Annex 8A

Full Hazard to Life/ Quantitative Risk Assessment Report (Rev 3)

[August 2015]

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1 INTRODUCTION

1.1 BACKGROUND

Dragages Hong Kong Limited (DHK) is undertaking the construction of a dual two-lane trunk road connecting the Liantang / Heung Yuen Wai Boundary Control Point (BCP) with Tolo / Fanling Highway for the Liantang / Heung Yuen Wai Boundary Control Point Work. Explosives are required for the blasting operation for tunnel construction. To enable a timely delivery of explosives to worksites and in order to meet the proposed construction work programme, an Explosives Storage Magazine (Magazine) is required. The purpose of the magazine is to maintain progress rate for construction activities, i.e. to meet multiple blasts per day and also act as a buffer in case of delivery interuptions by Mines Division (Mines) from the Geotechnical Engineering Office (GEO), Civil Engineering and Development Department (CEDD). Mines will deliver explosives and initiation devices (detonators) to the magazine on a daily basis and these will be withdrawn by the contractors as required. The transportation of explosives by Mines either to the magazine or directly to sites is under Mines' responsibility and falls outside the scope of this EIA study.

The existing Tai Lam Explosives Magazine (TLEM) (Tai Shu Ha, Yuen Long District, New Territories, Land Allocation GLA-TYL 1288) has been licensed and currently in use by MTR XRL 824 Contractor until end of 2015. It will be available for use from late 2015 or early 2016 (expected January 2016) to December 2017 by the Dragages Hong Kong Limited (DHK) for Hong Kong Liantang / Heung Yuen Wai Boundary Control Point Project (HKLTH). The magazine operation will remain the same as the current MTR XRL 824 Contractor. Explosives will be delivered by DHK to three worksites located at Sha Tau Kok Road – Wo Hang Section (North Portal), Po Kat Tsai Road (Mid-Ventilation Portal) and Tong Hang Tung Chuen (South Portal).

The appointed contractor DHK will transport explosives in the Mines Division licensed trucks to be operated by the contractors, from the Magazine to a particular construction site for one to three blasts per day depending on the requirements for construction. Generally, the quantity of explosives that can be transported in any third party contractor's truck is limited by the Mines Division to maximum 200 kg.

The explosives to be stored and transported from the Magazine to the worksites will include detonators, detonating cords, cast boosters and cartridged emulsion.

Under *Section 5(7)* of the Environmental Impact Assessment (EIA) Ordinance *(Cap. 499)* (EIAO), the Director of Environmental Protection (Director) from the Environmental Protection Department (EPD) has issued a Study Brief No. ESB-280/2014 for this project (EIA Study Brief). *Section 3.4.3* of the EIA Study

Brief specifies that a Hazard to Life Assessment should be conducted for the Project.

ERM-Hong Kong, Limited (ERM) was commissioned by DHK to undertake the Hazard to Life Assessment (also referred to as Quantitative Risk Assessment (QRA)) for the storage and transport of explosives from the proposed Tai Lam Explosives Magazine site to the three worksites and propose risk mitigation measures if necessary. The criteria and guidelines applicable for the Hazard to Life Assessment are stated in Annexes 4 and 22 of the Technical Memorandum (EIAO-TM Criteria).

The Hazard to Life Assessment requirements for the EIA Study Brief are shown below in *Table 1.1*.

Table 1.1 ***EIA Study Brief – Hazard to Life Requirements***

3.4.3	**Impact of Hazard to Life**
3.4.3.1	The Applicant shall follow the criteria for evaluating hazard to life as stated in Annex 4 of the TM.
3.4.3.2	The hazard assessment for the operation of the Project shall follow the detailed technical requirements given in Appendix B of this EIA Study Brief.
Appendix B	Requirements for Hazard to Life Assessment
1	The Applicant shall carry out hazard assessment as follows: (i) Identify hazardous scenarios associated with the storage and transport of explosives and then determine a set of relevant scenarios to be included in a Quantitative Risk Assessment (QRA); (ii) Execute a QRA of the set of hazardous scenarios determined in (i), expressing population risks in both individual and societal terms; (iii) Compare individual and societal risks with the criteria for evaluating hazard to life stipulated in Annex 4 of the TM; and (iv) Identifiy and assess practicable and cost-effective risk mitigation measures.
2	The methodology to be used in the hazard assessment should be consistent with previous studies having similar issues (e.g. Hong Kong Section of Guangzhou-Shenzhen-Hong Kong Express Rail Link (XRL) EIA report (Register No. AEIAR-143/2009))

This section of the EIA presents:

- The basis for the assessment;
- Description of the detailed methodology;
- The results for each QRA step; and
- The assessment of the risk against the EIAO-TM Risk Criteria.

The details of the methodology are elaborated further in various sections of this report.

1.2 *SCOPE OF HAZARD TO LIFE ASSESSMENT FOR THE STORAGE AND TRANSPORT OF EXPLOSIVES*

The Hazard to Life Assessment under this section of the EIA, addresses, in particular, the following:

- Storage of explosives at the existing Tai Lam Explosives Magazine (cartridged emulsion, detonating cord, cast boosters and detonators) including handling of explosives within the Magazine site; and
- Transport of Explosives to the three worksites.

The scope of the study concerns the transport of explosives (cartridged emulsion, detonating cord, cast boosters and detonators) from Tai Lam Explosives Magazine to the worksites.

Detonators are used in relatively small quantities and transported separately. Cartridged emulsion will be used to initiate the blasting explosive and transported together with the detonating cords and cast boosters.

To be consistent with previously approved projects (West Island Line Project (ERM 2008), Express Rail Link Project (ERM 2009), and Shatin to Central Project (ERM 2011)), the risks associated with transport of explosives are limited to the delivery by Contractor trucks up to the blasting sites' boundaries and exclude the transport from the delivery point to the blast face.

The Hazard to Life Assessment presented in this section relates to the storage and transport of explosives from the Tai Lam Explosives Magazine site to the three worksites.

1.3 *HAZARD TO LIFE ASSESSMENT OBJECTIVES AND RISK CRITERIA*

The main objective of this Hazard to Life Assessment is to demonstrate that the EIAO-TM Criteria will be met during the Project period and to identify, where applicable, practical mitigation measures to ensure the EIAO-TM Criteria are met.

The study will particularly focus on the following:

- Identification of hazardous scenarios associated with the transport and storage of explosives for blasting operations;
- Preparation of a Quantitative Risk Assessment (QRA) to estimate risks to the surrounding population in both individual and societal terms;
- Comparison of individual and societal risks with the EIAO-TM Criteria to determine the acceptability of the assessed risk (i.e. the Hong Kong Risk Guideline (HKRG)); and

- Identification and assessment of practicable and cost effective risk mitigation.

1.3.1 *EIAO-TM Risk Criteria*

The individual risk guidelines and societal risk guidelines specified in Annex 4 of the EIAO-TM are shown below.

Individual Risk (IR)

Individual risk is defined as the frequency of fatality per year to a specific individual due to the realisation of specified hazards, with account taken of presence factors.

The maximum level of off site individual risk should not exceed 1 in 100,000 per year, i.e. $1x10^{-5}$ per year.

Societal risk

Societal risk is defined as the risk to a group of people due to all hazards arising from a hazardous operation. The simplest measure of societal risk is the Rate of Death or Potential Loss of Life (PLL), which are the predicted equivalent fatalities per year.

Societal risk is also expressed in the form of an F-N curve, which represents the cumulative frequency (F) of all event outcomes leading to N or more fatalities. This representation of societal risk highlights the potential for accidents involving large numbers of fatalities.

The societal risk guidelines expressed in the form of F-N curve is shown in *Figure 1.1*. There are three regions identified:

- Unacceptable region where risk is so high that it should be reduced regardless of the cost of mitigation or the hazardous activity should not proceed;
- ALARP region where risk is tolerable providing it has been reduced to a level As Low As Reasonably Practicable (ALARP);
- Acceptable region where risk is broadly acceptable and does not require further risk reduction.

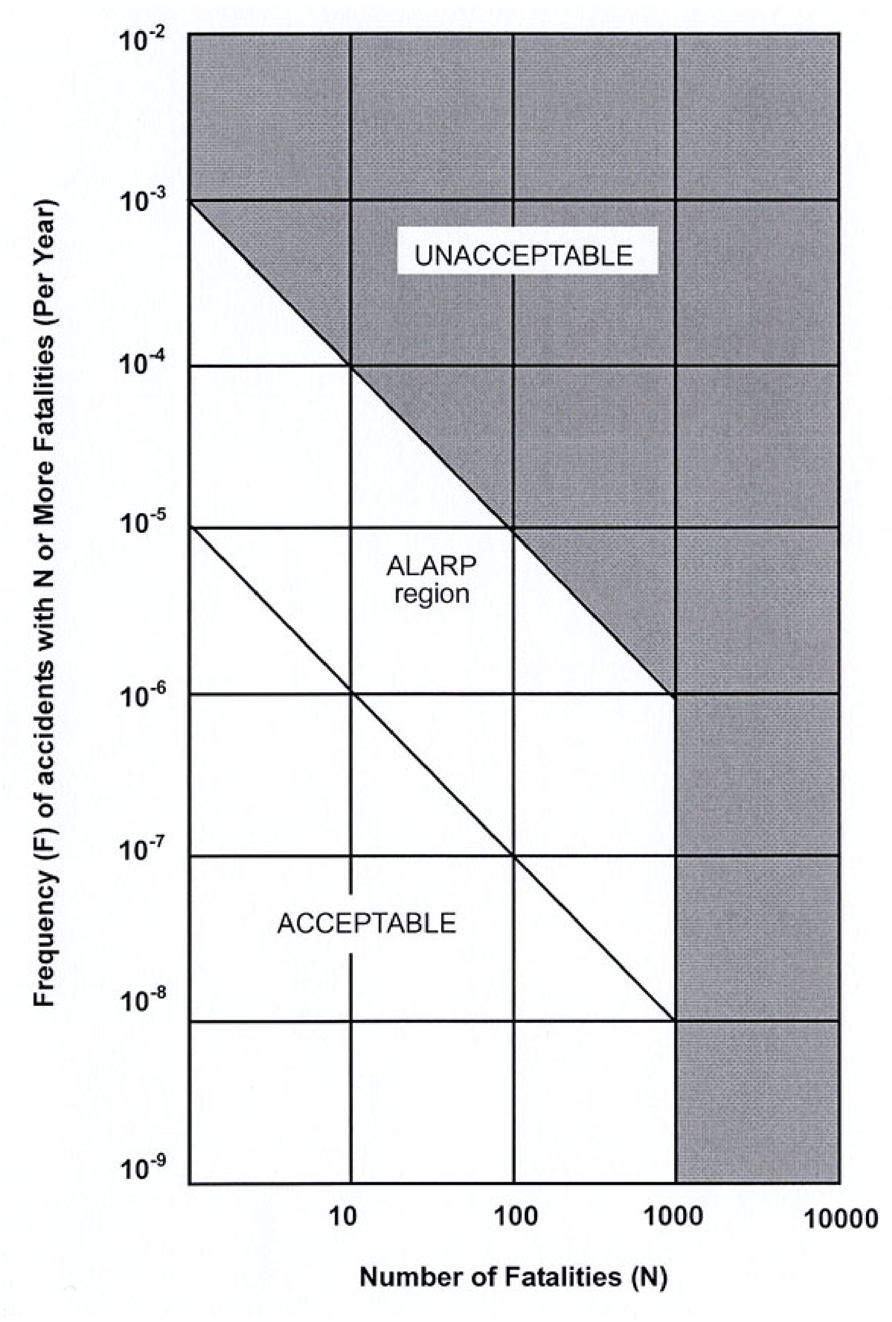
The risk guidelines incorporate a special requirement (as seen in *Figure 1.1*), that no hazardous scenario shall cause more than 1,000 fatalities. If so, the risks are deemed 'unacceptable' and need to be reduced regardless of the cost.

Application of Criteria

Making reference to other studies which involved the transportation of explosives in Hong Kong (ERM 2011, ERM 2009, ERM 2008), the risk guidelines specified in the EIAO-TM Criteria have been applied to the combined risk of fatality associated with the storage and transport of explosives. Injuries are not considered in the assessment and similarly, hazards due to operations within the construction site and Magazine operation other than those involving explosives are also not considered.

The risk guidelines have been generally applied for the public outside the boundary of the hazardous installation. In the context of this study, the risk guidelines are applied to the public outside the construction site and Magazine. Risk to workers on the project construction site, DHK staff or its contractors have not been included in the assessment.

Figure 1.1 *Societal Risk Criteria in Hong Kong*



2 *PROJECT DESCRIPTION AND BASIS FOR THE ASSESSMENT*

2.1 *PROJECT OVERVIEW*

Dragages Hong Kong Limited (DHK) is undertaking the construction of a dual two-lane trunk road connecting the Liantang / Heung Yuen Wai Boundary Control Point (BCP) with Tolo / Fanling Highway for the Liantang / Heung Yuen Wai Boundary Control Point Work. Explosives are required for the blasting operation for tunnel construction. To enable a timely delivery of explosives to worksites and in order to meet the proposed construction work programme, an Explosives Storage Magazine (Magazine) is required. The most suitable Magazine site location has been identified as the existing Tai Lam Explosives Magazine.

The Project comprises the following key elements:

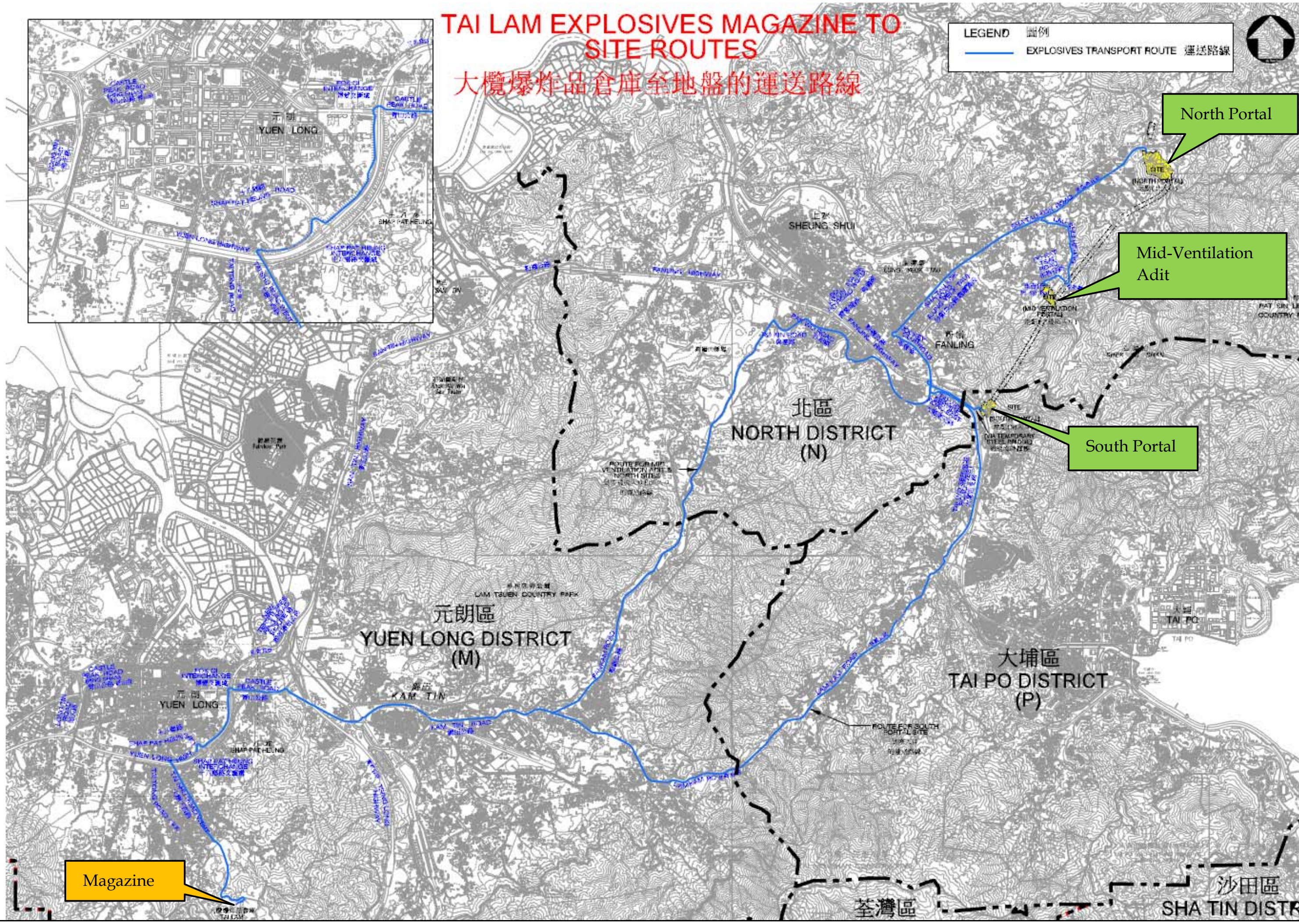
- Use of the existing Tai Lam Explosives Magazine from late 2015 or early 2016 (expected January 2016) to December 2017 with the same operation as current users; and

- Explosives transport from the existing Tai Lam Explosives Magazine to the three worksites by DHK using trucks approved by CEDD Mines Division.

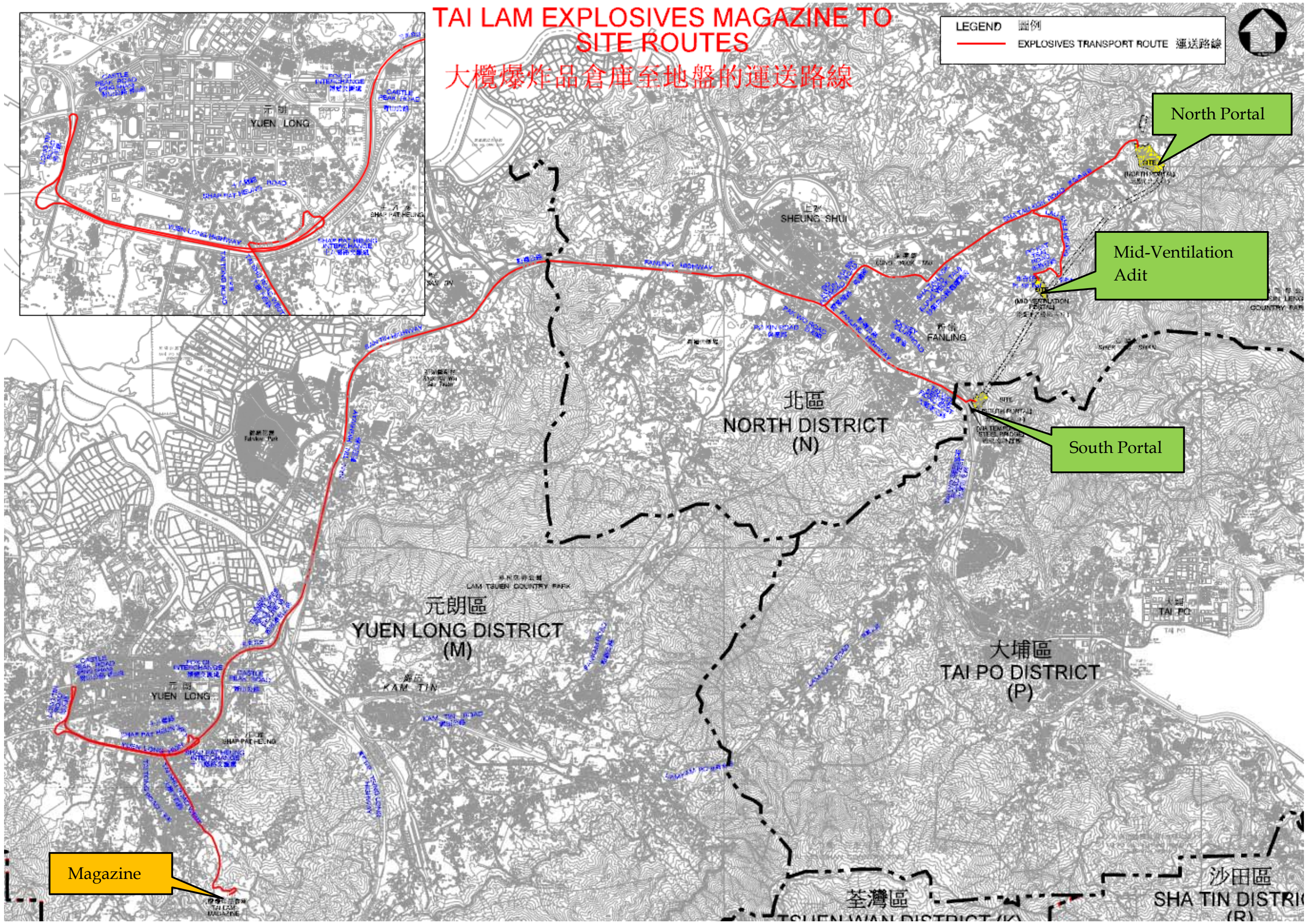
The proposed explosives transport routes to the three worksites are shown in *Figure 2.1*(Route Option R1, Route Option R2 and Route Option R3 respectively).

