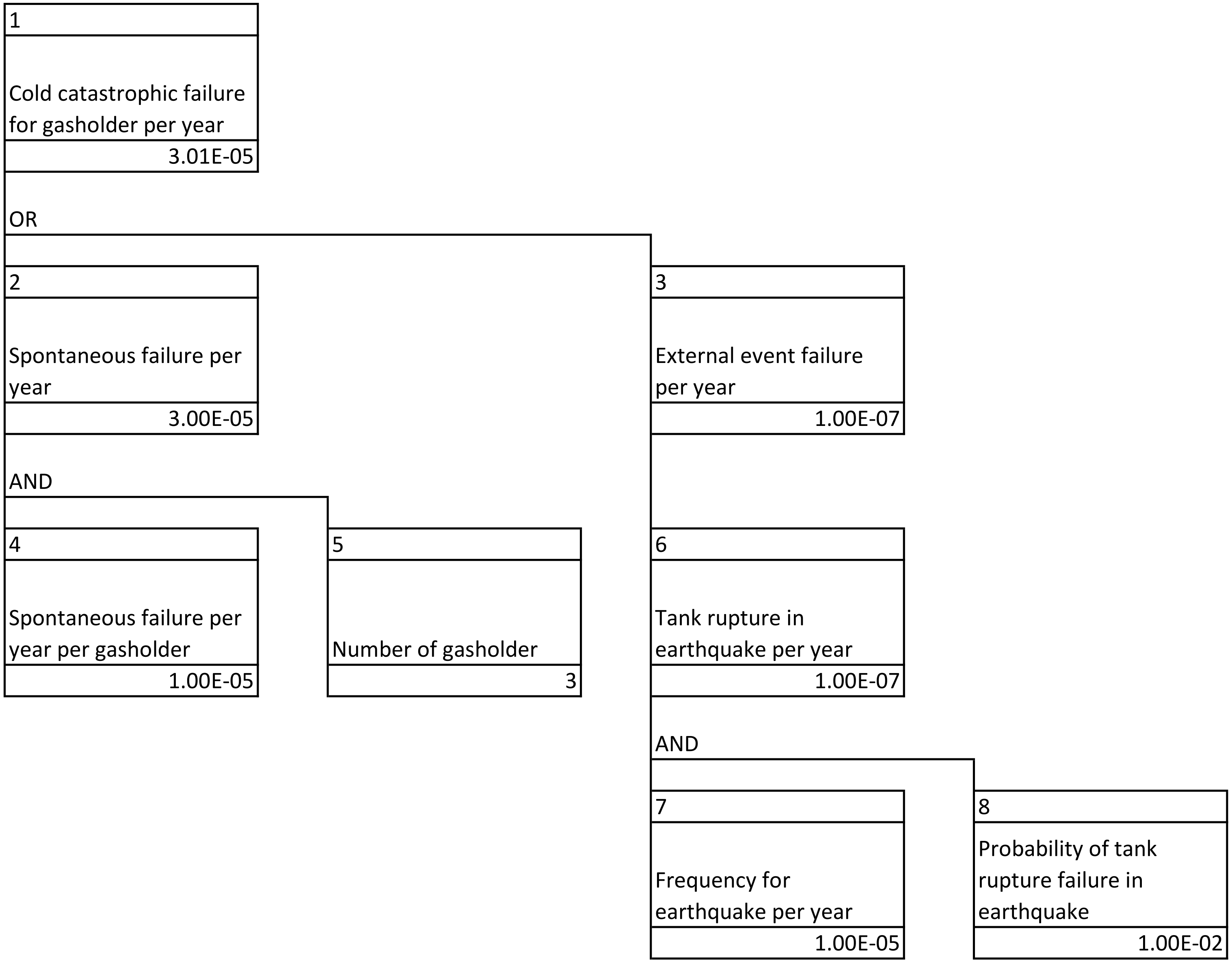
(viii) No record related to biogas accident was found in eMARS database.