Figure 2.1 Proposed Explosive Transport Routes Option R1, R2 and R3

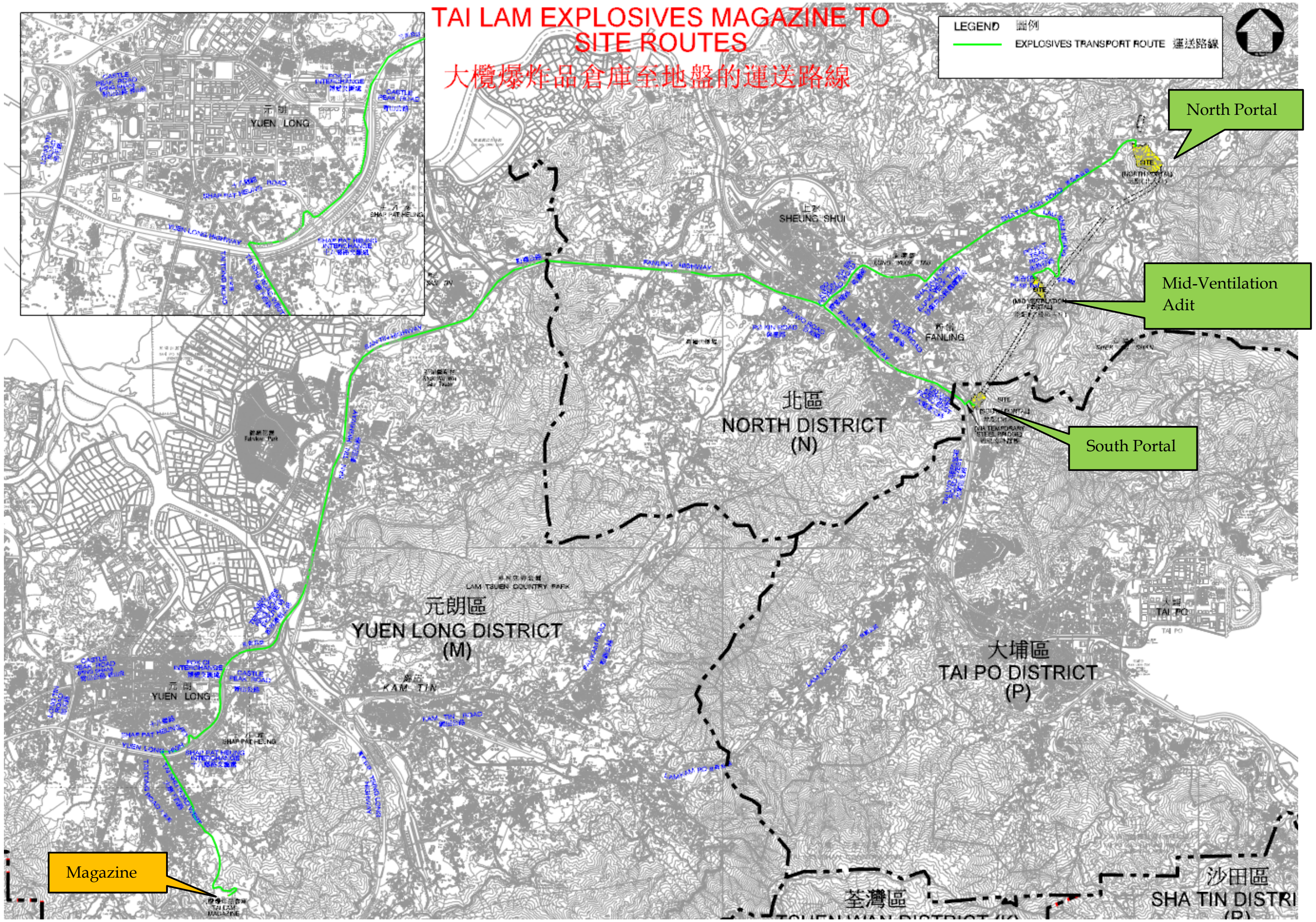
Route Option R1



Route Option R2



Route Option R3



The estimated project period for explosives storage and transport would be from late 2015 or early 2016 (expected January 2016) to December 2017.

The explosives required for the three worksites are envisaged to be delivered from the existing Tai Lam Explosives Magazine. The worksites are shown in *Table 2.1* below. The quantities (kg) of explosives mentioned in the report are represented in gross weight, unless they are clearly specified as TNT eqv. kg.

Table 2.1 ***Project Works Areas Requiring Delivery by Contractor***

Storage Magazine	Magazine Storage Requirement per Contract	Works Area	Blast Faces	Delivery Point
Tai Lam	800 kg (400 kg × 2 stores)	North Portal	Dual two-lane trunk road connecting the BCP with Tolo / Fanling Highway	Sha Tau Kok Road – Wo Hang Section
		Mid-Ventilation Portal	Dual two-lane trunk road connecting the BCP with Tolo / Fanling Highway	Po Kat Tsai Road
		South Portal	Dual two-lane trunk road connecting the BCP with Tolo / Fanling Highway	Tai Wo Service Road East

Note:
1. Two days storage to be maintained as much as possible in line with DHK's operating practice
2. During periods of peak explosives requirements one day storage capacity is envisaged.
3. If storage capacity is not able to satisfy demand direct delivery by Mines Division can be requested, or a blast can be delayed until the following day.

The Tai Lam Explosives Magazine consists of two stores of 400 kg each. Detonators are stored in a separate chamber within each store. Mines Division will deliver explosives and detonators to Tai Lam Explosives Magazine on a daily basis.

The appointed contractor DHK will transport explosives in licenced trucks (licenced by Mines Division) to be operated by the contractors, from Tai Lam Explosives Magazine to a particular worksite for one to three blasts per day depending on requirements for construction. Generally, the quantity of explosives that can be transported in any third party Contractor's truck is limited by Mines Division to a maximum of 200 kg.

2.2 *EXPLOSIVE TYPES FOR THE PROJECT*

2.2.1 *Proposed Explosives*

The explosives to be stored and transported from Tai Lam Explosives Magazine to the worksites will include detonators, detonating cord, cast boosters and cartridged emulsion. Detonators will be stored in dedicated chambers and transported separately on dedicated trucks.

Cartridged emulsion contains an oxidising agent mainly ammonium nitrate (single salt), water, and a hydrocarbon such as fuel oil. Cartridged emulsion contains 2-3% aluminium powder, which has been added at manufacture to increase the explosion temperature and hence its power.

Cartridged emulsion will be delivered from Tai Lam Explosives Magazine to the three worksites by the appointed contractor using Mines Division licenced trucks.

Detonators, cast boosters and detonating cord will be used to initiate the blast at the working face.

2.2.2 *Explosives Properties and Regulations*

Explosives that are relevant to the Project can be classified into two types:

- Blasting explosives; and
- Initiating explosives.

Their properties are shown in *Table 2.2*.

Table 2.2 Explosive Types

Type	Function	Use	Examples
Blasting explosives	A main blasting explosive	General blasting, shattering rock/structures	Cartridged emulsion
Initiating explosives	To initiate the main blasting explosives	Initiation of secondary explosive	Detonators, Cartridged emulsion, Detonating cord and cast boosters

2.2.3 *Cartridged Emulsion*

The cartridged explosive is designed as a small diameter packaged emulsion, which can be used for both priming and full column applications, particularly in underground mining. It is used for mining, quarrying and general blasting work.

It is packaged in a range of plastic films with the tips clipped at each end to form a cylindrical sausage, or wrapped in waxed paper. It is classified as a UN Class 1.1D explosive and Dangerous Goods (DG) Category 1 explosive under the Hong Kong classification system. It has a TNT equivalence of 0.96, i.e. 0.96 kg of TNT per 1 kg of emulsion.

Like all ammonium nitrate based blasting explosives, cartridged emulsion consists of a mixture of oxidisers and fuel. What makes emulsion unique is the high quantity of water it contains – typically around 10-14%. The oxidisers are typically ammonium nitrate, calcium nitrate or sodium nitrate. For cartridged emulsion used in Hong Kong, there is no perchlorate within the formulation. The fuels are waxes or oils such as diesel fuel. The mixture is complete with small amounts of emulsifiers (less than 1%), which keep the water and oil mixture homogeneous. Cartridged emulsion is detonator sensitive.

2.2.4 *Detonating Devices (Detonators, Detonating cord)*

Detonators

Detonators are small devices that are used to safely initiate blasting explosives in a controlled manner. In the past, electric detonators were used. Since these are no longer used, this study is limited to non-electric, or shock tube detonators. Detonators are classified as either UN 1.1B, 1.4B, or 1.4S, or DG Category 1 explosive under the Hong Kong classification system.

Although detonators contain the most sensitive types of explosives in common use, they are constructed and packaged in a manner such that they can be handled and used with minimal risk. If accidentally initiated, they should have no serious effects outside the package.

Detonators are manufactured with in-built delays that are of various durations. This is to facilitate effective blasting to allow blast holes to be initiated sequentially one at a time, rather than instantaneously, thereby enhancing the practical effects of the blast and reducing the effects of vibration. The detonators to be used in this project will be either millisecond delay period detonators (MS Series) or half second delay detonators (Long Period or LPD).

The delay time of a detonator is controlled by the burning time of a pyrotechnic ignition mixture pressed into a 6.5 mm diameter steel tube, which is the delay element. This element causes the primary explosive, which is typically a small amount of lead azide, to detonate. This in turn, causes the secondary, or output, explosive to detonate, which is usually PETN (Pentaerythritol Tetranitrate). The quantity of PETN within each detonator is approximately 0.9 g. Each detonator has a delay time that is based upon the length of steel tube and the compaction of the pyrotechnic mixture within it. In designing the blasting of a tunnel face, the general principle is to select the required detonators to ensure that no two blastholes will detonate less than 8 ms apart.

The ignition of the pyrotechnic mixture is achieved by the use of shock tubes. This is a small diameter plastic tube that has a light dusting of explosive powder on the inside surface along its length. When ignited by a hot, high pressure impulse the explosive powder combusts at a rate of over 2000 m/s ± 200 m/s, and causes ignition of the pyrotechnic mixture within the detonator.

Detonating Cord

Detonating cord is a thin, flexible tube with an explosive core. It detonates continually along its length and is suitable for initiating other explosives that are detonator sensitive, such as cartridged emulsion. Detonating cord along cartridged emulsion is used in perimeter pre-split holes to provide a smooth tunnel profile. It can also be used for synchronising multiple charges to detonate different charges almost simultaneously. It is used to chain together multiple explosive charges. The core of the cord is a compressed powdered explosive, usually PETN, and it is initiated by the use of a detonator.

Cast Boosters

Cast boosters are small devices, usually containing 12 gram in weight of high explosive into which a detonator is inserted and the whole assembly is then placed in the end of the blasthole, and once assembled is called a primer.

Cast boosters are usually manufactured from a 50/50% mixture TNT and PETN, termed Pentolite. Cast boosters detonate at speeds of 6,000m/sec and provide sufficient 'shock' energy to reliably detonate the bulk emulsion, after firstly being initiated by the delay detonator.

2.3 STATUTORY/LICENCING REQUIREMENTS AND BEST PRACTICE

The Commissioner of Mines is the authority for the approval of explosives for use in Hong Kong, the transportation, storage and use of explosives, Cat. 1 under *Dangerous Goods Ordinance (Cap. 295)* or are prepared from *Cat. 7 Dangerous Goods*.

Mines Division is responsible for giving approval for the issue of the Mine Blasting Certificate, Removal Permits for Explosives, Mode A Explosives Store Licence, Mode B Explosives Store Licence and Blasting Permits. A Mine Blasting Certificate permits the shotfirer to use explosives in blasting. A Removal Permit allows a person to move any explosives by land transport within Hong Kong. Mode A Explosives Store Licence permits the storage of blasting explosives. Mode B Explosives Store Licence permits the storage of certain types of explosives such as safety cartridges for industrial fastening tools, cartridges for small arms and marine distress signals. A Blasting Permit allows the Contractor to use explosives at a worksite for carrying out blasting. The Division is responsible for regulating the delivery of explosives to blasting sites and carrying out audit inspections on the blasting works at times that match with the work activities of the contractors.

2.3.1 *Transport of Explosives*

Supply of Detonators and Cartridged Emulsion Explosives

Detonators are imported into Hong Kong. Destructive product sample tests are conducted by the manufacturer before each order leaves the factory. These tests record the actual delay firing time of each sample detonator and must fall within the manufacturers upper and lower tolerances as dictated by their quality control and quality assurance (QC /QA) system. In the event that the tested sample falls outside of the delay time control, or tolerance limits the batch will be destroyed. The delay time, detonator shock tube length, batch number and date of manufacture are printed on each vacuum bag (inner packaging) and the delay time is printed on the aluminium shell and the coil tag of each detonator, where the detonator shock tube length is also shown. The detonators will be imported into Hong Kong and stored at the Mines Division Kau Shat Wan (KSW) magazine. Users will then place orders from Mines Division for delivery to their temporary on-site explosives magazine or to their blasting site as appropriate.

Class 1.1D (Cat. 1) explosives are imported into Hong Kong and stored at the KSW magazine and delivered to end users (magazines or delivery points) by Mines Division on a daily basis as required.

Approved Explosives for Blasting in Hong Kong

Under Dangerous Goods (General) Regulations *Cap. 295B*, conveyance and storage of explosives in Hong Kong shall not be allowed except under and in accordance with a licence or permit granted by the Authority. A permit to convey (Removal Permit) and a licence to store (Mode A or Mode B Store Licence) shall not be granted by the Commissioner of Mines unless suppliers of the explosives have submitted the necessary information related to safety, classification, and labelling and packing for vetting. After vetting by the Commissioner of Mines, the explosives will be included in the approved list. All the explosives to be transported in the project will be in the approved list. The current approved list is available from the Commissioner of Mines via CEDD website (CEDD 1).

Blast Design

The design of the blast will consider the quantity and type of explosives needed including MIC (maximum instantaneous charge), number of detonators required, as well as the sensitive receivers near the blasting location. The blast design will be prepared by the Blasting Engineer, in collaboration with the Registered Shotfirer, checked and approved by the Blasting Competent Supervisor, and then submitted to Mines Division for auditing prior to implementation. The blast plan will contain information covering the dimensions of the face to be blasted, MIC, location (generally tunnel chainage), size of blastholes, type and number of delay detonators required and powder factor (kg/ m^3), which is defined as the ratio of mass of explosives used to the volume of rock removed by the blast.

Blast Loading and Execution

Based on the blast design, immediately prior to loading, the required and approved amount of explosives, cartridged emulsion, detonating cord, cast boosters and detonators for the blast will be collected by the Registered Shotfirer and delivered to the blasting site by the licenced Contractors' Vehicles. The collection of the correct quantity of blasting explosives and initiating explosives will be checked by the Registered Shotfirer, a representative from the supervising engineer (i.e. Resident Explosives Supervisor) and a representative from the Contractor.

Licencing Requirements for Transportation of Explosives from the Magazine to the Work Areas

Application for Removal of Explosives

Under Regulation 4 of the Dangerous Goods (General) Regulations, a Removal Permit is required for any person to move explosives in and out of the explosive stores. Some removals are exempted from this requirement which include:

- the removal of safety cartridges for industrial fastening tools not exceeding 5,000 rounds or 5 kg of explosives content whichever is the less, or

- the removal of safety cartridges and cartridges for small arms not exceeding 1,000 rounds if such removal has already been licenced under the Firearms and Ammunition Ordinance (Cap. 238).

Application for Approval of an Explosives Delivery Vehicle

The explosive vehicle should comply with the safety requirements set in the Requirements for Approval of an Explosives Delivery Vehicle (Guidance Note) issued by Mines Division (CEDD 2). The Guidance Note includes the following provisions:

Any contractor intending to transport explosives from a Magazine to the blast sites on public roads shall submit an application to the Commissioner of Mines. The general conditions for approval are summarised as follows:

(a) Method statement including information on blast sites, duties of personnel, explosives delivery routes and procedures, design drawings of the proposed explosives delivery vehicle and emergency procedures;

(b) The vehicle shall have a valid 'Roads Worthiness Certificate' issued by the Transport Department, with a valid vehicle registration document and a valid licence issued by the Transport Department;

(c) The vehicle shall be tested by a testing body certifying the relevant weights, including the 'Permitted Gross Vehicle Weight' and 'Vehicle Net Weight', in order to determine the 'Permissible Laden Weight' of the approved explosives delivery vehicle; and

(d) The names of the driver and attendant with documentation indicating basic knowledge of safe handling of explosives, fire fighting and emergency procedures. The driver should be over the age of 25 years with less than 5 driving-offence points over the previous 3 years and more than 5 years driving experience and hold a current driving licence for the appropriate class of vehicle. The driver should also have attended a defensive driving course within the previous 12 months, passed a medical check and been assessed by a registered medical practitioner as being fit to drive explosives delivery vehicles.

Explosives Delivery Vehicle Design Features and Safety Requirements

The explosive delivery vehicle shall be designed and operated in accordance with the Requirements for Approval of an Explosives Delivery Vehicle (Guidance Note). Any improvements made to these requirements are permitted subject to approval by Mines Division. The minimum safety requirements are summarised below:

Condition of Vehicle:

(a) The vehicle shall be powered by a diesel engine;

(b) The vehicle's design, construction and strength must comply with the Road Traffic (Construction and Maintenance of Vehicles) Regulations, Chapter 374, Laws of Hong Kong;

(c) The vehicle shall be kept clean, in sound mechanical condition and roadworthy; and

(d) The vehicle shall be licensed to carry the maximum number of persons required for the delivery convoy. For example, if only one vehicle is going to be used for the delivery convoy, then the vehicle shall be licensed to carry at least 6 persons (including driver, registered shotfirer, Contractor's representative, RSS's resident explosives supervisor, armed security guard and Mines Division's representative). Subject to the agreement obtained from Mines Division and the Hong Kong Police Force, the armed security guard may be omitted provided that an approved Global Positioning System (GPS) has been installed in the vehicle. The applicant shall confirm the requirements with Mines Division.

Condition of Cargo Compartment:

(a) The cargo compartment of the vehicle, including the floor, shall be constructed with sheet metal at least 3 mm thick and lined internally with at least 13mm thick plywood, and there shall be no exposed ferrous metal in the interior of the goods compartment.

(b) The interior of the cargo compartment, including doors, shall be kept in good condition and free from defects or projections which might cause accidental damage to the packages.

(c) Electric wiring or electrical devices shall not be installed inside the cargo compartment.

(d) The door of the cargo compartment shall be capable of being locked using a padlock. The padlock shall meet BS EN 12320 Security Grade 4 or above requirements, or equivalent.

(e) Proper stowage facilities shall be provided to secure the load in a stable manner during transportation.

(f) If the vehicle is designed to carry both detonators and other types of blasting explosives at the same time, additional requirements for cargo compartment shall be required.

Safety Provisions:

(a) The driver's cabin shall be separated by a distance of not less than 150mm from the cargo compartment of the vehicle.

(b) The exhaust system must be located as far from the cargo compartment as possible, preferably at the front of the vehicle. The modification of the exhaust system shall be approved by the Transport Department.

(c) A quick-action cut-off at an easily accessible position shall be fitted to the fuel feed pipe and shall be clearly identified in Chinese and English languages, by a label prominently and legibly stating –

"EMERGENCY ENGINE STOP 緊急死火掣".

(d) The required number of fire extinguishers shall be agreed with Mines Division.

(e) All electrical installations shall be designed, constructed and protected so that they cannot cause any ignition or short-circuit under normal conditions of use of the vehicle or its electrical installations, and so that the risk of this occurring will be minimized in the event of an impact or deformation. All electrical wiring and fittings shall be shrouded in fire resisting conduits.

(f) The fuel tank shall be located either to the front or below the cargo compartment of the vehicle. It shall be protected from accidental damage, and designed to prevent accumulation of spilt fuel on any part of the vehicle.

(g) Fire resistant material shall be fitted between the wheel arches and the goods compartment.

(h) Detonators and other types of blasting explosives shall not be loaded or transported within the same cargo compartment of the vehicle.

(i) A hand-held lightning detector shall be provided in the vehicle for detection of lightning before and during loading and unloading of explosives. Should lightning be detected within a distance of 16 km from the loading/unloading point by the hand-held detector, loading or unloading of explosives shall cease until the lightning signal has cleared.

(j) At least one red strobe beacon is required.

(k) Laminated sheets containing (i) the Occupational Safety and Health information for first responders relating to the explosives being carried; (ii) the Emergency Procedures in the event of traffic accident or fire; and (iii) the Emergency Contact List shall be displayed in a conspicuous position in the driver's compartment. The applicant shall confirm the requirements with Mines Division. The driver and attendants shall be fully conversant with the safety/emergency procedures at all times.

Signage on Vehicle:

(a) Whenever the vehicle is carrying explosives, there shall be displayed:

(i) on both sides of the cargo compartment a placard (of minimum dimensions 250 mm × 250 mm) showing the label of the highest Hazard Code of explosives (see Specimen Labels of Hazard Code in *Section 2.2* of the document (CEDD 2), and

(ii) in a prominent position, a rectangular red flag of dimensions not less than 230mm x 300mm.

(b) A placard showing "EMPTY 空車" shall be displayed when the vehicle is empty.

(c) The vehicle shall be painted in white with warning words in the Chinese and English languages of at least 150mm height as follows:

"DANGER – EXPLOSIVES" and "危險 – 爆炸品"

The warning shall be in red or black and displayed on both sides and rear face of the cargo compartment. If possible, the warning shall also be displayed on the front face of the vehicle.

(d) The company name and contact telephone number of the Contractor/applicant together with the project name and contract number shall be displayed on the side doors of the vehicle in black.

A typical contractor's explosives vehicle and a typical Hong Kong Mode A Explosive Store is shown in *Figure 2.2*.

Figure 2.2 Typical Contractor's Explosive Truck and Magazine

From top to bottom: A typical contractor's explosives vehicle; warning displays of loaded explosives vehicle; and a typical Magazine site.

2.3.2 *Storage of Explosives*

Tai Lam Explosives Magazine

The existing Tai Lam Explosives Magazine complies with the general requirements from the Commissioner of Mines with respect to the construction of the store and security measures to be adopted. These general requirements are defined in the document "How to Apply for a Mode A Store Licence for Storage of Blasting Explosives". The magazine is a single storey detached bunded structure with dimensions as specified on Mines and Quarries Division Drawing MQ1630 "Typical Details of Explosives Magazine – Plan A". The magazine building is fenced and secured in accordance with the Commissioner of Mines' requirements and surfaced road access suitable for 11 tonne trucks are provided for delivery of explosives. The main requirements are summarized below:

The following are the general requirements (CEDD 3) from the Commissioner of Mines in processing the application:

(a) The maximum storage quantity should normally not exceed 1000 kg.

(b) The safety distances requirements from the UK Explosives Regulations 2014 for an explosives magazine will be used to assess the suitability of the proposed store location. A store made of substantial brickwork surrounded by earth mound is recommended. If the proposed Mode A store is in a densely populated area, a minimum separation distance of 400 m from buildings is normally required.

(c) No proposed Mode A store shall be located within 45 m and 75 m on plan from any high tension power cables carrying 440 V or 1 KV respectively. Diversion of the cables will be required if there is no alternative location.

(d) Approval from the Commissioner of Police will be required on the security aspects of the Mode A store location and on the security company.

(e) No other materials, likely to cause or communicate fire or explosion, shall be transported in any vehicle carrying explosives and no passengers other than persons assigned to assist in handling explosives shall be permitted on a vehicle transporting explosives. The driver and all workers engaged in the loading, unloading or conveying of explosives shall be trained in fire fighting and precautions for the prevention of accident by fire or explosion.

The following are the general requirements for the construction of the blasting explosives Mode A store:

(a) The store shall be a single storeyed detached structure made of substantial brickwork, masonry or concrete to a design approved by the

Commissioner of Mines with lightning protection and outer steel Mode A store doors.

(b) All hinges and locks shall be of non-ferrous metal.

(c) No ferrous metal is to be left exposed in the interior of the Mode A store.

(d) The interior and exterior walls of the Mode A store shall be painted white.

(e) The outer steel doors shall be painted red. The words

"DANGEROUS – EXPLOSIVES" and "危險 – 爆炸品"

shall be written in white on the outside of each door. The letters and characters shall be at least 10 cm high.

(f) A security fence surrounding the Mode A store shall be installed and set back at least 6 m from the Mode A store. The fence shall be 2.5 m high, stoutly constructed of chain link fencing having a mesh size not exceeding 50 mm. The fence shall be firmly fixed to metal or concrete posts and topped with a 0.7 m outward overhang of razor-bladed wire. The base of the fence located between the posts shall be secured with pegs to prevent intrusion.