Annex D

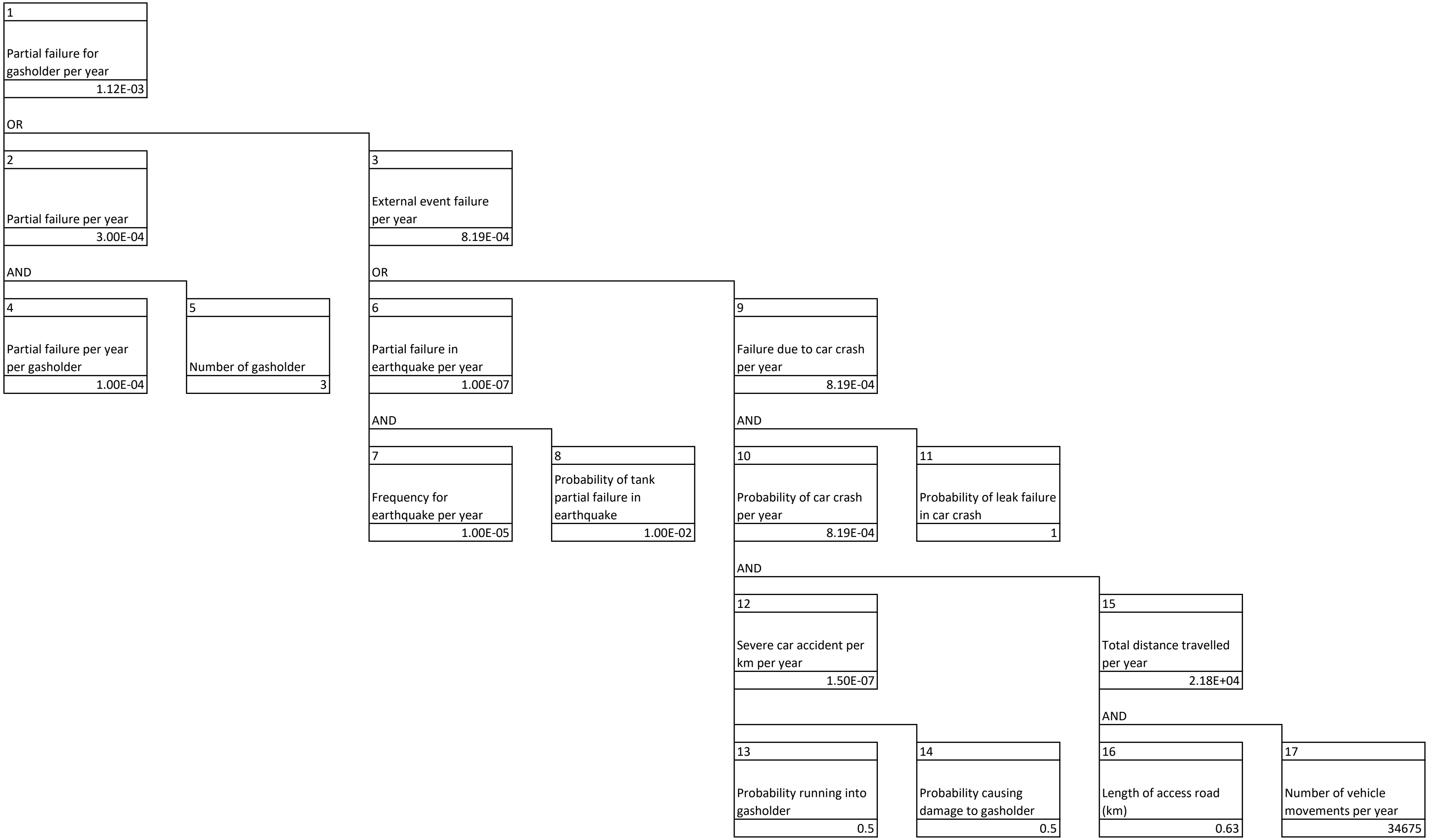
Fault Tree Analysis

Annex D - Fault Tree Analysis

F01 **Catastrophic