(g) The area between the security fence and the Mode A store shall be cleared of all vegetation. Vegetation clearance should also apply to a minimum distance of 1m on the exterior of the fence. A uniform cross-fall of at least 1 in 100 away from the Mode A store to a drainage system shall be constructed.

(h) Electric flood lighting, from at least eight light poles spaced along the security fence, shall be provided to illuminate the area between the Mode A store and the security fence and the area directly outside the security fence.

(i) The gate in the security fence shall be fitted with a lock of close shackle design with key-intention feature. A warning notice board with prohibited articles and substances painted in red and black, shown in symbols and in Chinese and English characters shall be posted at the gate. Each symbol shall be at least 10 cm in diameter. A sample of the warning notice board is available upon request from the Mines Division.

(j) A guard house for the Mode A store should be provided. Armed security guards shall be on duty outside the security fence adjacent to the gate. This guard house shall be protected by a separate fence.

(k) Inside the guard house, an arms locker constructed as an integral part of the house and fitted with a lock shall be required.

(l) A telephone shall be provided in the guard house.

(m) A watchdog should normally be provided for the store.

(n) The road leading to the Mode A store shall be concrete surfaced. It shall be constructed and maintained so that it can be used by 11 tonne trucks under all adverse weather conditions. A suitable turning circle or other alternative means for these trucks shall be provided so that the trucks can be driven up to the gate of the security fence.

(o) Fire fighting installations consisting of at least four 6 liter foam and one 4.5kg dry powder fire extinguishers, four buckets of sand to be positioned on two racks within the area between the security fence and the Mode A store and as near as is convenient to the Mode A store doors. In addition, the Fire Services Department (FSD) may require other additional fire fighting installations.

2.4 DESIGN AND LOCATION OF THE TAI LAM EXPLOSIVES MAGAZINE

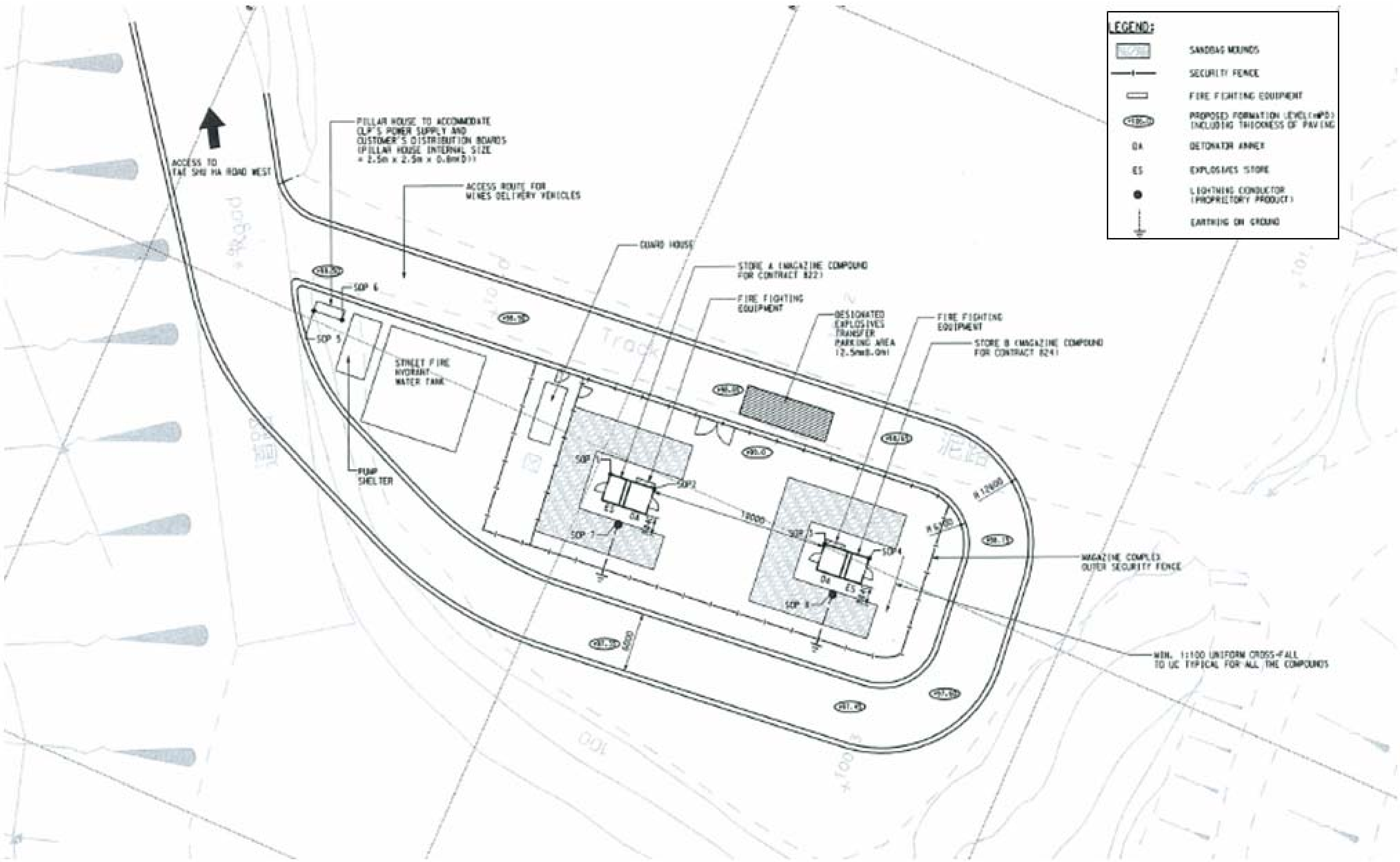
The existing Tai Lam Explosives Magazine has been identified as the most suitable site for explosive storage. The TLEM will serve the three worksites. The site complies with the separation requirements of Mines Division.

The magazine is designed to store sufficient quantities of explosives for two days so as to allow blasting to be carried out 24 hours per day and provide a buffer in the event of delivery interruption to the magazine by Mines Division. The storage quantity for the magazine has been determined with sufficient margin by the design consultant based on estimated project explosives consumption.

Tai Lam Explosives Magazine Site

A single site comprised of two magazine compounds, each with a single structure storing 400 kg explosives. The site is in an area of low population density, with little surrounding infrastructure. The site complies with the clearance requirements specified by UK HSE for storage of explosive (ER, 2014). The magazine site layout is provided in *Figure 2.3*. The location of the magazine is shown in *Figure 4.1*.

Figure 2.3 Tai Lam Explosives Magazine Site Layout



2.5 *EXPLOSIVES DELIVERY PROGRAMME OF THE PROJECT*

2.5.1 *Explosives Delivery-Storage-Blasting Cycle*

The proposed delivery-storage-blasting cycle will consist of the following elements:

1. Weekday morning deliveries of explosives and initiating systems to each Magazine by Mines Division as needed.

2. Storage in the Tai Lam Explosives Magazine Site stores.

3. Transfer from the explosives stores to the delivery points of the worksites utilizing public roads via routes as indicated in *Figure 2.7* and *Table 2.9*.

4. Transfer to the working face(s) of the excavation via the tunnels or underground adits.

5. Load and fire the face(s) to be blasted. Blasts in a particular area will be initiated from a common firing point once all personnel are clear and entry routes to each blast site are secured. All blasts are to be carried out underground.

2.5.2 *Drill and Blast Explosive Requirements*

Based on the envisaged construction programme, the blasting activities together with the required amount of explosives is summarised as shown in *Table 2.3*. The actual amount of explosives (cartridged emulsion and detonating cord) is based on the tunnel profiles described in *Table 2.4* and the types of explosives listed in *Table 2.5*.

Table 2.3 Project Drill and Blast Explosive Requirements (Summary)

Works Area	**Delivery Point**	**Blast Face**	**Approximate No. of Blasts**	**Explosive Load (kg/ blast)**
North Portal	Sha Tau Kok Road	Dual two-lane trunk road connecting the BCP with Tolo/Fanling Highway	570	35
Mid-Ventilation Portal	Po Kat Tsai Road	Dual two-lane trunk road connecting the BCP with Tolo/Fanling Highway	300	10-80
South Portal	Tai Wo Service Road East	Dual two-lane trunk road connecting the BCP with Tolo/Fanling Highway)	855	10-90

Table 2.4 Project Drill and Blast – Typical Tunnel Profiles

Profile	**Description**	**Section Area (m^2)**	**No. of Production Holes**	**No. of Perimeter Holes**	**Cartridged Emulsion (kg)**	**Detonating Cord (kg per metre drilled)**	**Detonators (kg)**	**Cast Boosters (kg)**
Dual two-lane trunk road connecting the BCP with Tolo/Fanling Highway	Typical section T1	125	109	44	17.6	0.08	0.138	3

Note 1: The following abbreviations apply: CE - Cartridged Emulsion, BE - Bulk Explosives
Note 2: Typical tunnel profile given for an assumed pull length of 5.0 m. For some tunnel sections, this is not achievable due to the proximity of sensitive receivers.

Table 2.5 Project Drill and Blast – Initiating Explosive Types

Explosives	**Quantity per Production/ Perimeter Hole**
Cartridged Emulsion	0.125 kg (125 g per cartridged emulsion) [1]
Detonating Cord	0.080 kg/m based on density of 0.040 kg/m (40 g/m)
Detonator	0.001 kg (0.9 g each)
Cast Booster	0.02 kg (20 g per mini cast booster)

Note 1: For blast where MIC is lower than 2 kg and Bulk Emulsion cannot be used; 0.208 kg cartridge types may be used.

2.5.3 *Explosive Transport Requirements Based on Blasting Programme*

Current Construction Programme

The approach adopted to derive the total number of trips and the total initiating explosives to be transported per trip is as follows:

- As far as practicable, the explosives (cartridged emulsion, cast boosters and detonating cord) required for all the blast faces of a given work area operated by the same Contractor will be transported on the same explosives delivery truck. Note that detonators are transported on dedicated trucks.

- Due to potential progress issues during the construction stage, arising from programme delay or change, it may not be possible to adhere strictly to the envisaged construction programme. This will result in blasts carried out at a different time for the various faces and separate deliveries.

- Loads will be limited to a maximum of 200 kg per truck in accordance with the Removal Permit issued by Mines Division.

- The quantity of Category 1 explosives on the roads has been minimised by using bulk emulsion, which will be manufactured on-site. The on-site manufacture of bulk emulsion will require the transportation of Cat. 7 Oxidising Substances which falls outside the scope of this study.

- It has been assumed in this report that the project will mostly require a separate explosives delivery from Tai Lam Explosives Magazine Site to each delivery point.

- The actual construction programme will depend on the detailed design and appointed contractors. It may also depend on the actual achievable progress rates which may vary due to site specific conditions (e.g. geology). To consider the uncertainty in the envisaged construction programme, a Base Case, which accounts for expected programme variations, and a Worst Case, which represents the worst programme scenario, have been considered for the assessment.

Base Case for the Hazard to Life Assessment

In this study, three Route Options were presented as the base case.

Based on the envisaged construction programme and sequence of works, the annual travel distance by explosive vehicles, carrying cartridged emulsion, cast boosters and detonating cord, will reach a peak in the period between March 2016 and February 2017, as shown in *Table 2.7*. This period is referred to the peak explosive delivery period which is taken to represent the Base Case scenario for the Hazard to Life Assessment. Within this period, taking Route Option R1 as an example, the annual number of deliveries is 2,100 while the explosive trucks travel distance is around 53,165 km. The delivery frequency has been estimated on the basis that, for a given delivery point, each delivery will be made to each blast face (or for a twin-track tunnel each two blast faces in the same direction) independently of the other blast faces even if the load could be transported on the same truck. This approach, although slightly conservative, accounts for envisaged delivery variations during the peak delivery period, within which, separate deliveries will be generally undertaken. The total number of trips has been estimated based on the typical licencing limit of 200 kg explosives per truck.

In the Base Case, it was considered that explosives delivery could be carried out at any time of the day depending on the blasting programme to allow for flexibility to the blasting programme.

The number of explosives delivery trips is estimated based on the blasts for the envisaged construction programme with contingency to take into account variation of geological conditions and construction programme affecting the number of explosives deliveries required.

It was generally assumed that explosives will not be returned to the Explosive Magazine.

The travel distance from Magazine site to each delivery point is provided in *Table 2.6*. The corresponding explosive load transported in the peak 12- month delivery period is shown in *Table 2.8* for each work area.

In this project, for a particular delivery point, it is possible that the explosive load required for each delivery will be higher than that indicated in the envisaged programme due to particular site conditions and blasting requirements; however, the truck load is conservatively assumed to be 200 kg in each trip as shown in *Table 2.8*. The actual truck load is 42 – 83 kg for North Portal, 43 – 65 kg for Mid-Ventilation Portal and 84 – 132 kg for South Portal, which are significantly lower than the maximum truck load of 200 kg.

In this Project, explosives transport will be scheduled with a total of two to six deliveries per day to the three worksites (explosives are required at two to three worksites per day) and maximum seven (7) days per week. CEDD Mines Division will supply the explosives to the magazine site on weekdays (Monday to Friday) and on Saturday if necessary.

Table 2.6 Travel Distance from Tai Lam Explosives Magazine Site to Each Delivery Point

Delivery Points	North Portal	Mid-Ventilation Portal	South Portal
Travel distance (km) from Tai Lam Explosives Magazine Site to Delivery Point (Route Option R1)	27.6	27.5	23.2
Travel distance (km) from Tai Lam Explosives Magazine Site to Delivery Point (Route Option R2)	30.8	30.9	27.8
Travel distance (km) from Tai Lam Explosives Magazine Site to Delivery Point (Route Option R3)	24.6	24.7	21.6

Table 2.7 Explosive Deliveries for Every 12-Month Period during Project Period

12-Month Delivery Period	Total Explosive Delivery Trips within the 12-Month Period			Total No. of Trips	Total Distance Travelled (km) Route Option R1	Total Distance Travelled (km) Route Option R2	Total Distance Travelled (km) Route Option R3
	North Portal	Mid-Ventilation Portal	South Portal				
Jan 2016 - Dec 2016	390	615	1075	2080	52607	60957	48061

12-Month Delivery Period	Total Explosive Delivery Trips within the 12-Month Period			Total No. of Trips	Total Distance Travelled (km) Route Option R1	Total Distance Travelled (km) Route Option R2	Total Distance Travelled (km) Route Option R3
	North Portal	Mid-Ventilation Portal	South Portal				
Feb 2016 - Jan 2017	480	525	1075	2080	52622	60945	48049
Mar 2016 - Feb 2017	570	450	1080	2100	53165	61535	48515
Apr 2016 - Mar 2017	660	360	1050	2070	52484	60688	47854
May 2016 - Apr 2017	750	270	1020	2040	51803	59840	47192
Jun 2016 - May 2017	820	180	990	1990	50569	58377	46039
Jul 2016 - Jun 2017	850	90	960	1900	48230	55681	43901
Aug 2016 - Jul 2017	850	0	930	1780	45062	52062	41026
Sep 2016 - Aug 2017	850	0	900	1750	44366	51227	40377
Oct 2016 - Sep 2017	840	0	870	1710	43394	50084	39482
Nov 2016 - Oct 2017	830	0	840	1670	42422	48941	38587
Dec 2016 - Nov 2017	820	0	750	1570	40058	46129	36395
Jan 2017 – Dec 2017	760	0	660	1420	36312	41776	32972

Note: (1) Peak delivery period selected for the Base Case based on total travel distance within the 12-Month Period

Table 2.8 Explosives Load Transported in the Peak 12-Month Delivery Period

Works Area	Explosive Load Transported (kg/ trip)
North Portal	200 (actual truck load is 42 – 83 kg)
Mid-Ventilation Portal	200 (actual truck load is 43 – 65 kg)
South Portal	200 (actual truck load is 84 – 132 kg)

Worst Case

The Hazard to Life Assessment also covers the Worst Case scenario. It addresses the possibility that, due to construction uncertainties or contractors' methods of working, the contractors propose an actual construction programme which differs from the envisaged construction programme. Such a case may result in a higher number of delivery trips. Return trips loaded with explosives will generally be avoided, however, due to some construction uncertainties, a number of return trips could be made. Overall, in the worst case, a 20% increase in the number of deliveries compared to the Base Case scenario may result based on previous project experience.

2.6 TRANSPORT OF BLASTING EXPLOSIVES AND INITIATION SYSTEMS

2.6.1 *Overview*

Blasting explosives (Bulk emulsion) will be manufactured on-site while the explosives required as part of the initiating system required for a particular Drill and Blast project will be delivered by Mines Division, stored within the contractor's Magazine and transported to the worksites by the contractor. Mines Division requires that blasthole loading is commenced immediately, as soon as practicable, upon receiving the explosives (it may take 2 to 4 hours to transport the explosives from the surface to the blast face, charge the face, evacuate the area and execute the blast). Storage of explosives at the work site is not permitted.

When approved by Mines Division, one or more dedicated Magazines can be constructed to service the particular needs of a project. This enables more than one blast per day.

Mines Division generally limits the amount of explosives that a contractor can transport from the Magazine to the blast site to 200 kg per explosive delivery truck. In some circumstances, this limit may necessitate more than one trip to deliver the required volume of explosives for a blast taking into account the Removal Permit licencing limit.

Detonators shall be transported in a separate licenced vehicle and are never to be carried together with explosives.

Mines Division allows any unused explosives or detonators from a blast to be returned to their Magazine store. However, in practice, any unused cartridged emulsion explosives is generally destroyed by burning in a controlled manner, and excess initiating systems (detonators) is also destroyed by linking them into the blast. Unused explosives may also result if a particular blast is delayed and hence the load needs to be returned to the Magazine.

2.6.2 *Transport Strategy – Magazine to Worksites*

Bulk emulsion will be manufactured on-site by an appointed third party supplier.

Explosives will be transferred from the relevant store by the relevant contractor. Two licenced explosive trucks will be required for each delivery - one will only transport detonators while the other will transport a cargo of cartridged emulsion, cast boosters and detonating cord. The explosives transport strategy is shown in *Figure 2.4*.

No more than one truck convoy loaded with explosives (made up of the truck carrying the cartridged emulsion, cast boosters and the detonating cord and the truck carrying the detonators) is generally expected within the explosives magazine complex at any one time. In any event, explosive trucks will maintain a separation headway of about 10 min.

2.6.3 *Transport Strategy - Worksites to Blasting Sites*

Explosives and detonators will be transported separately but in convoy from the Magazine to the designated access shafts / blasting sites by the contractors' licenced delivery vehicles under the escort of armed security guards.

To minimise the transport risk, the following principles have been observed in planning delivery routes between the Magazine and the various blasting sites:

- Routes have been planned to avoid areas of high population density and Potentially Hazardous Installations (PHIs) wherever possible.
- Explosive truck convoys for each work area will maintain, as far as possible, separation headway of around 10 min.
- The quantity of Category 1 Explosives on the roads has been minimised by using bulk emulsion wherever possible, which will be manufactured on-site. The manufacture of bulk emulsion will require the transportation of Category 7 Oxidizing Substances, which fall outside the scope of this study.

2.6.4 *Safety Features of Transport Vehicles*

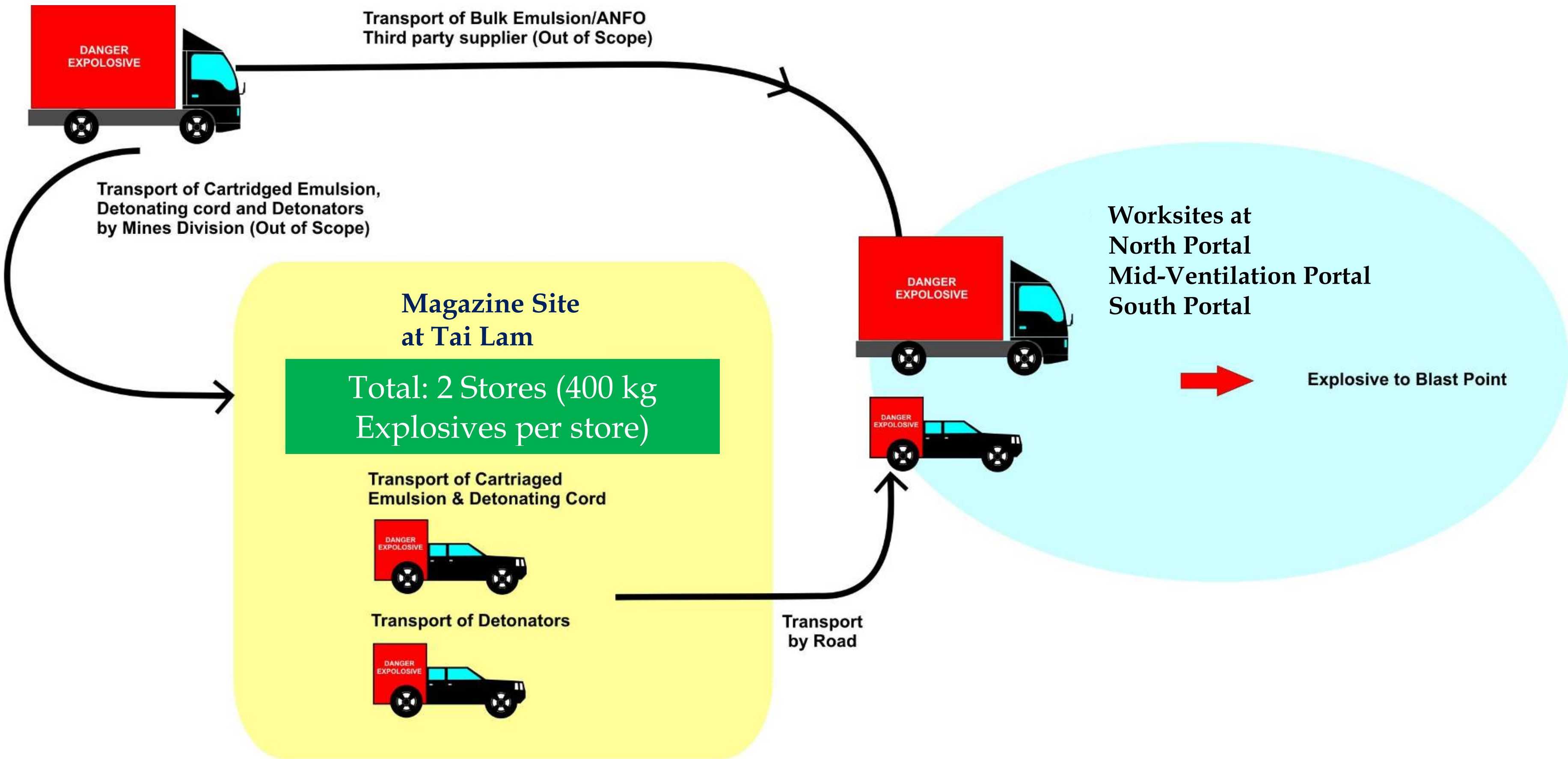
The contactors' pick up trucks (LGV pick up truck) for delivery of explosives from the Magazine to the blast faces will be licenced by Mines Division and will meet all regulatory requirements for that transport.