Failure of Gasholder**

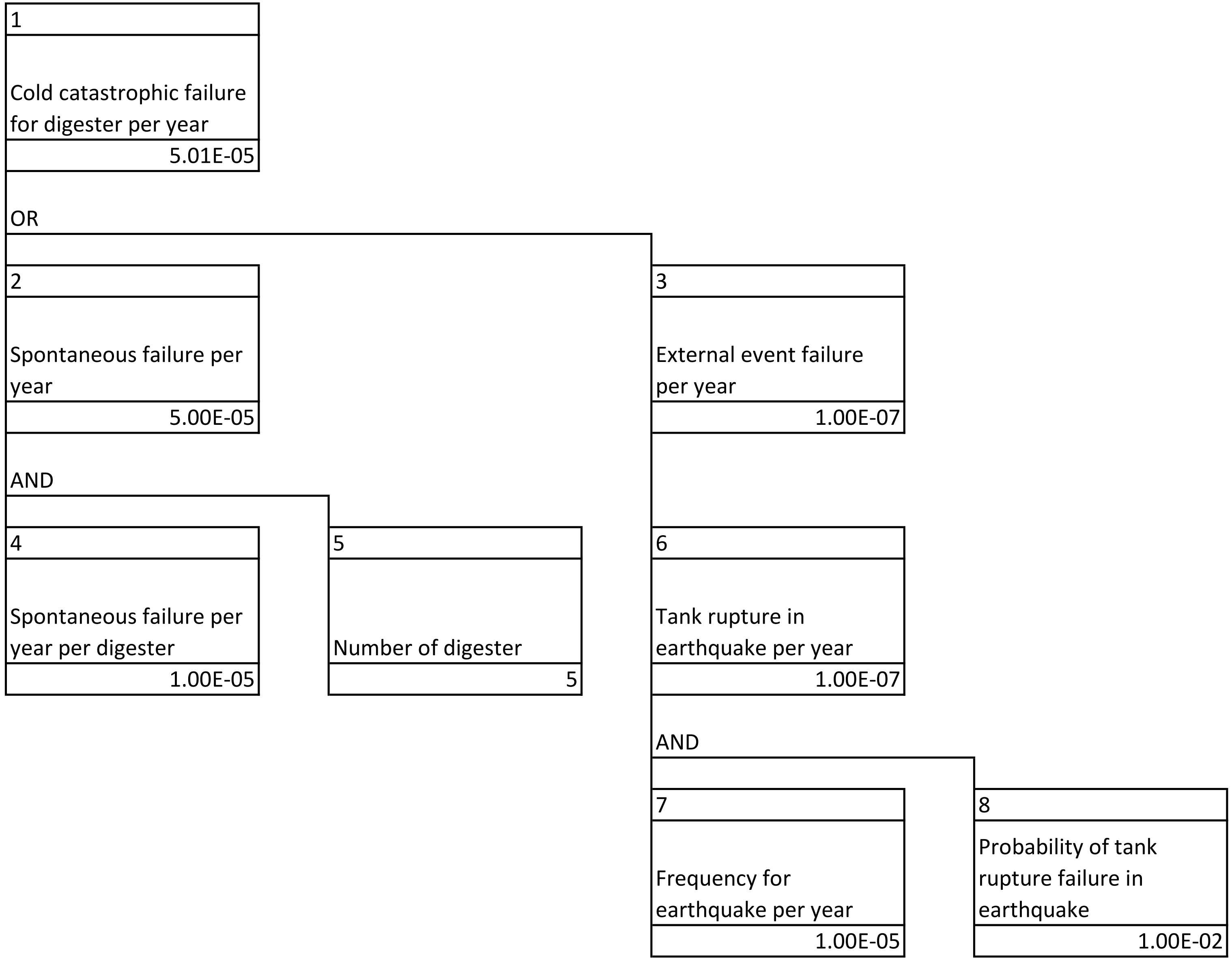


F02 **Partial Failure of Gasholder**

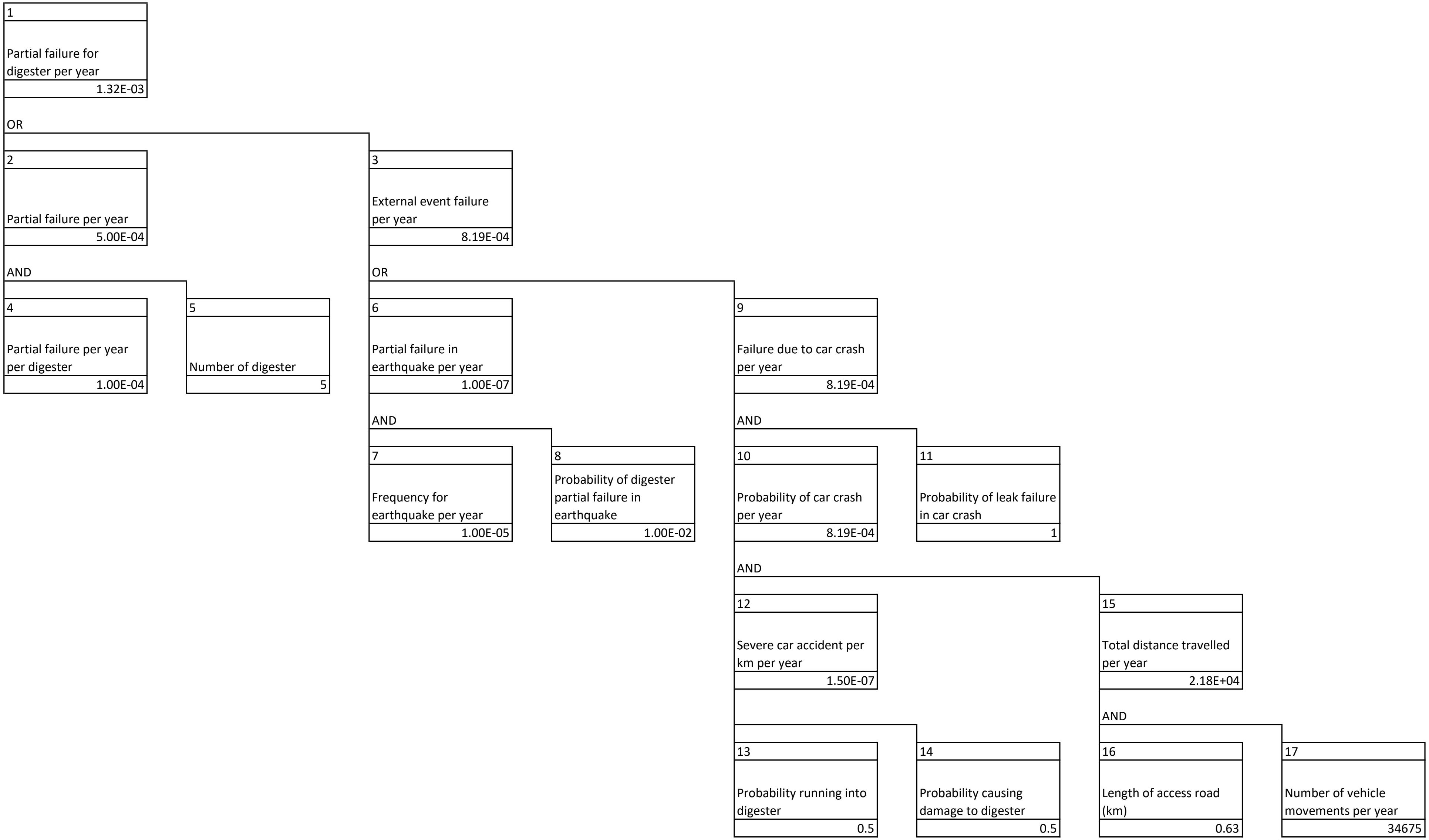


Annex D - Fault Tree Analysis

F03 **Catastrophic Failure of Digesters**