The proposed contractors' explosives delivery vehicle design, used as the basis for the QRA, will have the following safety features:

- Diesel powered;
- Driver's cabin is separated by a distance of not less than 150 mm from the cargo compartment of the vehicle;
- Manual fuel isolation switch;
- The exhaust system is located as far from the cargo compartment as possible. The modification of the exhaust system will be approved by the Transport Department;
- All electrical wiring and fittings will be shrouded in fire resisting conduits;
- Fuel tank will be protected from accidental damage, and designed to prevent accumulation of spilt fuel on any part of the vehicle;
- The required number of fire extinguishers shall be agreed with Mines Division;
- Fire resistant material shall be fitted between the wheel arches and the goods compartment;
- Hand-held lightning detector provided in the vehicle for lightning detection during loading and unloading of explosives;
- Lockable wood lined steel or aluminium receptacles mounted on the vehicle tray; and
- Fold down/ up explosives warning signs and red strobe beacons.

In addition to the minimum requirements, a fire screen will be fitted between the cab and the load compartment, both between the cab and the load compartment and underneath the load compartment. The fire screen shall be 3 mm; extend to 150 mm above [all sides of] and run completely under the load compartment; to at least 100 mm behind the cab of the vehicle.

Figure 2.4 Transport Strategy for the Explosives



2.6.5 *Details of Explosive Delivery Routes*

For the Base Case, the Explosives will be delivered from Tai Lam Explosives Magazine Site to the three work areas using the public roads as shown in *Figure 2.7* (Route Option R1), *Figure 2.8* (Route Option R2) and *Figure 2.9* (Route Option R3).

In Route Options R1 and R3, the explosives delivery truck will pass through Pok Oi Interchange and Shap Pat Heung Interchange. During the Fourth Meeting of Traffic and Transport Committee under Yuen Long District Council on 24 July 2014 (Thursday), members expressed concerns on the traffic conditions of Pok Oi Interchange. Currently there is road improvement work which leads to serious traffic jam, thus temporary road diversion and traffic control measures are enforced. The road improvement work is expected to be completed in 2015 but may be delayed due to the flyover foundation. Therefore, members generally did not prefer the use of Pok Oi Interchange by the explosives delivery truck during the road improvement work, and recommended to use Tong Yan San Tsuen Interchange and Yuen Long Road, which is Route Option R2.

The explosives delivery routes will be:

- At early stage of this project with road improvement work at Pok Oi Interchange (expected to be completed in 2015 but may be delayed), Route Option R2 will be used. Route Options R1 and R3 are not feasible.
- After road improvement work at Pok Oi Interchange is completed, all three routes will be available for use. The Route Option with minimum transport risk will be used.

The explosive delivery routes from the Tai Lam Explosives Magazine to the worksites (North Portal, Mid-Ventilation Portal, South Portal) will involve transportation on roads passing through mainly residential areas and commercial districts which can occasionally be crowded.

Since the explosive transport from the Magazine to the delivery points will cover between 20 - 30 kilometres of road with varying characteristics, each delivery route was broken down into sub-sections for the assessment. Route sectionalisation allows a more accurate determination of the population and of the risk.

The explosive delivery routes are listed in *Table 2.9.*

A temporary vehicular bridge has been constructed for the Project 'Liantang / Heung Yuen Wai Boundary Control Point and Associated Works' (EIA study has been approved and Environmental Permit has been issued). The temporary vehicular bridge has been constructed under Particular Specification of the Contract (Clause 1.17L(1)) , spanning across the East Rail Line of MTRC from the South Portal of Lung Shan Tunnel to a service road to the western side of East Rail Line, as shown in *Figure 2.5* and *Figure 2.6*. The design and construction of temporary vehicular bridge comply to the Transport Planning and Design Manual (TPDM), Highways standards and guidance, 'Code of Practice for Lighting, Signing and Guarding of Road Works' issued by the Hong Kong Government, Structures Design Manual for Highways and Railways issued by the Highways Department, as well as requirements imposed by MTR. The bridge will be used by CEDD Mines Division to transport explosives to the blasting worksites before Dragages Hong Kong obtains the approval for explosives transport from the Tai Lam Explosives Magazine site, and will be used by Dragages Hong Kong to transport explosive from the Tai Lam Explosives Magazine site after approval is obtained. Population affected by accidental detonation on the temporary vehicular bridge, such as passengers on the railway, are considered in the assessment.

Figure 2.5 Layout of the Temporary Vehicular Bridge

Figure 2.6 Site Photo of the Temporary Vehicular Bridge

Figure 2.7 Tai Lam Explosives Magazine Site Location and Explosives Transport Routes (Route Option R1)

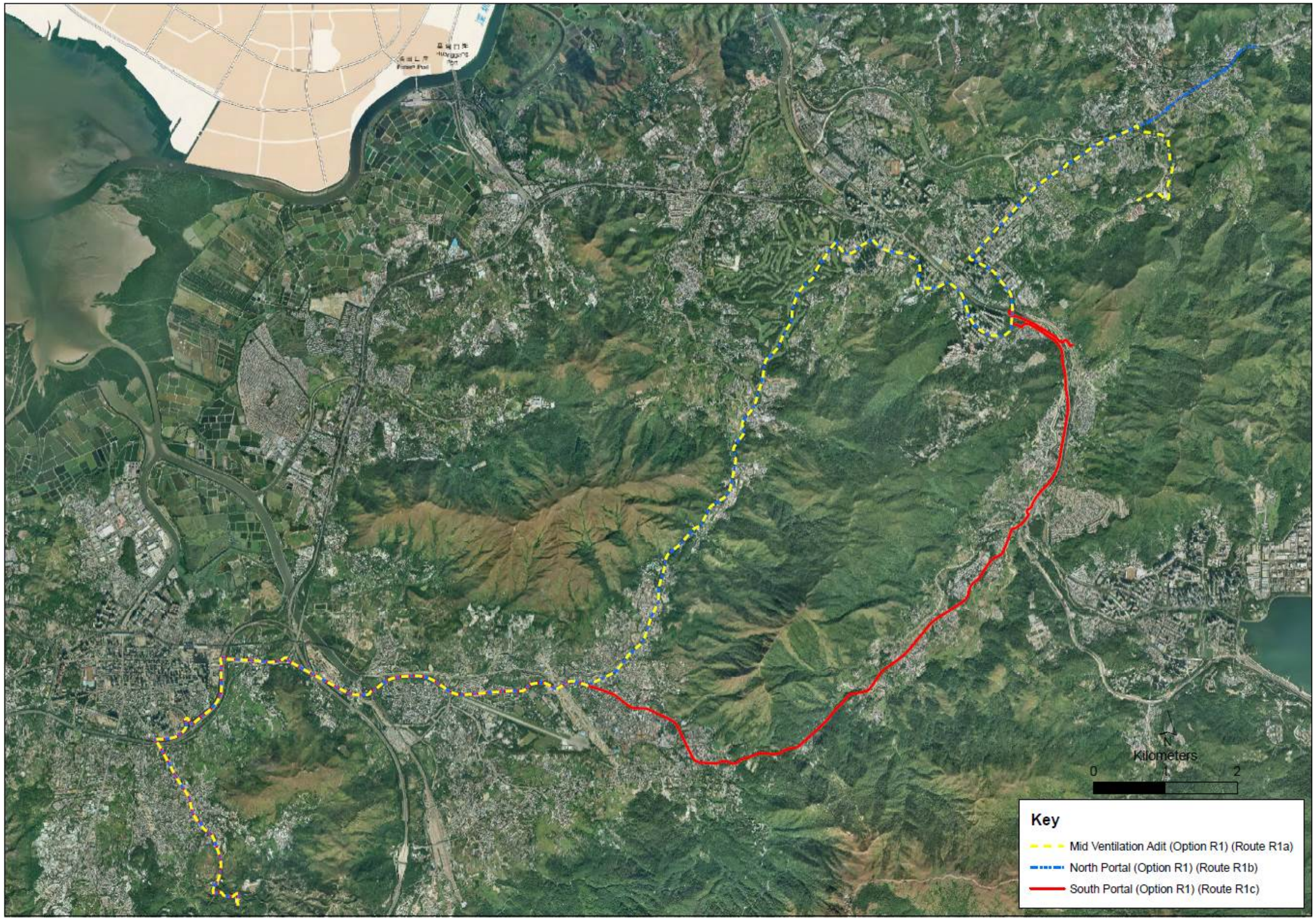


Figure 2.8 Tai Lam Explosives Magazine Site Location and Explosives Transport Routes (Route Option R2)

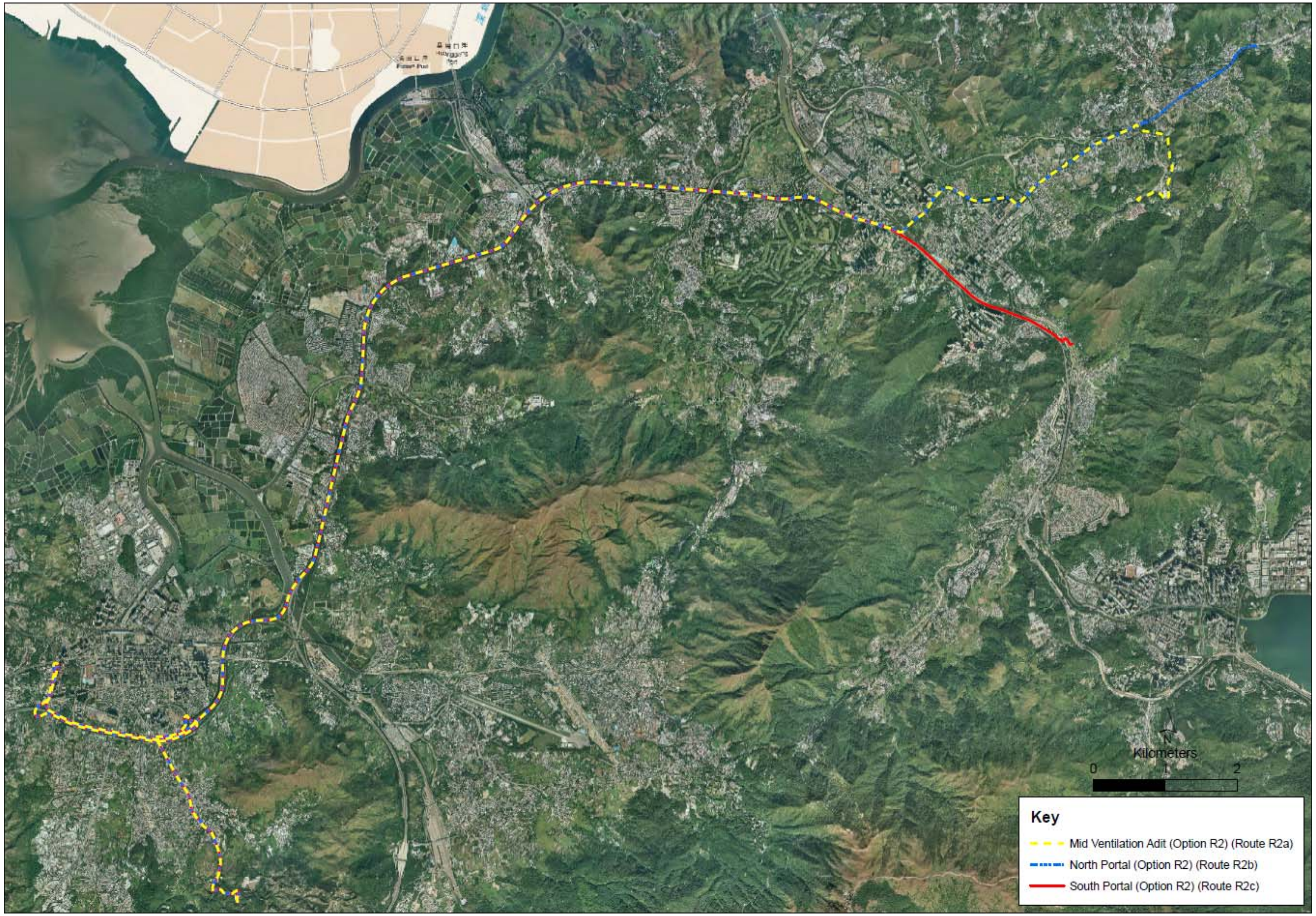


Figure 2.9 Tai Lam Explosives Magazine Site Location and Explosives Transport Routes (Route Option R3)

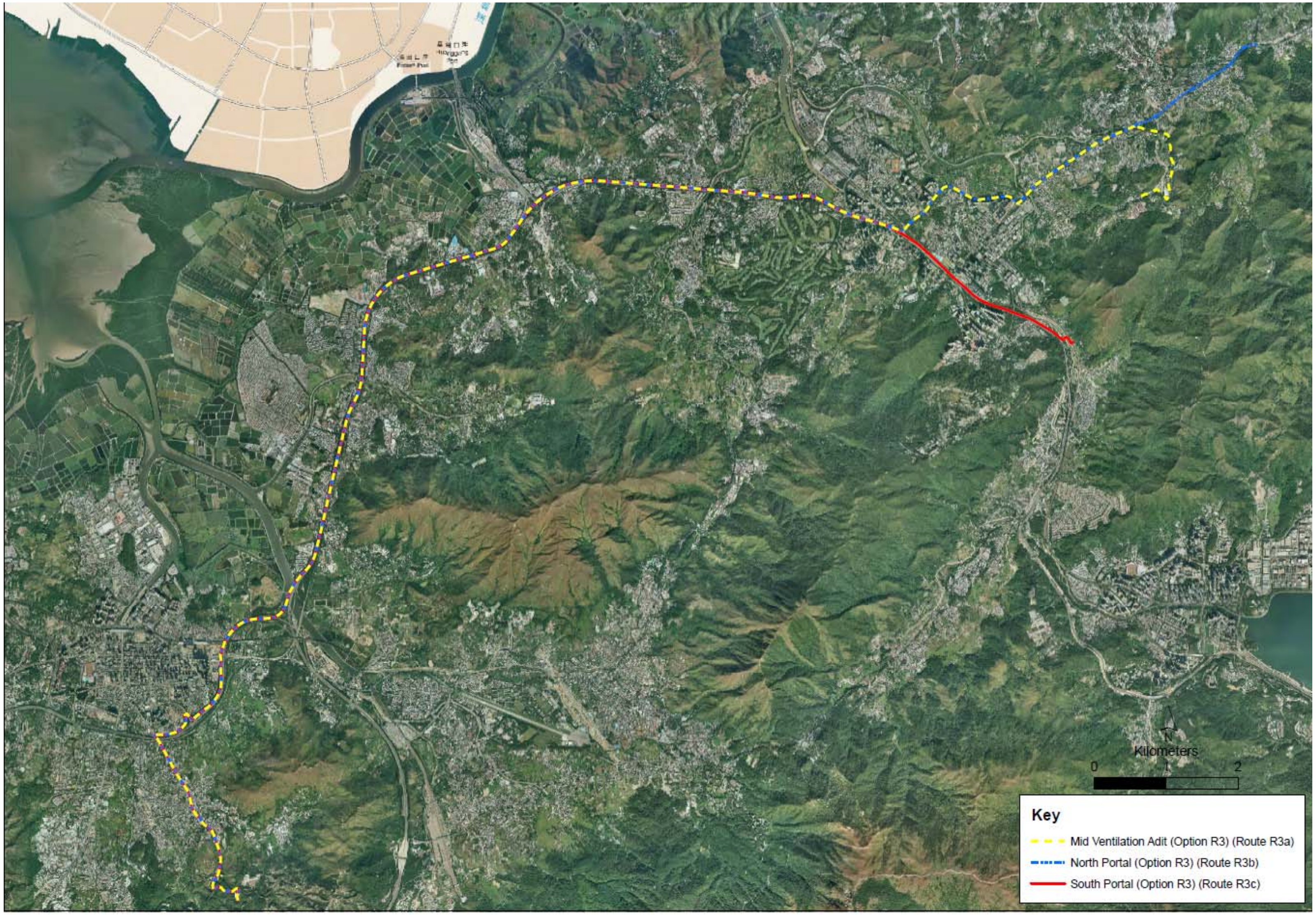


Figure 2.10 Tai Lam Explosives Magazine Site Location and Explosives Transport Routes (Yuen Long Highway and Pok Oi Interchange area close-up views)

Route Option R1

Route Option R2

Route Option R3

Table 2.9 Delivery Routes from Tai Lam Explosives Magazine Site to Worksites

Section ID	Description
Route R1a (Route Option R1: Tai Lam Explosives Magazine Site – Mid-Ventilation Adit)	
Road R1a1	Access road towards Tai Shu Ha Rd West
Road R1a2	Tai Shu Ha Road West 1
Road R1a3	Tai Shu Ha Road West 2
Road R1a4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)
Road R1a5	Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)
Road R1a6	Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)
Road R1a7	Castle Peak Road (Yuen Long) (Pok Oi Int - Kam Tin Rd)
Road R1a8	Kam Tin Rd (Castle Peak Rd (Yuen Long) - Kam Sheung Rd western junction)
Road R1a9	Kam Tin Bypass
Road R1a10	Kam Tin Rd (Kam Sheung Rd western junction - Fan Kam Rd)
Road R1a11	Fan Kam Rd (Kam Tin Rd - Castle Peak Rd)
Road R1a12	Po Kin Rd (Fan Kam Rd - Pak Wo Rd)
Road R1a13	Pak Wo Rd (Po Kin Rd - Slip rd to So Kwun Po Int)
Road R1a14	Pak Wo Rd (Slip rd to So Kwun Po Int - Yu Tai Rd)
Road R1a15	Pak Wo Rd (Yu Tai Rd - Pak Wo Rd RA)
Road R1a16	Pak Wo Rd (Pak Wo Rd RA - Wah Ming Rd)
Road R1a17	Pak Wo Rd (Wah Ming Rd - Wai Ming St)
Road R1a18	Pak Wo Rd (Wai Ming St - Yat Ming Rd)
Road R1a19	Pak Wo Rd (Yat Ming Rd - Wo Hop Shek Int)
Road R1a20	Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd)
Road R1a21	Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd) 2
Road R1a22	Jockey Club Rd (Lok Yip Rd - Sha Tau Kok Rd)
Road R1a23	Sha Tau Kok Rd (Lung Yeuk Tau) (Jockey Club Rd - Lok Yip Rd)
Road R1a24	Sha Tau Kok Rd (Lung Yeuk Tau) (Lok Yip Rd - Luen Shing St)
Road R1a25	Sha Tau Kok Rd (Lung Yeuk Tau) (Luen Shing St - On Kui St)
Road R1a26	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Lau Shui Heung Rd)
Road R1a27	Lau Shui Heung Rd (Sha Tau Kok Rd - Po Kat Tsai Rd)
Road R1a28	Po Kat Tsai Road (Lau Shui Heung Rd - Site)
Route R1b (Route Option R1: Tai Lam Explosives Magazine Site – North Portal)	
Road R1b1	Access road towards Tai Shu Ha Rd West
Road R1b2	Tai Shu Ha Road West 1
Road R1b3	Tai Shu Ha Road West 2
Road R1b4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)
Road R1b5	Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)
Road R1b6	Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)
Road R1b7	Castle Peak Road (Yuen Long) (Pok Oi Int - Kam Tin Rd)
Road R1b8	Kam Tin Rd (Castle Peak Rd (Yuen Long) - Kam Sheung Rd western junction)
Road R1b9	Kam Tin Bypass
Road R1b10	Kam Tin Rd (Kam Sheung Rd western junction - Fan Kam Rd)
Road R1b11	Fan Kam Rd (Kam Tin Rd - Castle Peak Rd)
Road R1b12	Po Kin Rd (Fan Kam Rd - Pak Wo Rd)
Road R1b13	Pak Wo Rd (Po Kin Rd - Slip rd to So Kwun Po Int)
Road R1b14	Pak Wo Rd (Slip rd to So Kwun Po Int - Yu Tai Rd)
Road R1b15	Pak Wo Rd (Yu Tai Rd - Pak Wo Rd RA)
Road R1b16	Pak Wo Rd (Pak Wo Rd RA - Wah Ming Rd)
Road R1b17	Pak Wo Rd (Wah Ming Rd - Wai Ming St)
Road R1b18	Pak Wo Rd (Wai Ming St - Yat Ming Rd)
Road R1b19	Pak Wo Rd (Yat Ming Rd - Wo Hop Shek Int)
Road R1b20	Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd) 1
Road R1b21	Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd) 2
Road R1b22	Jockey Club Rd (Lok Yip Rd - Sha Tau Kok Rd)

Section ID	Description
Road R1b23	Sha Tau Kok Rd (Lung Yeuk Tau) (Jockey Club Rd - Lok Yip Rd)
Road R1b24	Sha Tau Kok Rd (Lung Yeuk Tau) (Lok Yip Rd - Luen Shing St)
Road R1b25	Sha Tau Kok Rd (Lung Yeuk Tau) (Luen Shing St - On Kui St)
Road R1b26	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 1
Road R1b27	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 2
Route R1c (Route Option R1: Tai Lam Explosives Magazine Site Magazine – South Portal)	
Road R1c1	Access road towards Tai Shu Ha Rd West
Road R1c2	Tai Shu Ha Road West 1
Road R1c3	Tai Shu Ha Road West 2
Road R1c4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)
Road R1c5	Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)
Road R1c6	Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)
Road R1c7	Castle Peak Road (Yuen Long) (Pok Oi Int - Kam Tin Rd)
Road R1c8	Kam Tin Rd (Castle Peak Rd (Yuen Long) - Kam Sheung Rd western junction)
Road R1c9	Kam Tin Bypass
Road R1c10	Kam Tin Rd (Kam Sheung Rd western junction - Fan Kam Rd)
Road R1c11	Kam Tin Rd (Fan Kam Rd - Kam Sheung Rd eastern junction)
Road R1c12	Lam Kam Rd (Kam Sheung Rd - Lam Kam Rd Int)
Road R1c13	Lam Kam Rd (Lam Kam Rd Int - Tai Wo Service Rd W)
Road R1c14	Tai Wo Service Rd W (Lam Kam Rd Int - Kau Lung Hang FO)
Road R1c15	Tai Wo Service Rd W (Kau Lung Hang FO - Wo Hing Rd)
Road R1c16	Unnamed road (Wo Hing Rd - Pak Wo Rd)
Road R1c17	Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd)
Road R1c18	Slip Rd (Jockey Club Rd - Fanling Highway)
Road R1c19	Fanling Highway (Wo Hop Shek Int - Kau Lung Hang Lo Wai)
Road R1c20	Tai Wo Service Rd East (Slip rd from Fanling Highway - Road to Site 1)
Road R1c21	Road to Site 1 (Tai Wo Service Rd East - Road to Site 2)
Road R1c22	Road to Site 2 (Road to Site 1 - Site)
Route R2a (Route Option R2: Tai Lam Explosives Magazine Site – Mid-Ventilation Adit)	
Road R2a1	Access road towards Tai Shu Ha Rd West
Road R2a2	Tai Shu Ha Road West 1
Road R2a3	Tai Shu Ha Road West 2
Road R2a4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)
Road R2a5	Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)
Road R2a6	Shap Pat Heung Interchange (Shap Pat Heung Road - Yuen Long Highway)
Road R2a7	Yuen Long Highway (Shap Pat Heung Int - Tong Yan San Tsuen Int)
Road R2a8	Connecting road from Tong Yan San Tsuen Int to Long Tin Road
Road R2a9	Long Tin Road (Tong Yan San Tsuen Int - Castle Peak Rd (Ping Shan))
Road R2a10	Connecting road from Long Tin Road North Bound to South Bound
Road R2a11	Long Tin Road (Castle Peak Rd (Ping Shan) - Tong Yan San Tsuen Int)
Road R2a12	Connecting road from Long Tin Rd to Tong Yan San Tsuen Int
Road R2a13	Yuen Long Highway (Tong Yan San Tsuen Int - Shap Pat Heung Int)
Road R2a14	Yuen Long Highway (Shap pat Heung Int - Nr Tsing Long Highway)
Road R2a15	Yuen Long Highway (to San Tin Highway 1)
Road R2a16	Yuen Long Highway (to San Tin Highway 2)
Road R2a17	San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)
Road R2a18	San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)
Road R2a19	Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)
Road R2a20	Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)
Road R2a21	So Kwun Po Rd (Fanling Highway - So Kwun Po Rd Int)
Road R2a22	So Kwun Po Rd (So Kwun Po Rd Int - Jockey Club Rd)
Road R2a23	Ma Sik Rd (Jockey Club Rd - Tin Ping Rd)
Road R2a24	Ma Sik Rd (Tin Ping Rd - Fan Leng Lau Rd)
Road R2a25	Ma Sik Rd (Fan Leng Lau Rd - Luen Chit St)

Section ID	Description
Road R2a26	Ma Sik Rd (Luen Chit St - Wo Tai St)
Road R2a27	Ma Sik Rd (Wo Tai St - Sha Tau Kok Rd (Lung Yeuk Tau))
Road R2a28	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Lau Shui Heung Rd)
Road R2a29	Lau Shui Heung Rd (Sha Tau Kok Rd - Po Kat Tsai Rd)
Road R2a30	Po Kat Tsai Road (Lau Shui Heung Rd - Site)
Route R2b (Route Option R2: Tai Lam Explosives Magazine Site – North Portal)	
Road R2b1	Access road towards Tai Shu Ha Rd West
Road R2b2	Tai Shu Ha Road West 1
Road R2b3	Tai Shu Ha Road West 2
Road R2b4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)
Road R2b5	Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)
Road R2b6	Shap Pat Heung Interchange (Shap Pat Heung Road - Yuen Long Highway)
Road R2b7	Yuen Long Highway (Shap Pat Heung Int - Tong Yan San Tsuen Int)
Road R2b8	Connecting road from Tong Yan San Tsuen Int to Long Tin Road
Road R2b9	Long Tin Road (Tong Yan San Tsuen Int - Castle Peak Rd (Ping Shan))
Road R2b10	Connecting road from Long Tin Road North Bound to South Bound
Road R2b11	Long Tin Road (Castle Peak Rd (Ping Shan) - Tong Yan San Tsuen Int)
Road R2b12	Connecting road from Long Tin Rd to Tong Yan San Tsuen Int
Road R2b13	Yuen Long Highway (Tong Yan San Tsuen Int - Shap Pat Heung Int)
Road R2b14	Yuen Long Highway (Shap pat Heung Int - Nr Tsing Long Highway)
Road R2b15	Yuen Long Highway (to San Tin Highway 1)
Road R2b16	Yuen Long Highway (to San Tin Highway 2)
Road R2b17	San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)
Road R2b18	San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)
Road R2b19	Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)
Road R2b20	Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)
Road R2b21	So Kwun Po Rd (Fanling Highway - So Kwun Po Rd Int)
Road R2b22	So Kwun Po Rd (So Kwun Po Rd Int - Jockey Club Rd)
Road R2b23	Ma Sik Rd (Jockey Club Rd - Tin Ping Rd)
Road R2b24	Ma Sik Rd (Tin Ping Rd - Fan Leng Lau Rd)
Road R2b25	Ma Sik Rd (Fan Leng Lau Rd - Luen Chit St)
Road R2b26	Ma Sik Rd (Luen Chit St - Wo Tai St)
Road R2b27	Ma Sik Rd (Wo Tai St - Sha Tau Kok Rd (Lung Yeuk Tau))
Road R2b28	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 1
Road R2b29	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 2
Route R2c (Route Option R2: Tai Lam Explosives Magazine Site – South Portal)	
Road R2c1	Access road towards Tai Shu Ha Rd West
Road R2c2	Tai Shu Ha Road West 1
Road R2c3	Tai Shu Ha Road West 2
Road R2c4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)
Road R2c5	Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)
Road R2c6	Shap Pat Heung Interchange (Shap Pat Heung Road - Yuen Long Highway)
Road R2c7	Yuen Long Highway (Shap Pat Heung Int - Tong Yan San Tsuen Int)
Road R2c8	Connecting road from Tong Yan San Tsuen Int to Long Tin Road
Road R2c9	Long Tin Road (Tong Yan San Tsuen Int - Castle Peak Rd (Ping Shan))
Road R2c10	Connecting road from Long Tin Road North Bound to South Bound
Road R2c11	Long Tin Road (Castle Peak Rd (Ping Shan) - Tong Yan San Tsuen Int)
Road R2c12	Connecting road from Long Tin Rd to Tong Yan San Tsuen Int
Road R2c13	Yuen Long Highway (Tong Yan San Tsuen Int - Shap Pat Heung Int)
Road R2c14	Yuen Long Highway (Shap pat Heung Int - Nr Tsing Long Highway)
Road R2c15	Yuen Long Highway (to San Tin Highway 1)
Road R2c16	Yuen Long Highway (to San Tin Highway 2)
Road R2c17	San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)
Road R2c18	San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)

Section ID	Description
Road R2c19	Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)
Road R2c20	Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)
Road R2c21	Fanling Highway (So Kwun Po Int - Wo Hop Shek Int)
Road R2c22	Fanling Highway (Wo Hop Shek Int - Kau Lung Hang Lo Wai)
Road R2c23	Tai Wo Service Rd East (Slip rd from Fanling Highway - Kau Lung Hang FO)
Road R2c24	Road to Site 1 (Tai Wo Service Rd East - Road to Site 2)
Road R2c25	Road to Site 2 (Road to Site 1 - Site)
Route R3a (Route Option R3: Tai Lam Explosives Magazine Site – Mid-Ventilation Adit)	
Road R3a1	Access road towards Tai Shu Ha Rd West
Road R3a2	Tai Shu Ha Road West 1
Road R3a3	Tai Shu Ha Road West 2
Road R3a4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)
Road R3a5	Shap Pat Heung Road (Tai Tong Rd - Shap Pat Heung Interchange)
Road R3a6	Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)
Road R3a7	Yuen Long Highway
Road R3a8	Yuen Long Highway (to San Tin Highway 1)
Road R3a9	Yuen Long Highway (to San Tin Highway 2)
Road R3a10	San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)
Road R3a11	San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)
Road R3a12	Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)
Road R3a13	Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)
Road R3a14	So Kwun Po Rd (Fanling Highway - So Kwun Po Rd Int)
Road R3a15	So Kwun Po Rd (So Kwun Po Rd Int - Jockey Club Rd)
Road R3a16	Ma Sik Rd (Jockey Club Rd - Tin Ping Rd)
Road R3a17	Ma Sik Rd (Tin Ping Rd - Fan Leng Lau Rd)
Road R3a18	Ma Sik Rd (Fan Leng Lau Rd - Luen Chit St)
Road R3a19	Ma Sik Rd (Luen Chit St - Wo Tai St)
Road R3a20	Ma Sik Rd (Wo Tai St - Sha Tau Kok Rd (Lung Yeuk Tau))
Road R3a21	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Lau Shui Heung Rd)
Road R3a22	Lau Shui Heung Rd (Sha Tau Kok Rd - Po Kat Tsai Rd)
Road R3a23	Po Kat Tsai Road (Lau Shui Heung Rd - Site)
Route R3b (Route Option R3: Tai Lam Explosives Magazine Site – North Portal)	
Road R3b1	Access road towards Tai Shu Ha Rd West
Road R3b2	Tai Shu Ha Road West 1
Road R3b3	Tai Shu Ha Road West 2
Road R3b4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)
Road R3b5	Shap Pat Heung Road (Tai Tong Rd - Shap Pat Heung Interchange)
Road R3b6	Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)
Road R3b7	Yuen Long Highway
Road R3b8	Yuen Long Highway (to San Tin Highway 1)
Road R3b9	Yuen Long Highway (to San Tin Highway 2)
Road R3b10	San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)
Road R3b11	San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)
Road R3b12	Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)
Road R3b13	Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)
Road R3b14	So Kwun Po Rd (Fanling Highway - So Kwun Po Rd Int)
Road R3b15	So Kwun Po Rd (So Kwun Po Rd Int - Jockey Club Rd)
Road R3b16	Ma Sik Rd (Jockey Club Rd - Tin Ping Rd)
Road R3b17	Ma Sik Rd (Tin Ping Rd - Fan Leng Lau Rd)
Road R3b18	Ma Sik Rd (Fan Leng Lau Rd - Luen Chit St)
Road R3b19	Ma Sik Rd (Luen Chit St - Wo Tai St)
Road R3b20	Ma Sik Rd (Wo Tai St - Sha Tau Kok Rd (Lung Yeuk Tau))

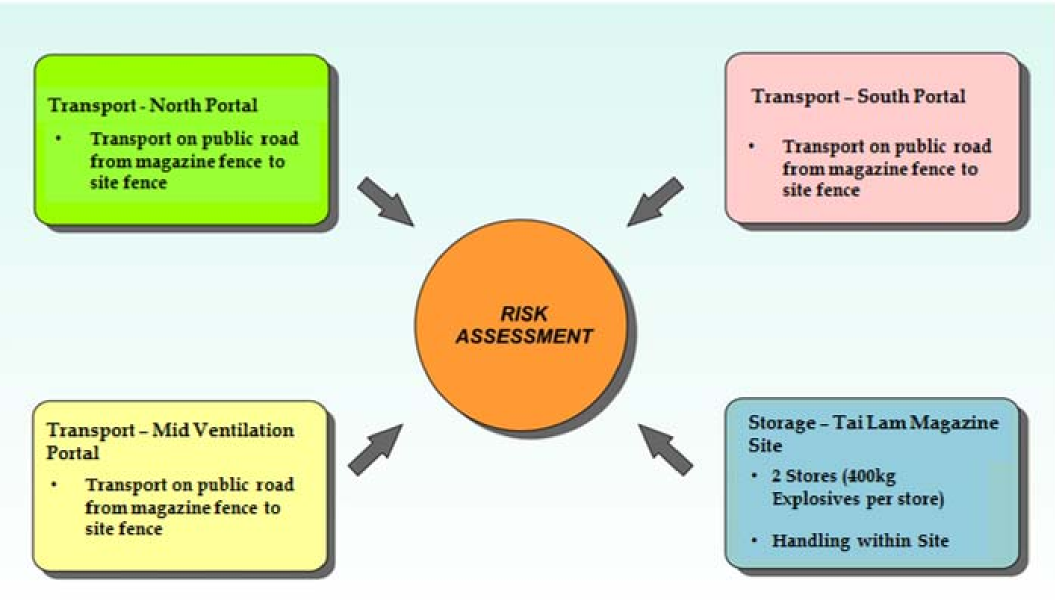
Section ID	Description
Road R3b21	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 1
Road R3b22	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 2
Route R3c (Route Option R3: Tai Lam Explosives Magazine Site – South Portal)	
Road R3c1	Access road towards Tai Shu Ha Rd West
Road R3c2	Tai Shu Ha Road West 1
Road R3c3	Tai Shu Ha Road West 2
Road R3c4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)
Road R3c5	Shap Pat Heung Road (Tai Tong Rd - Shap Pat Heung Interchange)
Road R3c6	Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)
Road R3c7	Yuen Long Highway
Road R3c8	Yuen Long Highway (to San Tin Highway 1)
Road R3c9	Yuen Long Highway (to San Tin Highway 2)
Road R3c10	San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)
Road R3c11	San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)
Road R3c12	Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)
Road R3c13	Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)
Road R3c14	Fanling Highway (So Kwun Po Int - Wo Hop Shek Int)
Road R3c15	Fanling Highway (Wo Hop Shek Int - Kau Lung Hang Lo Wai)
Road R3c16	Tai Wo Service Rd East (Slip rd from Fanling Highway - Kau Lung Hang FO)
Road R3c17	Road to Site 1 (Tai Wo Service Rd East - Road to Site 2)
Road R3c18	Road to Site 2 (Road to Site 1 - Site)

3 HAZARD TO LIFE ASSESSMENT METHODOLOGY

3.1. OVERVIEW OF THE METHODOLOGY

The methodology presented in this section and used in the assessment is the same methodology which has been used on previously approved EIA projects (ERM 2011, ERM 2009, ERM 2008). The overall methodology for the Hazard to Life Assessment addresses the risk associated with the storage and transport of explosives for the Project (see *Figure 3.1*).

Figure 3.1 ***Components of the Risk Assessment***



The potential hazards considered to pose a risk to the general population include overpressure and other effects such as projectiles.

The elements of the QRA are shown schematically in *Figure 3.2*. It includes the following steps.

- Collection and review of relevant data for the Tai Lam Explosives Magazine Site, the transport from Tai Lam Explosives Magazine Site, as well as population and vulnerable receptors, such as slopes, retaining walls etc., in the vicinity of the worksites and proposed transport routes;
- Hazard identification. A review of literature and accident databases was undertaken and updated. These formed the basis for identifying all the hazardous scenarios for the QRA study;
- Frequency estimation. The frequencies, or the likelihood, of the various outcomes that result from the hazards associated with the storage and transport of explosives was taken primarily from previous EIA QRAs that have been accepted by the relevant authorities. Where necessary, to

consider specific factors applicable for the Project and to reflect the current knowledge on the explosives' properties, these frequencies were modified or updated making reference, as far as possible to published references; such as the previous Hong Kong studies, UK HSE, US DoD, Dutch TNO (TNO Purple Book), latest accident statistics from the Transport Department and Fire Services Department, etc.;

- For all identified hazards, the frequency assessment has been documented and the consequences of the event were modelled;

- The consequence model employed in this study is the ESTC model (ESTC, 2000) developed by the UK Health and Safety Commission (HSC). Although, there have been a number of recent studies suggesting that the ESTC (2000) models should be reviewed for applicability to explosive stores and transport, these models are still the recommended models in the UK and have been adopted in previous Hong Kong EIAs;

- The same frequency model was adopted in this study as that of ERM (2011) and ERM (2009) studies, which has been derived to reflect the current Transport Department statistics, Fire Services Department statistics, specific design features applicable for the Project and current knowledge of explosives;

- The consequence and frequency data were subsequently combined using ERM's in-house Explosive Transport GIS Risk Assessment tool (E-TRA), which has been developed to account for three-dimensional blast effects on buildings and the effect of accidental explosions on elevated roads. It also accounts for traffic jam scenarios which could occur in some accidental scenarios as reported in the DNV (1997) study. The model is summarised in the next section and has been validated against ERM in-house proprietary software Riskplot TM. This risk assessment tool has been employed in ERM (2011) and ERM (2009) studies; and

- Finally, the results from the risk assessment were compared to the EIAO-TM Criteria. Recommendations have been made where required to ensure compliance with EIAO-TM Criteria, relevant best practice, and to reduce the overall risk levels.

Making reference to other relevant Hong Kong QRA studies, this Hazard to Life Assessment has performed an update of the QRA parameters considered in other studies and reviewed their applicability to the transport and storage elements of the QRA as applicable for the Project. Although, some QRA parameters may differ from previous studies, as required by the EIA Study Brief, the methodology adopted is consistent with the following studies:

- Shatin to Central (SCL (TAW-HUH)) study (ERM 2011)

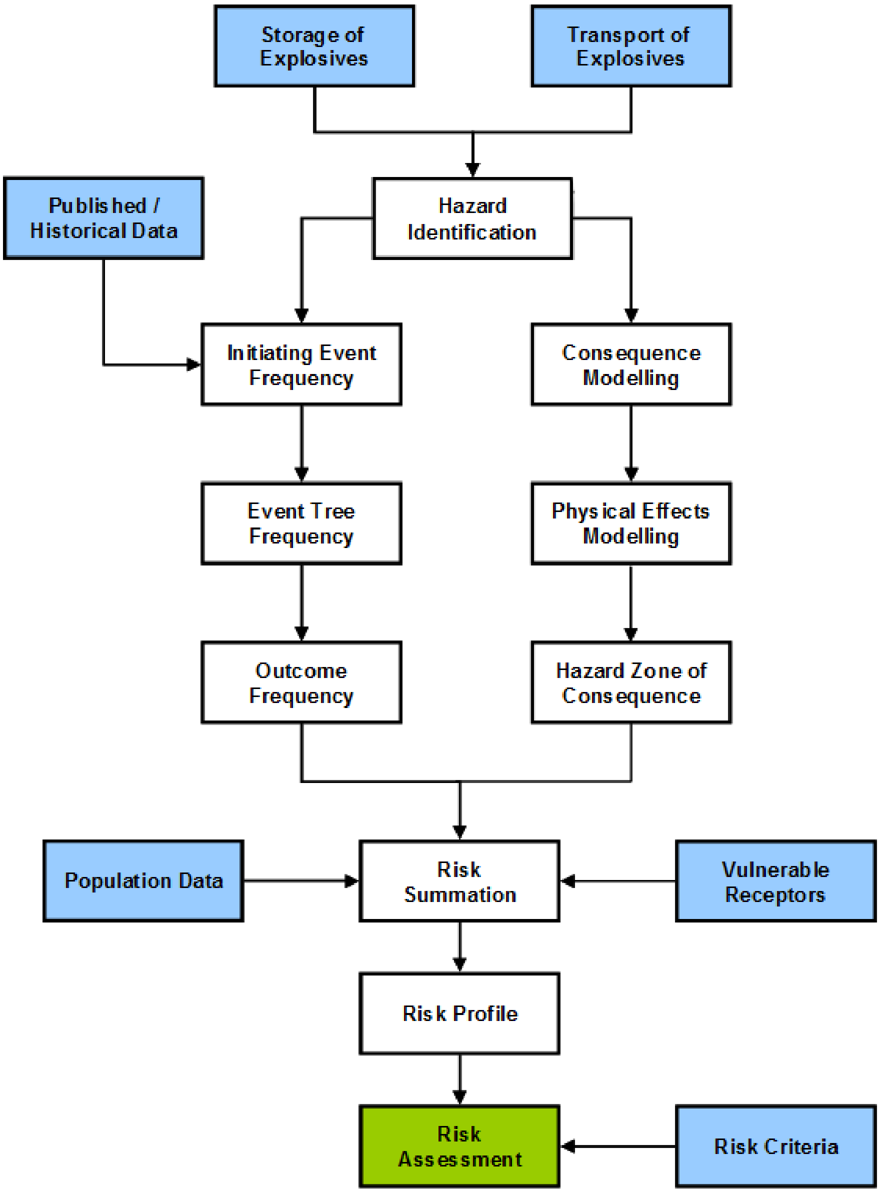
- South Island Line (East) (SIL(E)) study (ERM, 2010a);

- Kwun Tong Line Extension (KTE) study (ERM, 2010b);

- Express Rail Link (XRL) study (ERM, 2009);
- West Island Line (WIL) study (ERM, 2008);
- Hazard to Life Assessment section of the Ocean Park Development study (Maunsell, 2006);
- The territory wide study for the transport of explosives (DNV, 1997); which was the basis for the XRL study (ERM, 2009), and the ACDS study (ACDS, 1995) which was the basis for the DNV study (DNV, 1997). The basis for the frequency assessment data and methodology for the DNV study, as well as the ACDS study, has been reported separately by the UK HSE (Moreton, 1993); and
- Hazard to Life Assessment section of the Penny's Bay Rail Link EIA, (ERM, 2001).

According to Appendix B of the EIA Study Brief, ERM (2009) study for the XRL project is the primary reference for the Project Hazard to Life Methodology.

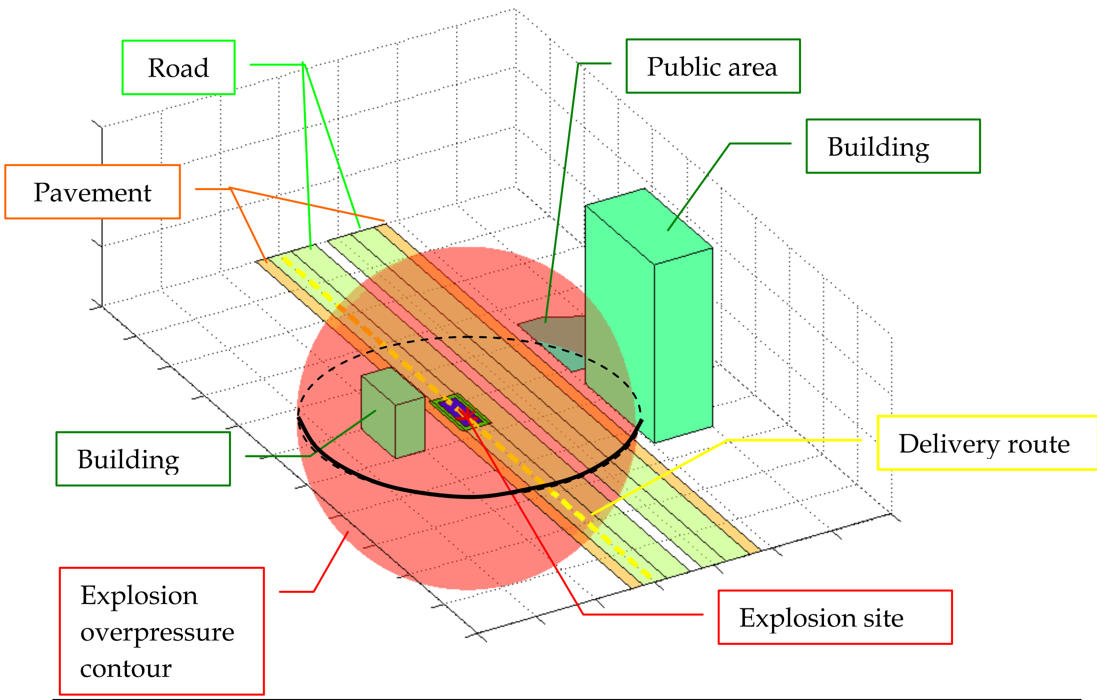
Figure 3.2 Schematic Diagram of the QRA Process



3.2. *OVERVIEW OF THE EXPLOSIVE TRANSPORT RISK ASSESSMENT TOOL AND METHODOLOGY*

The approach to modelling the risks for the transport of explosives is similar to that adopted in earlier studies (ERM, 2011) (ERM, 2009) and is fully 3-dimensional and GIS based. It accounts for the potential increased risk when the explosive truck travels on elevated roads. The route from the Magazine to each worksite is divided into sections for analysis, according to road characteristics. If initiation of the explosives on a delivery truck occurs, spherical blast waves and fragmentation may be produced which may impact on surrounding population such as other road users, buildings, as well as outdoor population on pavements and in public areas (*Figure 3.3*). The number of fatalities from an explosion at a particular location is determined by calculating the degree of overlap between explosion overpressure contours and populated areas.