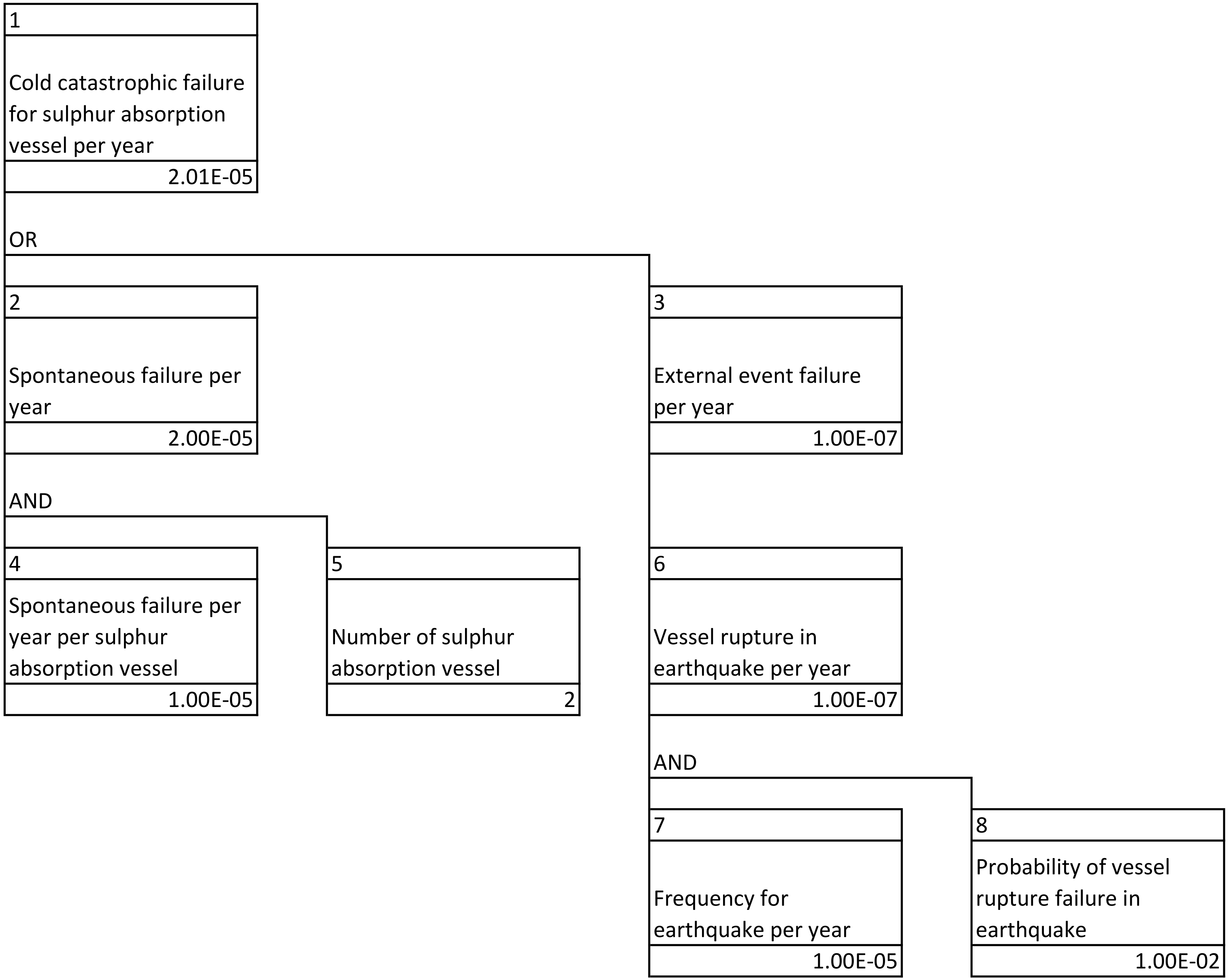


F04 **Partial Failure of Digesters**

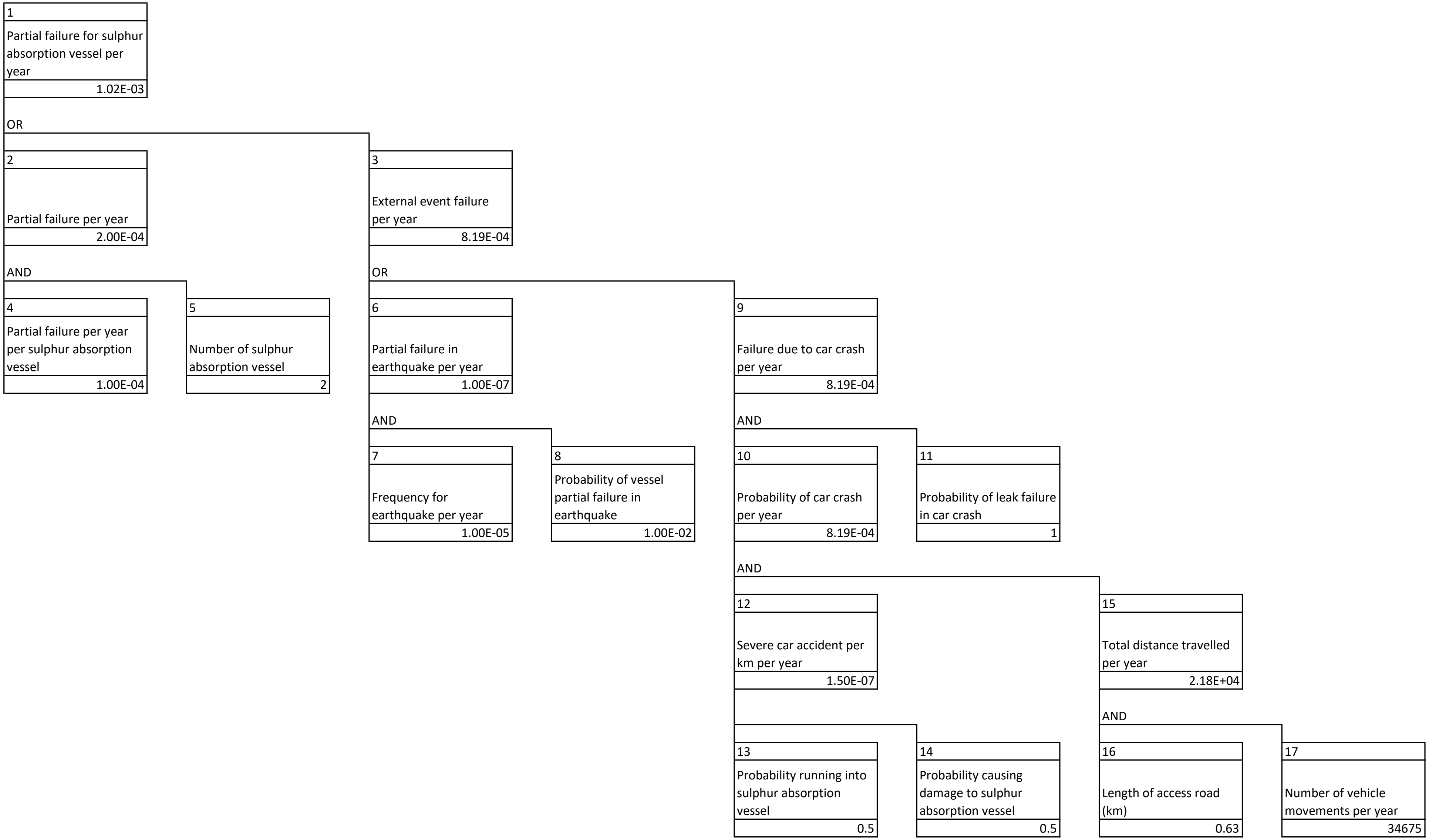