Figure 3.3 *Explosion Impact on Surrounding Population*



2-Dimensional Calculations

In order to describe the 3-dimensional procedure, the 2-dimensional case at ground level is described first for illustration purposes (*Figure 3.4*). Polygons are used to define population areas for traffic lanes, pavement areas, buildings and public areas. A number of explosion effect levels are calculated to determine the hazard footprint and fatality probability at various distances from the explosives truck. These hazard footprints are then overlaid on the population polygons to determine overlap areas and the number of fatalities resulting from an explosion.

To improve accuracy and be ensured that the risk is not underpredicted, several explosion effect contours are generally used to describe different fatality probabilities (90%, 50%, 10%, 3% and 1%) at different distances from the truck. Geometric means have been applied in the model. Although the geometric means have no physical meaning, the levels calculated with the geometric means using the fatality probabilities listed above closely match the true average explosive effect distances.

To define the population polygons, each section of a route is characterised in terms of the number of traffic lanes on the nearside and the far side, the widths of the traffic lanes, the width of the centre divide and the widths of the nearside and far side pavements. Polygons describing buildings and public areas on each side of the road were obtained from a GIS database. The building types, such as high rise residential, low rise industrial, commercial etc., are used to estimate building population and a distinction is made between population indoors and outdoors. Road population densities are estimated for two traffic conditions: flowing traffic and traffic jam. Road traffic is based on the latest Annual Average Daily Traffic data (AADT) from 2013, available from the Transport Department. Further details of the population can be found in *Section 4*.

Although an initiation of an explosives truck could occur anywhere along the delivery routes, it is necessary to consider discrete locations in the modelling. Explosion sites are therefore considered with a spacing of about 10 m. This gives 100 potential explosion sites for each kilometre of the transport route.

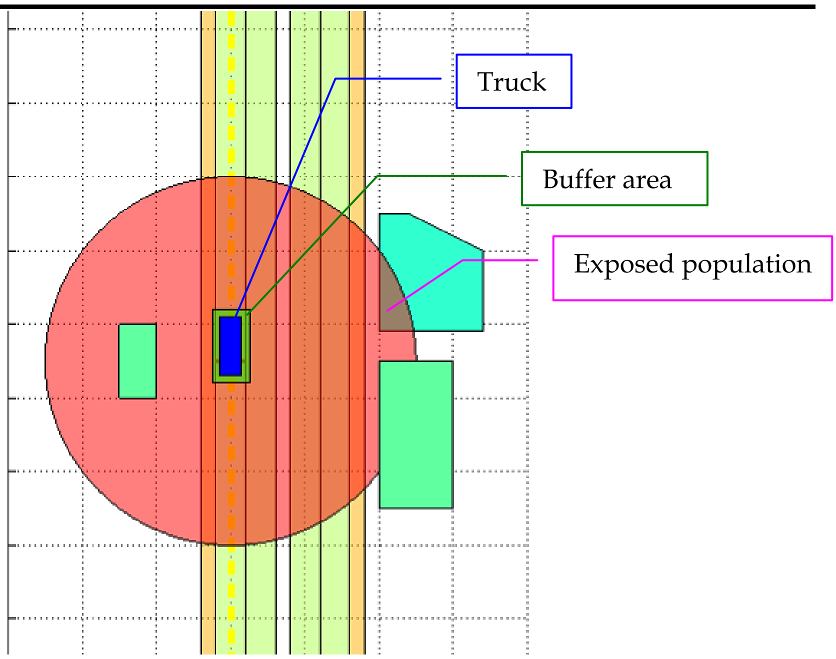
Other assumptions made in the model include:

- The explosives trucks are assumed to be located in the slow lane of multilane roads and hence the explosion site is assumed to be centred on the slow lane;

- The explosives trucks present a hazard only during delivery of explosives from the Magazine to the work area. The return journey to the Magazine presents no risk since the truck is empty. Partial deliveries of explosives i.e. delivery of partial load to worksite A, followed by direct routing to worksite B etc. are not considered in the model;

- The explosives trucks are expected to be a light truck e.g. a LGV pick-up truck. There will not be any member of the public located within the area occupied by the truck itself. Also, there will not be any other road vehicles within a couple of metres of the truck because of natural separation of vehicles and width of lanes. A buffer area (*Figure 3.4*) is therefore defined as 5 m × 10 m in which the population is taken to be zero. Consistent with the previously approved SCL (TAW-HUH) study (ERM, 2011) and XRL study (ERM, 2009), the explosives are assumed to be located at a position 2.5 m from the left edge and 7 m from the front edge of the buffer area. This buffer area has taken into account the area occupied by the truck and the normal separation among vehicles.

Figure 3.4 Explosion Overpressure Footprint at Ground Level



Extension to 3-Dimensional Modelling

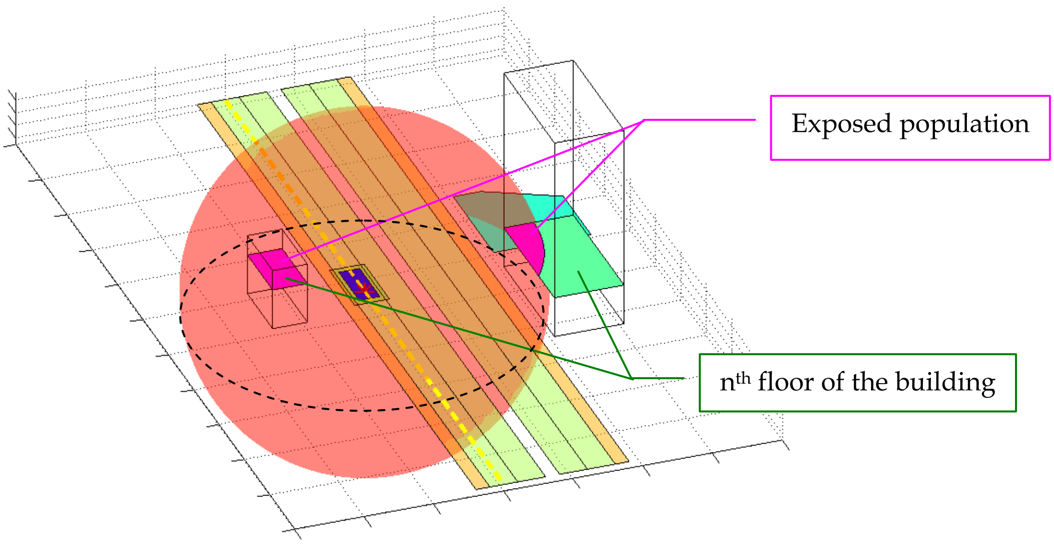
Buildings are modelled in 3-dimensions. This is achieved in essentially the same manner as the 2-D calculations, but the overlap areas between explosion overpressure contours and building polygons are calculated floor by floor (*Figure 3.5*). Since the explosion effects are spherical, the extent of the overpressure contours varies with height above the road. This is taken into account in the model. It is therefore possible that only a few floors of a building may be affected. Any elevation difference between the road and building is also allowed for since a fully 3-dimensional coordinate system is used to define roads and population polygons.

The GIS database of buildings includes details such as podiums on lower levels. These variations in building geometry are therefore captured by the model.

Buildings, in general, have multiple accommodation units, only half of which on average will overlook the road. The calculation of overlap areas therefore has a prescribed upper limit of 0.5 to reflect that at most half of each floor will be affected by a blast. The shielding provided by other buildings is not taken into account in the modelling, however, with explosion effect contours extending to a maximum of only about 60 m, there will be very few instances of impacts reaching the second line of buildings from the road. In any case, neglect of shielding by buildings is a conservative simplification.

Elevation differences between the explosion site on the road and surrounding areas such as parks and playgrounds is also taken into account in the modelling.

Figure 3.5 3-Dimensional Treatment of Buildings



The number of fatalities from an explosion is calculated by summing the fatalities in buildings with those outdoors and those on the road before pairing them to the *f* value in an f-N pair. The frequency of an explosion is calculated based on the number of trips for a particular route section and the probability of initiation per kilometre and the separation between explosion sites (about 10 m). This combination of number of fatalities *N*, and frequency *f* form one dataset pair for the explosion event. Summing over all explosion sites along the transport route gives the societal risk, calculated as either Potential Loss of Life (PLL) or presented as F-N curves.

$$PLL = \sum_i f_i N_i$$

F-N curves plot the frequency *F*, of *N* or more fatalities against *N*. The frequency *F* is therefore a cumulative frequency calculated from:

$$F_j = \sum_{N_i > N_j} f_i \ .$$

Individual risk is also calculated and presented as contours overlaid on transport routes.

4 POPULATION ESTIMATES

4.1 POPULATION ESTIMATE NEAR TAI LAM EXPLOSIVE MAGAZINE

The use of the existing Tai Lam Explosive Magazine is required in order to enable efficient delivery of explosives to work areas (see *Figure 4.1*).

The Tai Lam Explosive Magazine Site is located in the northern New Territories at Tai Lam and will supply explosives to all three worksites. The Tai Lam Explosive Magazine Site is located on a disused quarry near Yuen Long. This is a relatively remote location surrounded by woodland (*Figure 4.1*). The site sits at the top of a small plateau, with gentle gradients descending on all sides. Most of these slopes appear to be natural. There are no known (current or future) buildings or any other structures in the hazard zone of the Magazine.

The Hong Kong Model Engineering Club periodically flies model aircrafts at a site about 300 m from the Magazine. The distance of the entrance of the club to the magazine is about 200 m. According to the club staff, the population on the site will generally be about 100 during week day events, 200 at week-ends and public holidays. The club also occasionally hold 5 or 6 major events attracting a crowd of around 1,000 people. The populated area, however, being more than 200 m from the Magazine, is outside the area of interest, i.e. the separation distance for the Magazine.

This Magazine site has been selected based on consideration of separation distances from public areas and buildings, as well as practicality grounds for its proximity to works areas and transport routes.

Population within the vicinity of the Magazine site is based on surveys conducted by ERM in June 2014. Additional information was gathered from the XRL Study (ERM 2009), GIS tools and aerial maps. From these, potential sensitive receivers in the vicinity of each site were identified and their population estimated.

Table 7.1 of the consequence analysis (*Section 7*) demonstrated that the maximum effect radius from a blast at the Magazine which could produce 1% fatality is about 71 m. All population within 71 m radius from the Magazine was therefore estimated.

The only population within the effects radius is the transient population on the roads and pavements. This was estimated as a population density in the same manner as described in *Section 4.2.*

Figure 4.1 Aerial Photo of the Tai Lam Explosives Magazine Site

4.2 POPULATION ALONG EXPLOSIVES DELIVERY ROUTES

Three types of population have been considered:

- Pedestrian population on footpaths and pavements next to delivery routes;
- Road population; and
- Building population.

For areas not supported by surveys or where information is not available from other pertinent sources of information, the assumptions in *Table 4.1* have been used, consistent with the SCL study (ERM, 2011) and XRL study (ERM, 2009) .

Table 4.1 *Population Assumptions*

Type of Population	Assumption	Remarks
Residential Building	3 persons / flat	Government Territorial Population and Employment Data Matrices (TPEDM) indicate current Persons Per Unit (PPU) in the transport area of slightly less than 3. A value of 3 has been adopted as a conservative assumption.
Commercial Building	9 m^2/person	Code of Practice for the Provision of Means of Escape in Case of Fire indicates 9m^2/person as a minimum requirement. For buildings considered to bear an impact on the risk results, a specific survey has been conducted.
Footpath	0.5 persons /m^2	Density figure of 0.5 persons/m^2 is defined as footpath Level Of Service (LOS) in the Highway Capacity Manual. This is considered as a reasonable conservative density for the footpaths in the study area and will be used unless specific surveys indicate lower values.
Education Institute	500 persons / hall	

The methodology followed in establishing the population was, to a large degree, consistent with previously approved EIAs including the SCL study (ERM, 2011), XRL study (ERM, 2009), WIL study (ERM, 2008) and the LNG Receiving Terminal EIA (ERM, 2006), which included a detailed population survey for most parts of the explosive transportation route.

Population on the roads was estimated fromAnnual Traffic Census 2013 (ATC, 2013).

Population in buildings adjacent to transport routes was estimated from data obtained from:

- Centamap (2015); and
- Geographic Information System (GIS) database (2015 data).

In the event of an absence of data from either of these sources a site survey was carried out.

Accounting for the maximum licensing limit of 200 kg for the transport of explosives, all buildings within a 100 m corridor each side of the transport routes were included in the assessment. This corridor width is more than sufficient to describe the building population that may be affected by explosion from even the largest transport loads. The 1% fatality effects from the initiation of 200 kg of explosives, for example, does not extend as far as 100 m and all transport loads considered in this project are less than or equal to 200 kg.

All of the buildings along each delivery route have been entered individually into the E-TRA model, so as to accurately represent the population. Particular attention has been considered regarding the effects of accidental explosion on buildings where the vehicle is located on an elevated road.

A population density approach has been adopted for modelling the presence of pedestrians and road users.

Road users have been considered depending on the explosion scenarios as equally distributed, or under a slow / congested traffic. Referring to the frequency components of the transport QRA (see *Section 6*), an accidental explosion due to vehicle collision or transport of unsafe explosives will be spontaneous and can only impact on free flowing traffic. Explosive initiation following a vehicle fire (following a traffic accident or otherwise) could impact on queuing traffic conservatively assumed to occur within each lane on either side of the road in day or night conditions. Half jams are assumed in the analysis, whereby a traffic jam occurs behind the incident vehicle with a clear road in front. For such fire scenarios, traffic jam (half jam) is conservatively assumed to develop in 50% of the cases as, under low traffic conditions, such as during night time or day time at non-peak hours, road users may use alternative lanes or reverse which would not give rise to traffic jam.

In addition to road and building populations, the outdoor population on pavements was also estimated, based on a survey undertaken by ERM in June 2014.

The following sections present the approach taken for the Base Case scenario, where the deliveries could be scheduled at predetermined times during the entire day. For the Worst Case scenario, a 20% increase in the number of deliveries compared to the base case scenario was considered.

4.2.1 *Route Sectionalisation*

The explosives delivery routes from Tai Lam Explosives Magazine Site to the worksites (North Portal, Mid-Ventilation Portal, and South Portal) have been broken down into sub-sections for the assessment as described in *Section 2.6.5*.

4.2.2 *Road Population*

The traffic density information used in this study is based on the latest 2013 Annual Traffic Census. A growth of 1% per year to the year of completion of the blasting work (2017) has been assumed in the analysis for delivery to various points.

A population density approach was adopted for estimating the population within vehicles on the road. Vehicle occupants were conservatively estimated as indoor with regards to consequence models (i.e. subject to glass debris impact).

AADT data gives daily average traffic conditions and, for some stations, data are available at different times of the day. AADT data therefore appropriately represents normal traffic flows at non-peak hours.

Flowing Traffic Population

The traffic density information used in this study was based on the latest 2013 Annual Traffic Census (ATC, 2013) developed by the Transport Department. A growth of 1% per year was assumed to extrapolate current data to the year of excavation by blasting, 2017.

Road population density was calculated using the following expressions:

Annual Average Daily Traffic (AADT)

Population Density (persons/m^2) = AADT × P / 1000 / 24 / V / W

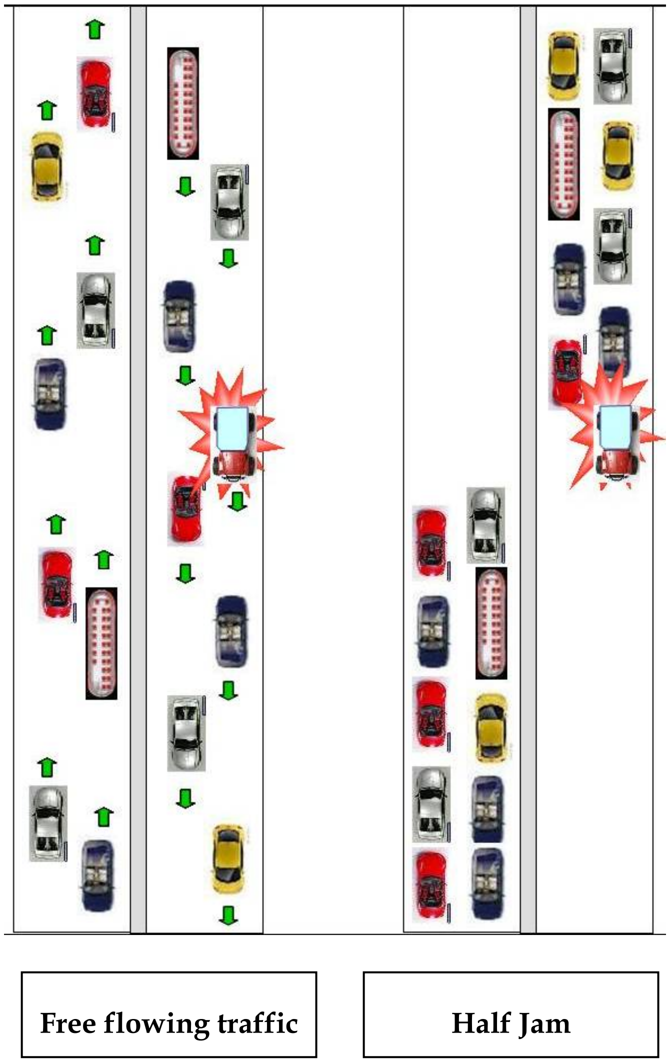
where:
P is the average number of persons per vehicle
W is the road width in metre, based on actual road width data
V is the vehicle speed in km/hr

Based on average vehicle occupancy reported in the Traffic Census for the relevant transportation routes, the average vehicle occupancy is around 3.2 persons per vehicle. This includes buses and trucks as well as taxis and private cars.

V has been selected as 60 km/hr for expressways and 50 km/hr for non-expressway route sections, consistent with previous Hong Kong studies.

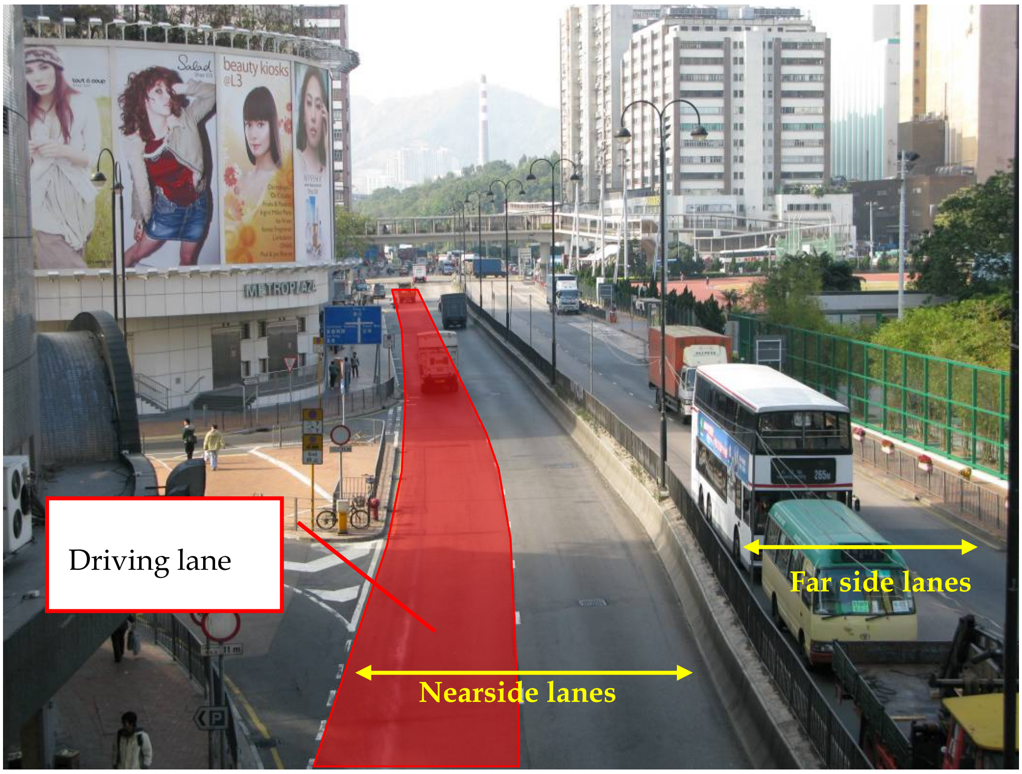
The above formulae based on AADT provide population information for average and peak flowing traffic conditions respectively. There is a possibility of a traffic jam when explosive initiation occurs. For example, if the explosives truck catches fire either due to an accident or due to other causes, the incident could disrupt traffic flow and lead to a traffic jam before initiation occurs (*Figure 4.2*).

Figure 4.2 Road Traffic Conditions and Scenarios Considered



The road population estimates take into consideration the number of lanes and distinguishes between traffic on the nearside lanes and traffic flowing in the opposite direction to the explosives truck (the far side lanes) (*Figure 4.3*).

Figure 4.3 *Road Population Model*



Traffic Jam Population

It is possible that the traffic flow will be disrupted when an explosion initiation occurs on the delivery truck. If a traffic accident is severe enough to lead to a vehicle fire, for example, a traffic jam could develop before the fire spreads to the explosive load causing initiation. The transport model includes scenarios with traffic jam conditions which will in general have higher population densities compared to flowing traffic due to the reduced separation between vehicles.

The traffic jam population density depends only on vehicle mix and not on traffic volume. The length of road occupied by vehicles of different type is estimated as follows:

- Private cars, taxis and motorcycles – 5 m
- Public light buses – 10 m
- Goods vehicles – 20 m
- Buses – 20 m

The occupancies for each type of vehicle were taken from the Annual Traffic Census (ATC) for 2013. Two core stations were selected as representative of the transport routes from Tai Lam Explosives Magazine Site which are shown in *Table 4.2*. As a conservative measure, the peak occupancy numbers from these 2 core stations were used in the assessment.

Table 4.2 *Core Stations along the Proposed Transport Routes*

Core Station	Description	Applicable Transport Route
Stn 5003	Fanling Highway (So Kwun Po Int – Wo Hop Shek Int)	All routes
Stn 5016	San Tin Highway	All routes

Table 4.3 *Vehicle Occupancy for Different Types of Vehicle*

Vehicle Type	AADT Core Station		Average
	5003	5016	
Motorcycle	1.2	1.1	1.15
Private car	1.6	1.6	1.6
Taxi	2.5	2.6	2.55
Public light bus	0	16.1	8.05
Goods vehicle	1.7	1.6	1.65
Bus	25.9	69	47.45

The traffic jam population density depends on the vehicle mix. The vehicle mix was estimated from the Vehicle Kilometres Travelled (TD, 2013) (VKT) by each type of vehicle in 2013 (*Table 4.4*). This approach gives the average vehicle mix for the whole territory and was used as an estimate of the vehicle mix along the transport routes. As a check on the calculation, the results were compared with the vehicle mix recorded at the 2 core stations listed in *Table 4.2* and found to match closely, however the vehicle mix average for the whole territory gives a higher population density and therefore is used in order to be conservative. Combining the vehicle mix with vehicle occupancies from *Table 4.3* gives an average population density within vehicles of 0.440 persons per metre of road. For sections of the transport routes with multiple traffic lanes, a population density of 0.440 persons/m per lane was used. Road populations were further converted to a density per square metre using the lane width.

Table 4.4 *Road Population Density*

Vehicle Type	VKT in 2013 (million)	Fraction of VKT	Fraction of VKT Average of Core Stations	Occupants	Length of Road per Vehicle (m)	Population (persons/m)
Motorcycle	291	0.0229	0.0123	1.15	5	0.005
Private car	5315	0.4179	0.4353	1.6	5	0.134
Taxi	2399	0.1886	0.0585	2.55	5	0.096
Public light bus	335	0.0263	0.0272	8.05	10	0.021
Goods vehicle	3519	0.2767	0.4242	1.65	20	0.023
Bus	860	0.0676	0.0428	47.45	20	0.160
Total	**12719**	**1**	**1**			**0.440**

4.2.3 *Pedestrian Population*

Pedestrian flow on the pavement was assessed along the explosives delivery routes by site survey carried out in June 2014. The site survey also aimed to collect site specific information such as the width of pavement, surrounding conditions of the roads etc. The results from the survey were then analysed and used to calculate population densities for all the pavements along the delivery routes following the steps below:

- All roads along the delivery routes were selected for the survey (Table 4.5);
- Pavement population was collected and the population density calculated from:

$$\text{Pavement population (persons/m}^2\text{)} = P / 1000 / Q / W$$

where:
P is the number of pedestrians passing a given point
W is the pavement width (m)
Q is the pedestrian speed (km/ hr)

- Consistent with the SCL (TAW-HUH) study (ERM, 2011) and XRL Study (ERM, 2009), the calculated population density was further increased by 10% as a conservative measure and applied to the time periods. The results are shown in *Table 4.5*; and
- As with the road population in vehicles, a distinction is made between population on the nearside pavement and population on the far side pavement.

Table 4.5 Pavement Population Density on Roads Covered in Site Survey

Road Segments	**Pavement Population Density (person/ m^2) (1)(2)**
Route R1a (Route Option R1: Tai Lam Explosives Magazine Site – Mid-Ventilation Adit)	
Access road towards Tai Shu Ha Rd West	0 - 0
Tai Shu Ha Road West 1	0.003 - 0.009
Tai Shu Ha Road West 2	0.003 - 0.012
Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	0 - 0
Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)	0 - 0
Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)	0 - 0
Castle Peak Road (Yuen Long) (Pok Oi Int - Kam Tin Rd)	0.004 - 0.01
Kam Tin Rd (Castle Peak Rd (Yuen Long) - Kam Sheung Rd western junction)	0 - 0.001
Kam Tin Bypass	0 - 0
Kam Tin Rd (Kam Sheung Rd western junction - Fan Kam Rd)	0.001 - 0.002
Fan Kam Rd (Kam Tin Rd - Castle Peak Rd)	0.003 - 0.004
Po Kin Rd (Fan Kam Rd - Pak Wo Rd)	0.002 - 0.005
Pak Wo Rd (Po Kin Rd - Slip rd to So Kwun Po Int)	0.006 - 0.023
Pak Wo Rd (Slip rd to So Kwun Po Int - Yu Tai Rd)	0.003 - 0.006
Pak Wo Rd (Yu Tai Rd - Pak Wo Rd RA)	0.002 - 0.004
Pak Wo Rd (Pak Wo Rd RA - Wah Ming Rd)	0.005 - 0.033
Pak Wo Rd (Wah Ming Rd - Wai Ming St)	0.013 - 0.023
Pak Wo Rd (Wai Ming St - Yat Ming Rd)	0.004 - 0.006
Pak Wo Rd (Yat Ming Rd - Wo Hop Shek Int)	0 - 0
Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd)	0 - 0
Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd) 2	0 - 0.002
Jockey Club Rd (Lok Yip Rd - Sha Tau Kok Rd)	0 - 0.001

Road Segments	Pavement Population Density (person/ m^2) (1)(2)
Sha Tau Kok Rd (Lung Yeuk Tau) (Jockey Club Rd - Lok Yip Rd)	0.025 - 0.031
Sha Tau Kok Rd (Lung Yeuk Tau) (Lok Yip Rd - Luen Shing St)	0.009 - 0.019
Sha Tau Kok Rd (Lung Yeuk Tau) (Luen Shing St - On Kui St)	0.006 - 0.007
Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Lau Shui Heung Rd)	0.004 - 0.012
Lau Shui Heung Rd (Sha Tau Kok Rd - Po Kat Tsai Rd)	0 - 0
Po Kat Tsai Road (Lau Shui Heung Rd - Site)	0 - 0
Route R1b (Route Option R1: Tai Lam Explosives Magazine Site – North Portal)	
Access road towards Tai Shu Ha Rd West	0 - 0
Tai Shu Ha Road West 1	0.003 - 0.009
Tai Shu Ha Road West 2	0.003 - 0.012
Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	0 - 0
Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)	0 - 0
Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)	0 - 0
Castle Peak Road (Yuen Long) (Pok Oi Int - Kam Tin Rd)	0.004 - 0.01
Kam Tin Rd (Castle Peak Rd (Yuen Long) - Kam Sheung Rd western junction)	0 - 0.001
Kam Tin Bypass	0 - 0
Kam Tin Rd (Kam Sheung Rd western junction - Fan Kam Rd)	0.001 - 0.002
Fan Kam Rd (Kam Tin Rd - Castle Peak Rd)	0.003 - 0.004
Po Kin Rd (Fan Kam Rd - Pak Wo Rd)	0.002 - 0.005
Pak Wo Rd (Po Kin Rd - Slip rd to So Kwun Po Int)	0.006 - 0.023
Pak Wo Rd (Slip rd to So Kwun Po Int - Yu Tai Rd)	0.003 - 0.006
Pak Wo Rd (Yu Tai Rd - Pak Wo Rd RA)	0.002 - 0.004
Pak Wo Rd (Pak Wo Rd RA - Wah Ming Rd)	0.005 - 0.033
Pak Wo Rd (Wah Ming Rd - Wai Ming St)	0.013 - 0.023
Pak Wo Rd (Wai Ming St - Yat Ming Rd)	0.004 - 0.006
Pak Wo Rd (Yat Ming Rd - Wo Hop Shek Int)	0 - 0
Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd) 1	0 - 0
Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd) 2	0 - 0.002
Jockey Club Rd (Lok Yip Rd - Sha Tau Kok Rd)	0 - 0.001
Sha Tau Kok Rd (Lung Yeuk Tau) (Jockey Club Rd - Lok Yip Rd)	0.018 - 0.056
Sha Tau Kok Rd (Lung Yeuk Tau) (Lok Yip Rd - Luen Shing St)	0.017 - 0.022
Sha Tau Kok Rd (Lung Yeuk Tau) (Luen Shing St - On Kui St)	0.004 - 0.01
Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 1	0.002 - 0.003
Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 2	0.003 - 0.004
Route R1c (Route Option R1: Tai Lam Explosives Magazine Site – South Portal)	
Access road towards Tai Shu Ha Rd West	0 - 0
Tai Shu Ha Road West 1	0.003 - 0.009
Tai Shu Ha Road West 2	0.003 - 0.012
Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	0 - 0
Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)	0 - 0
Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)	0 - 0
Castle Peak Road (Yuen Long) (Pok Oi Int - Kam Tin Rd)	0.004 - 0.01
Kam Tin Rd (Castle Peak Rd (Yuen Long) - Kam Sheung Rd western junction)	0 - 0.001
Kam Tin Bypass	0 - 0
Kam Tin Rd (Kam Sheung Rd western junction - Fan Kam Rd)	0.001 - 0.002
Kam Tin Rd (Fan Kam Rd - Kam Sheung Rd eastern junction)	0.001 - 0.003
Lam Kam Rd (Kam Sheung Rd - Lam Kam Rd Int)	0.001 - 0.003
Lam Kam Rd (Lam Kam Rd Int - Tai Wo Service Rd W)	0 - 0
Tai Wo Service Rd W (Lam Kam Rd Int - Kau Lung Hang FO)	0 - 0.003
Tai Wo Service Rd W (Kau Lung Hang FO - Wo Hing Rd)	0 - 0
Unnamed road (Wo Hing Rd - Pak Wo Rd)	0 - 0
Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd)	0 - 0

Road Segments	Pavement Population Density (person/ m²) (1)(2)
Slip Rd (Jockey Club Rd - Fanling Highway)	0 - 0
Fanling Highway (Wo Hop Shek Int - Kau Lung Hang Lo Wai)	0 - 0
Tai Wo Service Rd East (Slip rd from Fanling Highway - Road to Site 1)	0 - 0
Road to Site 1 (Tai Wo Service Rd East - Road to Site 2)	0 - 0
Road to Site 2 (Road to Site 1 - Site)	0 – 0
<u>*Route R2a (Route Option R2: Tai Lam Explosives Magazine Site – Mid-Ventilation Adit)*</u>	
Access road towards Tai Shu Ha Rd West	0 - 0
Tai Shu Ha Road West 1	0.003 - 0.009
Tai Shu Ha Road West 2	0.003 - 0.012
Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	0 - 0
Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)	0 - 0
Shap Pat Heung Interchange (Shap Pat Heung Road - Yuen Long Highway)	0 - 0
Yuen Long Highway (Shap Pat Heung Int - Tong Yan San Tsuen Int)	0 - 0
Connecting road from Tong Yan San Tsuen Int to Long Tin Road	0 - 0
Long Tin Road (Tong Yan San Tsuen Int - Castle Peak Rd (Ping Shan))	0 - 0
Connecting road from Long Tin Road North Bound to South Bound	0 - 0
Long Tin Road (Castle Peak Rd (Ping Shan) - Tong Yan San Tsuen Int)	0 - 0
Connecting road from Long Tin Rd to Tong Yan San Tsuen Int	0 - 0
Yuen Long Highway (Tong Yan San Tsuen Int - Shap Pat Heung Int)	0 - 0
Yuen Long Highway (Shap pat Heung Int - Nr Tsing Long Highway)	0 - 0
Yuen Long Highway (to San Tin Highway 1)	0 - 0
Yuen Long Highway (to San Tin Highway 2)	0 - 0
San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)	0 - 0
San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)	0 - 0
Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)	0 - 0
Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)	0 - 0
So Kwun Po Rd (Fanling Highway - So Kwun Po Rd Int)	0 - 0
So Kwun Po Rd (So Kwun Po Rd Int - Jockey Club Rd)	0 - 0
Ma Sik Rd (Jockey Club Rd - Tin Ping Rd)	0.005 - 0.041
Ma Sik Rd (Tin Ping Rd - Fan Leng Lau Rd)	0.011 - 0.02
Ma Sik Rd (Fan Leng Lau Rd - Luen Chit St)	0.005 - 0.008
Ma Sik Rd (Luen Chit St - Wo Tai St)	0.003 - 0.006
Ma Sik Rd (Wo Tai St - Sha Tau Kok Rd (Lung Yeuk Tau))	0.004 - 0.007
Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Lau Shui Heung Rd)	0.004 - 0.012
Lau Shui Heung Rd (Sha Tau Kok Rd - Po Kat Tsai Rd)	0 - 0
Po Kat Tsai Road (Lau Shui Heung Rd - Site)	0 - 0
<u>*Route R2b (Route Option R2: Tai Lam Explosives Magazine Site – North Portal)*</u>	
Access road towards Tai Shu Ha Rd West	0 - 0
Tai Shu Ha Road West 1	0.003 - 0.009
Tai Shu Ha Road West 2	0.003 - 0.012
Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	0 - 0
Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)	0 - 0
Shap Pat Heung Interchange (Shap Pat Heung Road - Yuen Long Highway)	0 - 0
Yuen Long Highway (Shap Pat Heung Int - Tong Yan San Tsuen Int)	0 - 0
Connecting road from Tong Yan San Tsuen Int to Long Tin Road	0 - 0
Long Tin Road (Tong Yan San Tsuen Int - Castle Peak Rd (Ping Shan))	0 - 0
Connecting road from Long Tin Road North Bound to South Bound	0 - 0
Long Tin Road (Castle Peak Rd (Ping Shan) - Tong Yan San Tsuen Int)	0 - 0
Connecting road from Long Tin Rd to Tong Yan San Tsuen Int	0 - 0
Yuen Long Highway (Tong Yan San Tsuen Int - Shap Pat Heung Int)	0 - 0
Yuen Long Highway (Shap pat Heung Int - Nr Tsing Long Highway)	0 - 0
Yuen Long Highway (to San Tin Highway 1)	0 - 0

Road Segments	Pavement Population Density (person/ m²) (1)(2)
Yuen Long Highway (to San Tin Highway 2)	0 - 0
San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)	0 - 0
San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)	0 - 0
Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)	0 - 0
Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)	0 - 0
So Kwun Po Rd (Fanling Highway - So Kwun Po Rd Int)	0 - 0
So Kwun Po Rd (So Kwun Po Rd Int - Jockey Club Rd)	0 - 0
Ma Sik Rd (Jockey Club Rd - Tin Ping Rd)	0.005 - 0.041
Ma Sik Rd (Tin Ping Rd - Fan Leng Lau Rd)	0.011 - 0.02
Ma Sik Rd (Fan Leng Lau Rd - Luen Chit St)	0.005 - 0.008
Ma Sik Rd (Luen Chit St - Wo Tai St)	0.003 - 0.006
Ma Sik Rd (Wo Tai St - Sha Tau Kok Rd (Lung Yeuk Tau))	0.004 - 0.007
Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 1	0.003 - 0.004
Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 2	0.003 - 0.004
Route R2c (Route Option R2: Tai Lam Explosives Magazine Site – South Portal)	
Access road towards Tai Shu Ha Rd West	0 - 0
Tai Shu Ha Road West 1	0.003 - 0.009
Tai Shu Ha Road West 2	0.003 - 0.012
Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	0 - 0
Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)	0 - 0
Shap Pat Heung Interchange (Shap Pat Heung Road - Yuen Long Highway)	0 - 0
Yuen Long Highway (Shap Pat Heung Int - Tong Yan San Tsuen Int)	0 - 0
Connecting road from Tong Yan San Tsuen Int to Long Tin Road	0 - 0
Long Tin Road (Tong Yan San Tsuen Int - Castle Peak Rd (Ping Shan))	0 - 0
Connecting road from Long Tin Road North Bound to South Bound	0 - 0
Long Tin Road (Castle Peak Rd (Ping Shan) - Tong Yan San Tsuen Int)	0 - 0
Connecting road from Long Tin Rd to Tong Yan San Tsuen Int	0 - 0
Yuen Long Highway (Tong Yan San Tsuen Int - Shap Pat Heung Int)	0 - 0
Yuen Long Highway (Shap pat Heung Int - Nr Tsing Long Highway)	0 - 0
Yuen Long Highway (to San Tin Highway 1)	0 - 0
Yuen Long Highway (to San Tin Highway 2)	0 - 0
San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)	0 - 0
San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)	0 - 0
Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)	0 - 0
Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)	0 - 0
Fanling Highway (So Kwun Po Int - Wo Hop Shek Int)	0 - 0
Fanling Highway (Wo Hop Shek Int - Kau Lung Hang Lo Wai)	0 - 0
Tai Wo Service Rd East (Slip rd from Fanling Highway - Kau Lung Hang FO)	0 - 0
Road to Site 1 (Tai Wo Service Rd East - Road to Site 2)	0 - 0
Road to Site 2 (Road to Site 1 - Site)	0 - 0
Route R3a (Route Option R3: Tai Lam Explosives Magazine Site – Mid-Ventilation Adit)	
Access road towards Tai Shu Ha Rd West	0 - 0
Tai Shu Ha Road West 1	0.003 - 0.009
Tai Shu Ha Road West 2	0.003 - 0.012
Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	0 - 0
Shap Pat Heung Road (Tai Tong Rd - Shap Pat Heung Interchange)	0 - 0
Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)	0 - 0
Yuen Long Highway	0 - 0
Yuen Long Highway (to San Tin Highway 1)	0 - 0
Yuen Long Highway (to San Tin Highway 2)	0 - 0
San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)	0 - 0

Road Segments	Pavement Population Density (person/ m^2) (1)(2)
San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)	0 - 0
Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)	0 - 0
Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)	0 - 0
So Kwun Po Rd (Fanling Highway - So Kwun Po Rd Int)	0 - 0
So Kwun Po Rd (So Kwun Po Rd Int - Jockey Club Rd)	0 - 0
Ma Sik Rd (Jockey Club Rd - Tin Ping Rd)	0.005 - 0.041
Ma Sik Rd (Tin Ping Rd - Fan Leng Lau Rd)	0.011 - 0.02
Ma Sik Rd (Fan Leng Lau Rd - Luen Chit St)	0.005 - 0.008
Ma Sik Rd (Luen Chit St - Wo Tai St)	0.003 - 0.006
Ma Sik Rd (Wo Tai St - Sha Tau Kok Rd (Lung Yeuk Tau))	0.004 - 0.007
Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Lau Shui Heung Rd)	0.004 - 0.012
Lau Shui Heung Rd (Sha Tau Kok Rd - Po Kat Tsai Rd)	0 - 0
Po Kat Tsai Road (Lau Shui Heung Rd - Site)	0 - 0
Route R3b (Route Option R3: Tai Lam Explosives Magazine Site – North Portal)	
Access road towards Tai Shu Ha Rd West	0 - 0
Tai Shu Ha Road West 1	0.003 - 0.009
Tai Shu Ha Road West 2	0.003 - 0.012
Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	0 - 0
Shap Pat Heung Road (Tai Tong Rd - Shap Pat Heung Interchange)	0 - 0
Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)	0 - 0
Yuen Long Highway	0 - 0
Yuen Long Highway (to San Tin Highway 1)	0 - 0
Yuen Long Highway (to San Tin Highway 2)	0 - 0
San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)	0 - 0
San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)	0 - 0
Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)	0 - 0
Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)	0 - 0
So Kwun Po Rd (Fanling Highway - So Kwun Po Rd Int)	0 - 0
So Kwun Po Rd (So Kwun Po Rd Int - Jockey Club Rd)	0 - 0
Ma Sik Rd (Jockey Club Rd - Tin Ping Rd)	0.005 - 0.041
Ma Sik Rd (Tin Ping Rd - Fan Leng Lau Rd)	0.011 - 0.02
Ma Sik Rd (Fan Leng Lau Rd - Luen Chit St)	0.005 - 0.008
Ma Sik Rd (Luen Chit St - Wo Tai St)	0.003 - 0.006
Ma Sik Rd (Wo Tai St - Sha Tau Kok Rd (Lung Yeuk Tau))	0.004 - 0.007
Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 1	0.003 - 0.004
Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 2	0.003 - 0.004
Route R3c (Route Option R3: Tai Lam Explosives Magazine Site – South Portal)	
Access road towards Tai Shu Ha Rd West	0 - 0
Tai Shu Ha Road West 1	0.003 - 0.009
Tai Shu Ha Road West 2	0.003 - 0.012
Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	0 - 0
Shap Pat Heung Road (Tai Tong Rd - Shap Pat Heung Interchange)	0 - 0
Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)	0 - 0
Yuen Long Highway	0 - 0
Yuen Long Highway (to San Tin Highway 1)	0 - 0
Yuen Long Highway (to San Tin Highway 2)	0 - 0
San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)	0 - 0
San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)	0 - 0
Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)	0 - 0
Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)	0 - 0
Fanling Highway (So Kwun Po Int - Wo Hop Shek Int)	0 - 0

Road Segments	Pavement Population Density (person/ m²) (1)(2)
Fanling Highway (Wo Hop Shek Int - Kau Lung Hang Lo Wai)	0 - 0
Tai Wo Service Rd East (Slip rd from Fanling Highway - Kau Lung Hang FO)	0 - 0
Road to Site 1 (Tai Wo Service Rd East - Road to Site 2)	0 - 0
Road to Site 2 (Road to Site 1 - Site)	0 - 0

Note 1: Growth factor of 1% per year is taken into account in above data
Note 2: "0 - 0" is the road segment with no pavement or no pedestrian observed during the site survey.

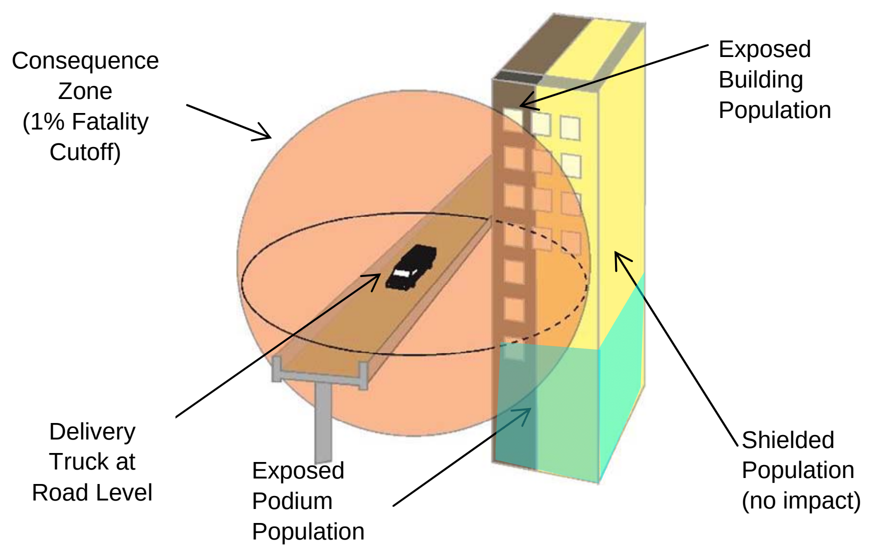
4.2.4 *Land and Building Population*

Buildings within a 200 m corridor (100 m either side) of each transport route were included in the assessment, to encompass the effects radius of all explosive transport loads. Buildings that extended only partly into this corridor were also included. Rather than considering density based averages of population, the analysis is based on individual buildings. This involves estimating the population for over 6900 buildings along the routes. The task of assessing population building-by-building is substantial but is necessary to accurately model the F-N pairs with high N values.