Annex D - Fault Tree Analysis

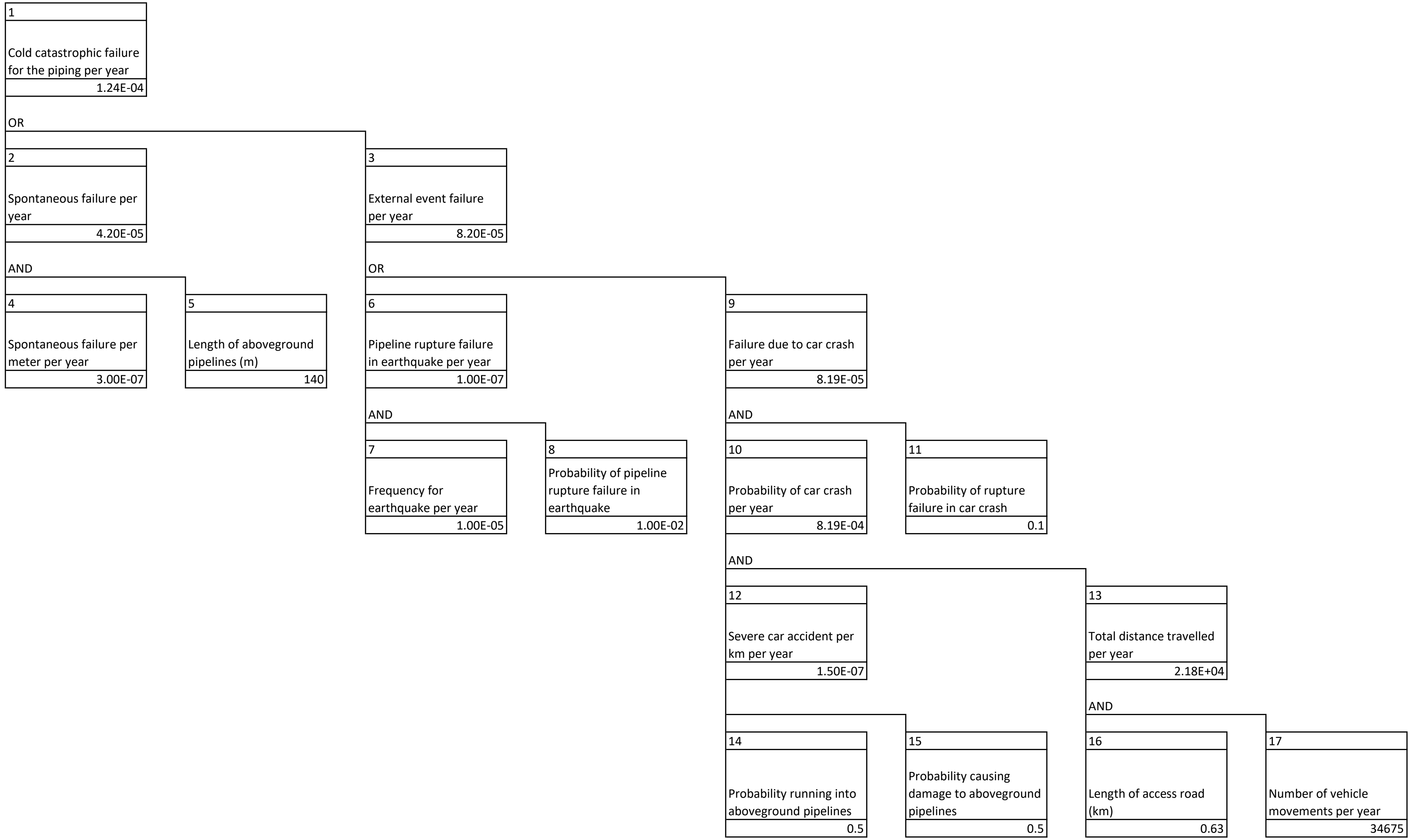
F05 **Catastrophic Failure of Sulphur Absorption Vessels**



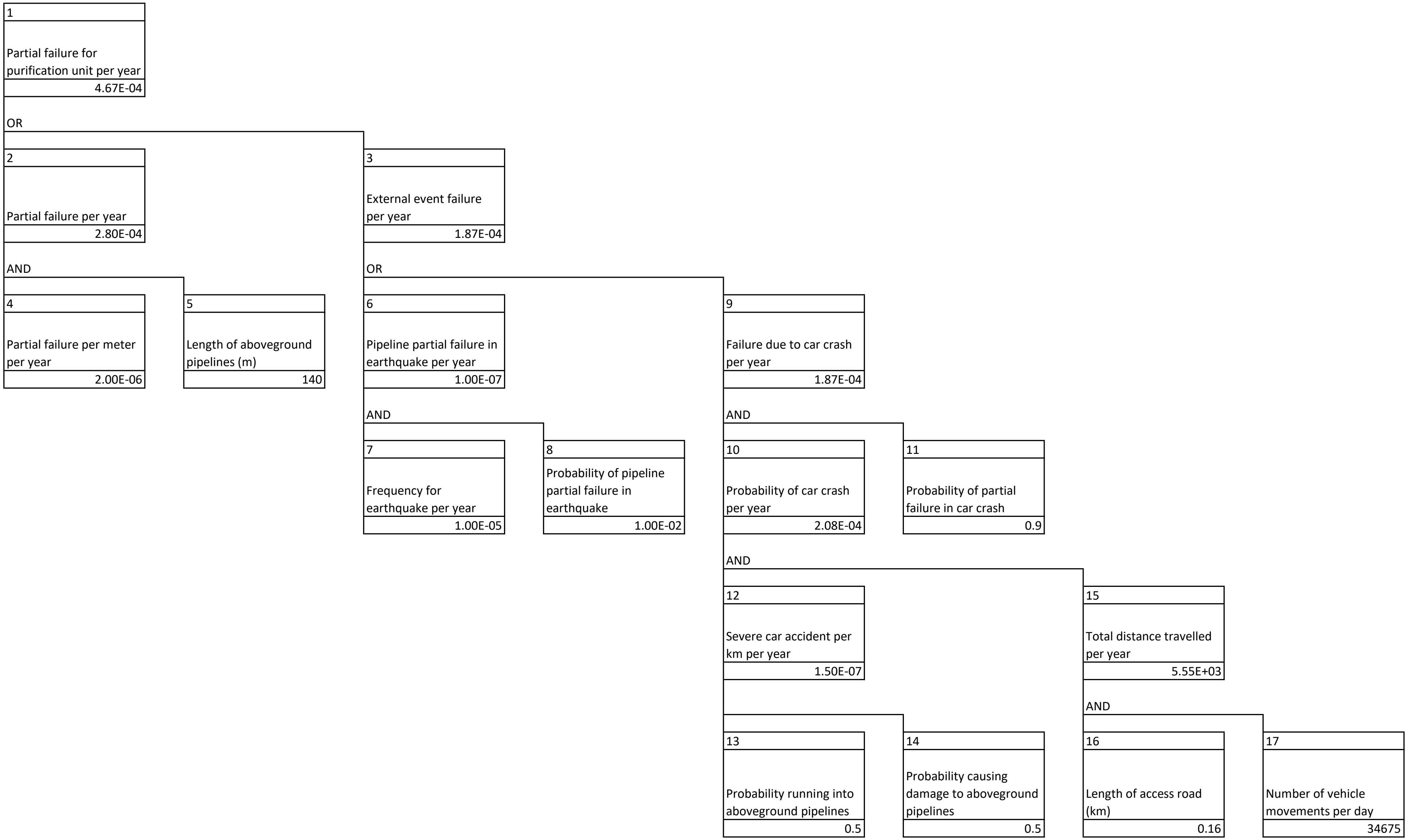
F06 **Partial Failure of Sulphur Absorption Vessels**



F07 **Catastrophic Failure of Aboveground Pipelines**



F08 **Partial Failure of Aboveground Pipelines**



Annex E

Event Tree Analysis

Annex E - Event Tree Analysis

E01 Gasholder Release

	Leak Size	Ignition	Explosion	Outcome	Frequency (per year)
Gasholder Release (size = 1,600m^3)	Leak, 300mm hole (~ 18.4kg/s) 1.12E-03	Immediate 0.035		Jet Fire	3.92E-05
		Delay 0.035	Yes 0.12	VCE	4.70E-06
			No 0.88	Flash Fire	3.45E-05
		No 0.93		No Consequence	1.04E-03
	Rupture (release quantity = 1,600m^3) 3.01E-05	Immediate 0.15		Fire Ball	4.52E-06
		Delay 0.15	Yes 0.3	VCE	1.35E-06
			No 0.7	Flash Fire	3.16E-06
		No 0.7		No Consequence	2.11E-05

Note: There are 2 nos. of gasholders on-duty with 1,600m^3 each.

E02 Digester Release

	Leak Size	Ignition	Explosion	Outcome	Frequency (per year)
Digester Release (biogass volume = 330m^3)	Leak, 300mm hole (~ 18.1kg/s) 1.32E-03	Immediate 0.035		Jet Fire	4.62E-05
		Delay 0.035	Yes 0.12	VCE	5.54E-06
			No 0.88	Flash Fire	4.06E-05
		No 0.93		No Consequence	1.23E-03
	Rupture (release quantity = 330m^3) 5.01E-05	Immediate 0.15		Fire Ball	7.52E-06
		Delay 0.15	Yes 0.3	VCE	2.25E-06
			No 0.7	Flash Fire	5.26E-06
		No 0.7		No Consequence	3.51E-05

Note: There are 3 nos. of digesters on-duty with 330m^3 each.

E03 Sulphur Absorption Vessel Release

	Leak Size	Ignition	Explosion	Outcome	Frequency (per year)
Sulphur Absorption Vessel Release (size = 50m^3 of methane)	Leak, 10mm hole (~ 0.02kg/s) 1.02E-03	Immediate 0.005		Jet Fire	5.10E-06
		Delay 0.005	Yes 0.04	VCE	2.04E-07
			No 0.96	Flash Fire	4.89E-06
		No 0.99		No Consequence	1.01E-03
	Rupture (release quantity = 50m^3) 2.01E-05	Immediate 0.15		Fire Ball	3.02E-06
		Delay 0.15	Yes 0.3	VCE	9.05E-07
			No 0.7	Flash Fire	2.11E-06
		No 0.7		No Consequence	1.41E-05

Note: There are 2 nos. of sulphur absorption vessels on-duty with 50m^3 each.

E04 Aboveground Piping Release

	Leak Size	Ignition	Explosion	Outcome	Frequency (per year)
Aboveground Piping Release	Leak, 15mm hole (~ 0.05kg/s) 4.67E-04	Immediate 0.005		Jet Fire	2.34E-06
		Delay 0.005	Yes 0.04	VCE	9.35E-08
			No 0.96	Flash Fire	2.24E-06
		No 0.99		No Consequence	4.63E-04
	Rupture, 150mm dia. (~4.6kg/s) 1.24E-04	Immediate 0.035		Jet Fire	4.34E-06
		Delay 0.035	Yes 0.12	VCE	5.21E-07
			No 0.88	Flash Fire	3.82E-06
		No 0.93		No Consequence	1.15E-04

Note: 100m length of DN150 aboveground pipeline is assumed.