The hazards due to an explosion during the transport of explosives are principally overpressure and flying debris. For the purpose of this study, it is considered that people at the rear of the building will not be impacted by blast effects.

The hazard footprint was overlaid on the population polygons (road lanes, pavement areas and building areas) considering relative elevations to establish overlap area for each floor of the building impacted from which the number of fatalities could be estimated. A spherical vulnerability model was adopted.

Figure 4.4 ***Consideration of Population Inside Building***



A systematic methodology was employed to allow the estimation of present and future population of individual buildings along the transport routes. The methodology involves 4 steps:

- Step 1: Identify existing buildings within the study area
- Step 2: Identify buildings' attributes and usage, and estimate their population
- Step 3: Project the present population to the assessment year (2017) and distribute predicted future residential population data among identified residential buildings based on a uniform population growth factor of 1% per year
- Step 4: Adjust future population numbers of non-residential buildings

Following *Steps 3* and *4*, the occupancy of building populations was then determined for different time periods.

4.2.5 ***Step 1: Identify existing buildings that lie within the Study Area***

The Lands Department of the HKSAR Government maintains a Geographic Information System (GIS) database of buildings in Hong Kong. To identify buildings within the study area, ERM obtained a recent GIS map layer containing all buildings. Additionally, the GIS building height information for most of the buildings (but usually not podiums or other similar structures) were also obtained from Lands Department (LD, 2014). The buildings at least partly within 100 m of the defined explosives transport routes were selected for further processing. Each of the buildings was assigned a unique label and its grid coordinates were also recorded.

4.2.6 ***Step 2: Identify building attributes, usage and population***

There is no publicly available data on the population of individual buildings in Hong Kong. Therefore, to provide a basis for estimating the number of people in a building, it was necessary to identify each building's attributes and usage.

The buildings and structures in the GIS database are classified as: regular building (BP), building under elevated structure (BUP), open-sided structure (OSP), proposed building (PBP), podium (PD), podium under elevated structure (PDU), ruin (RU) and temporary structure (TSP). Using the above information, the information from property developers' websites as well as aerial photographs, the actual or likely usage category of buildings identified in *Step 1* was determined and each building was assigned to one of the following building usage categories:

- Abandoned / Unpopulated Building;
- Administrative / Commercial;

- Car Park;
- Clinic;
- College;
- Fire Station;
- Hospital;
- Industrial Building;
- Kindergarten;
- Leisure;
- MTR station/Bus terminus
- Petrol Station;
- Podium;
- Police Station;
- Residential Building;
- School;
- Station such as sewage treatment, electrical substation, pump house etc;
- Storage; and
- Temple / Church / Chapel.

Note that unless their usage could be determined from other available sources, the GIS categories OSP, TSP and RU, were assumed to be unpopulated.

Following this, the same information sources were used to sub-categorise buildings by other attributes, such as the number of floors. Details on the building attributes and categories and associated assumptions are presented below.

Number of Floors

Building height data was available from the GIS database for most buildings and the number of floors was estimated from these data, assuming 3 m height per floor. For most of the high-rise residential buildings (excluding the housing estates) the floor number information, considered more accurate, was also available from the property developer website. When neither of the above information was available and where it was possible, the number of floors was estimated from 3-dimensional aerial photos. In the event of an absence of data from any of the above sources a site survey was carried out.

Residential Buildings

Generally a population of 3 persons per unit was assumed. For most of the high-rise residential buildings, the total number of units was available from the property developers' websites. For all the remaining buildings, including the village houses and estate high-rises, the number of units per floor was estimated from the floor area, assuming 1 unit per about 65 m^2 (700 square feet). Based on this assumption, small structures in village setting of area less than about 30 m^2 were assumed to be unpopulated.

Other Buildings

While residential type buildings are well defined, less information is available for other types of buildings such as commercial, industrial etc. The approach to estimate other building population generally follows that adopted in the EIA for the Liquefied Natural Gas (LNG) Receiving Terminal (EIA 125/2006), and is based on typical Hong Kong building structure, usage, height, and typical capacity of public facilities. The details are presented in *Table 4.6.* In the application of typical values from *Table 4.6*, further refinements were made based on building height and area and taking into account the maximum density of people in most non-residential building as one person per 9 m^2 (the Code of Practice for the Provision of Means of Escape in Case of Fire).

Table 4.6 **Building Population Assumptions**

Category	**Building Height / Size(1)**	**Assumption**			**Total**
Car Park		Basic assumptions are listed below. In some cases the car park population was adjusted based on the building area. For car parks located in podiums of residential, commercial or industrial buildings, the podium population was assumed as 1% of the population of associated buildings.			
		Parking Levels	**Parking Spaces**	**People/Parking Space**	
	H	5	40	0.2	40
	L	1	20	0.2	4
Police Station		About 27750 Policemen are employed in Hong Kong. Assumed that they are evenly spread over 55 branches. It is also assumed that they will roster on 2 shifts each day and about 50% will be out for patrol.			125
Petrol Station		It is assumed that, there are 2 staff stationed in the convenience shop, 4 stationed in fuel area for filling, and 4 vehicles each with 3 people, parked into the Petrol Station for petrol filling			18
Fire Station & Ambulance Depots		About 8600 uniformed staff are employed in Hong Kong. It is assumed that members of fire stream are evenly spread over 76 fire stations and members of ambulance stream are over 33 ambulance depots. It is also assumed that members of fire stream will roster on 24 hours (on-duty) and 48 hours (off-duty) and members of ambulance stream will roster on 12 hours, 2 shifts each day.			30
Station	H	5 people in Refuse disposals, and Mortuaries			5
	M	2 people in Traffic Control Stations			2

Category	Building Height / Size(1)	Assumption			Total
	L	No people will stay in Sewage treatment works, Toilet, Electric substation, or pump house			0
Kindergarten		10 students per class, 4 classes for each grade, 3 grades in Kindergarten Total 10 staff employed by each kindergarten			130
College - Secondary School		For Form 1 – Form 5, 45 students per class, 4 classes per form. For Form 6 – Form 7, 30 students per class, 2 classes per form, Total 60 staff employed by a school			1080
School - Primary School	H	Same as College – Secondary School			
	L	30 students for each class, 2 classes per grade, 6 grades in primary school Total 30 staff employed by a school			390
Hospital		Assumed that the population for hospitals for each building height category is as follows:			
		Floors	**Unit**	**People/Unit**	
	H	10	15	7	1050
	M	5	10	5	250
	L	3	10	5	150
Clinic		Assumed that the population for Clinic for each building height category is as follows:			
		Floors	**Unit**	**People/Unit**	
	H	3	20	3	180
	M	2	10	2	40
	L	1	1	10	10
Temple	H	100 people for large sized temple			100
	M	50 people for medium sized temple			50
	L	10 people for small sized temple			10
MTR Station/Bus Terminus		Based on the building area			
Storage Building		Same as Car Park			
Industrial Building		**Floors**	**Units**	**People/unit**	
	H	25	8	8	1600
	M	15	6	8	720
	L	8	6	6	288
Administrative / Commercial		**Floors**	**Unit**	**People/Unit**	
	H	10	20	2	400
	M	5	20	2	200
	L	2	10	2	40
Leisure	H	200 people for large sized leisure facility			200
	M	100 people for medium sized leisure facility			100
	L	50 people for small sized leisure facility			50
	LL	10 people for very small sized leisure facility			10

ERM determined the type of buildings for population estimation based on the survey and experience.

Note:

(1) Legend for Building Height / Size
- H for Tall / Large,

- M for Medium,
- L for Low / Small
- LL for Very Low/Very Small

Using the above approach, a database providing characterisation of each building by their broad attributes including population was developed.

4.2.7 ***Step 3: Distribute predicted future residential population data among identified residential buildings***

A uniform population growth factor of 1% per year was assumed for the study area in line with the SCL study (ERM, 2011) and XRL study (ERM, 2009).

While the exact distribution of the future population between the existing and future buildings is unknown, it was assumed that the distribution of the new building population will be similar to that for the existing buildings. Thus, the population estimates of *Step 2* for the existing residential buildings identified in *Step 1* have been scaled up according to the population growth factor. In this way, while the locations of any new residential buildings are unknown, the population growth is taken into account and distributed according to the present building locations.

4.2.8 ***Step 4: Adjust future population numbers for non-residential buildings***

In the absence of information for non-residential population trends, it was assumed that population in non-residential buildings would follow trends of the residential population. In this way, an approach was adopted whereby the population of non-residential buildings was adjusted to be in line with residential population trends.

4.3 TIME PERIODS AND OCCUPANCY

Since population can vary during different time periods, the analysis considers 3 day categories (weekdays, Saturdays and Sundays) with 4 time periods for each day. These are summarised in *Table 4.7*.

Table 4.7 Population Time Periods

Day Category	Time Period	Description
Weekdays	AM Peak	7:00am to 9:00am
	Daytime	9:00am to 6:00pm
	PM Peak	6:00pm to 8:00pm
	Night	8:00pm to 7:00am
Saturdays	AM Peak	7:00am to 9:00am
	Daytime	9:00am to 6:00pm
	PM Peak	6:00pm to 8:00pm
	Night	8:00pm to 7:00am
Sundays	AM Peak	7:00am to 9:00am
	Daytime	9:00am to 6:00pm
	PM Peak	6:00pm to 8:00pm
	Night	8:00pm to 7:00am

The occupancy of buildings during each time period is based on assumptions as listed in *Table 4.8*. These are based on extensive surveys conducted in the Castle Peak LNG study (ERM, 2006). For vehicle and pavement populations, distribution across time periods were based on data provided in AADT and site surveys.

Table 4.8 ***Population Distribution (Based on extensive site survey conducted as part of the ERM (2006) Study)***

Type	Occupancy					
	Night (Weekdays / Saturdays / Sundays)	AM Peak (Weekdays / Saturdays / Sundays)	PM Peak (Weekdays / Saturdays / Sundays)	Weekday Daytime	Saturday Daytime*	Sunday Daytime
Administrative/ Commercial (H)	10%	10%	10%	100%	100%	100%
Administrative/ Commercial (L)	10%	10%	10%	100%	100%	100%
Administrative/ Commercial (M)	10%	10%	10%	100%	100%	100%
Car Park/Podium - residential	10%	100%	100%	70%	70%	70%
Car Park/Podium – Commercial/Industrial	0%	100%	100%	70%	45%	20%
Car Park/Podium – MTR	10%	100%	100%	70%	60%	50%
Clinic (H)	0%	10%	10%	100%	100%	100%
Clinic (L)	0%	10%	10%	100%	100%	100%
Clinic (M)	0%	10%	10%	100%	100%	100%
College	0%	10%	10%	100%	55%	10%
Fire Station/Ambulance Depot	100%	100%	100%	100%	100%	100%
Hospital (H)	80%	80%	80%	100%	90%	80%
Hospital (L)	80%	80%	80%	100%	90%	80%
Hospital (M)	80%	80%	80%	100%	90%	80%
Hotel	90%	50%	50%	20%	50%	80%
Industrial Building (H)	10%	10%	10%	100%	55%	10%
Industrial Building (L)	10%	10%	10%	100%	55%	10%
Industrial Building (M)	10%	10%	10%	100%	55%	10%
Industrial/Warehouse	0%	1%	1%	100%	51%	1%
Kindergarten	0%	10%	10%	100%	55%	10%
Leisure (H)	0%	10%	10%	70%	85%	100%
Leisure (L)	0%	10%	10%	70%	85%	100%
Leisure (LL)	0%	10%	10%	70%	85%	100%
Leisure (M)	0%	10%	10%	70%	85%	100%
MTR/bus terminus	10%	100%	100%	70%	60%	50%
Petrol Station	1%	100%	100%	50%	50%	50%
Police Station	30%	30%	30%	100%	65%	30%
Power Station	10%	10%	10%	100%	55%	10%
Residential Building (H)	100%	50%	50%	20%	50%	80%
Residential Building (L)	100%	50%	50%	20%	50%	80%
Residential Building (LL)	100%	50%	50%	20%	50%	80%
Residential Building (M)	100%	50%	50%	20%	50%	80%
School (H)	0%	10%	10%	100%	55%	10%

Type	Occupancy					
	Night (Weekdays / Saturdays / Sundays)	AM Peak (Weekdays / Saturdays / Sundays)	PM Peak (Weekdays / Saturdays / Sundays)	Weekday Daytime	Saturday Daytime*	Sunday Daytime
School (L)	0%	10%	10%	100%	55%	10%
Station (H)	10%	10%	10%	100%	55%	10%
Station (L)	10%	10%	10%	100%	55%	10%
Station (M)	10%	10%	10%	100%	55%	10%
Storage Building (L)	0%	1%	1%	100%	51%	1%
Temple/ Church/ Chapel (H)	0%	10%	10%	50%	75%	100%
Temple/ Church/ Chapel (L)	0%	10%	10%	50%	75%	100%
University	90%	30%	30%	70%	60%	50%
Highway	20%	100%	100%	100%	100%	100%

* Estimated as average of Weekday daytime and Sunday daytime

4.4 *FEATURES CONSIDERED IN THIS STUDY*

A number of manmade slopes and retaining walls were identified in the vicinity of Tai Lam Explosive Magazine site as shown in *Table 4.9.* These have been considered in the Hazard to Life Assessment.

Table 4.9 Slopes Identified in the Vicinity of Tai Lam Explosive Magazine site

Slope Tag	Site	Distance from Explosive Store (m)	Population
6SW-D/F124	Tai Lam site	50	Adjacent to the magazine access road
6SW-D/C186	Tai Lam site	50	No road or population nearby
6SW-D/C187	Tai Lam site	55	No road or population nearby

5 HAZARD IDENTIFICATION

5.1 OVERVIEW

Hazard identification consisted of a review of:

- explosive properties;
- scenarios presented in previous relevant studies;
- historical accidents; and
- discussions with explosives and blasting specialists.

5.2 ACCIDENTAL INITIATION DUE TO HAZARD PROPERTIES OF EXPLOSIVES

5.2.1 *Explosive Type and Physical Properties*

The physical properties for the explosives to be stored and transported as part of this project are shown in *Table 5.1*.

Table 5.1 Explosive Types and Properties

Explosive Type	TNT Equivalency	Melting Point (°C) @ 1 atm	Bullet Test Sensitivity	Auto-ignition Point (°C) @ 1 atm	UN Hazard Division
Emulsion (packaged in cartridges)	0.96	170 *	>500 m/s	230-265**	1.1D
PETN (as provided for detonating cord)	1.4	135 - 145	> 450 m/s	190	1.1D
PETN (as provided within detonators)	1.4	120	> 450 m/s	190	1.4B 1.4S
Cast Boosters (75% PETN)	1.3	80	>450 m/s	299	1.1D

* This refers to the melting point of Ammonium Nitrate: Ammonium Nitrate undergoes phase changes at 32 - 83 °C and starts to melt at 170° C.

** Depends of type of oil used

Explosives are considered 'initiated' when a self sustaining exothermic reaction is induced. Such a reaction results in either a violent burning with no progression to explosion, a deflagration or a detonation. A deflagration may transit to detonation. The mechanism of transition from deflagration to detonation is still a subject of research. However, both modes of explosion can lead to significant injuries and fatalities and are considered in the Hazard to Life Assessment. The main difference between a deflagration and detonation is that a detonation produces a reaction front travelling at greater than sonic velocity, whereas a deflagration has a subsonic flame front. Both explosion types can cause extensive injury and damage.

Where explosives are stored under controlled conditions in purpose built and operated magazines or stores, the likelihood of accidental initiation in situ is remote. This is because the storage environment is unlikely to experience extremes of heat, shock, impact, or vibration of sufficient intensity to initiate detonation. The most common means of accidental initiation is principally the introduction of fire. Other means of initiation include severe impact and friction.

Generally, for an event to cause casualty concerns, a deflagration has to propagate. For a deflagration to occur, the explosive should be, at least but not only, subject to a stimulus which could be:

- Local stimulus: such as to generate a 'hot spot' (e.g. sparks, friction, impact, electrostatic discharge etc.);
- Shock stimulus: Subject to shock or high velocity impact: (e.g. bullet impact, detonation of other explosives etc.); or
- Thermal stimulus: Subject to mass heating leading to exothermic reaction (e.g. subject to intense heat or fire). For all systems, it can be envisaged that there can be no significant event until the medium becomes molten (and in the case of the emulsion, much of the water is lost).

For the types of explosives used in this project, not all of these causes necessarily lead to a deflagration or detonation.

In this study, accidental initiation of explosives has been categorised as either fire or non-fire induced.

The following sections briefly describe the initiation mechanisms and events applicable for this Hazard to Life Assessment.

5.2.2 *Hazardous Properties of Emulsion Type Explosives*

The family of emulsion explosives typically contains over 78% AN, which is a powerful oxidising agent. Emulsion based explosives will not explode due to friction or impact found in normal handling. However, it can explode under heat and confinement or severe shock, such as that from an explosion. The sensitivity of AN based explosives to deflagration or detonation is increased at elevated temperatures.

There are two broad categories of emulsions:

- Packaged emulsion (sensitised); and
- Bulk emulsion precursor (void-free liquid).

Cartridged emulsions are sensitised to fulfil their intended function (the emulsion is sensitised by either adding gassing solution or plastic microspheres) at the point of manufacture, they are then transported in a sensitised state. Bulk emulsions are sensitised at the point of use on sites. The chemical properties for these two categories of emulsion mainly differ due to the presence of sensitizer.

Matrix or bulk emulsion (no voids) is not sensitive to shock as there is no known mechanism for the shock front to propagate. Also, a very high pressure would be required to heat a void free liquid.

In normal atmospheric conditions, a local stimulus generating 'hot spots' including sparks, friction, impact, electrostatic discharge, extremes of ambient air temperature etc., does not cause packaged emulsions (sensitised) to readily deflagrate. A pressure in excess of 5 bar above atmospheric pressure, is additionally required in the "deflagrating mass" to generate a deflagration which may subsequently transit to a detonation.

The behaviour of packaged emulsion following a shock or thermal stimulus is discussed below.

5.2.3 *Accidental Packaged Emulsion Initiation by Fire*

In a fire, pools of molten AN may be formed, and may explode, particularly if they become contaminated with other materials e.g. copper. In a fire, AN may also melt and decompose with the release of toxic fumes (mainly oxides of nitrogen). Beyond 140 °C (ERP, 2009) or in its molten form, AN sensitivity to local stimuli increases.

A number of tests indicate that, when subjected to fire engulfment, many explosives ignite and burn, deflagrate, and in some cases detonate. The time for an explosive to ignite is dependent upon its physical characteristics and chemical composition.

It is generally considered that cartridged emulsions are generally less sensitive to fire engulfment as a means of initiation due to the high water content. However, when exposed to heat or fire, the water content of the emulsion will be driven off, leading to possible initiation if the energy levels are high enough, long duration and confinement pressure increases.

A fire surrounding the explosive load will clearly raise the temperature of any reactive media and enable evaporation of components e.g. water. The rate at which this occurs is dependent on the fire (extent) and the heat transfer considering the cargo container wall design. The external part of the container wall will heat by direct contact with the flame and heat will eventually be transferred to the explosive load.

Transport accident statistics for ANFO, another type of ammonium nitrate based explosive, indicate a minimum time to deflagration of about 30 minutes. Emulsion is considered more difficult to initiate than ANFO due to its water content.

The consequences of an accidental explosion due to thermal stimulus could be a thermal explosion (cook-off) or detonation or some combination of the two.

5.2.4 *Accidental Packaged Emulsion Initiation by Means Other Than Fire*

Non-fire initiation mechanisms are commonly divided into two distinct groups; mechanical and electrical energy. The term 'mechanical' encompasses both shock and friction initiation, because in most accidental situations, it is difficult to distinguish between them. It has been recorded that some explosives (not emulsion type) can initiate (in the absence of piercing) mechanically at an impact velocity as low as 15 m/s. If the explosives are pierced, for example by a sharp metal object, then it is likely that the required velocity will be far less than 15 m/s. This is due to localised heat generation resulting from frictional rubbing between layers of explosive, and is referred to as 'stab-initiation'.

However, cartridged emulsion is insensitive to initiation via impact, as demonstrated by the bullet impact test from a high velocity projectile. Based on the bullet impact test, it requires at least 10 times the energy level of that required to detonate nitroglycerine (NG) based explosive.

All explosives have a minimum ignition energy level, above which initiation will occur. Typically, minimum ignition energy levels range between 0.015 J and 1.26 J.

For the vast majority of explosives, including cartridged emulsions, the required ignition energy level is far exceeded by contact with mains electricity. In comparison, the energy levels possible from batteries or alternators fitted to motor vehicles, or that due to static build-up on clothing, are typically much less than that required to initiate most commercial explosives (e.g. 0.02 J or less). Hence, only very sensitive explosives are likely to ignite from these electrical energy sources. Therefore, electrical energy is not a possible energy source for the types of explosives intended to be used in this project.

Possible degradation of cartridged emulsion is from water loss and prolonged temperature cycling above and below 34 °C, which leads to potential caking or a change in ammonium nitrate crystalline state and increase in volume. Both modes of degradation do not lead to the detonation of the cartridged emulsion by means other than fire.

5.2.5 *Hazardous Properties of Detonating Devices*

These detonating devices may detonate when exposed to heat or flame, or with friction, impact, heat, low-level electrical current or electrostatic energy. Detonation produces shrapnel. Hazardous gases / vapours produced in fire could be lead fumes, nitrogen oxides and carbon monoxide. However, these gases depend on the type of material used in the detonators.

The main explosive contained in detonating devices including detonating cord and detonators is pentaerythritol tetranitrate (PETN). Detonators also contain a primary explosive substance, e.g. lead azide, which is very sensitive to initiation.

In the case of detonating cord PETN has similar sensitivities (somewhat less sensitive) to NG based explosives. It is generally more sensitive than emulsions.

PETN has the potential to deflagrate at ambient pressure following a local stimulus. Local initiation can lead to a deflagration (ambient pressure or higher) and from this to a detonation. As an explosive, it has a comparatively small critical diameter (i.e. the smallest physical size of a charge of an explosive that can sustain its own detonation wave) for detonation. When compared to emulsion, PETN can readily initiate by shock but its shock sensitivity is still low compared to NG based explosives. Based on the bullet impact test, it requires at least 10 times the energy level of that required to detonate an NG based explosive (ERP, 2009).

5.3 ACCIDENTAL INITIATION ASSOCIATED WITH STORAGE AT MAGAZINE

For the proposed Magazine, the possible means of accidental initiation of the explosives by fire are as follows:

- Inadequately controlled maintenance work (e.g. hot work);
- Poor housekeeping (e.g. ignition of combustible waste from smoking materials);
- Inappropriate methods of work;
- Electrical fault within the store, which ignites surrounding combustible material resulting in a fire; or
- Arson.

Possible means of accidental initiation of the explosives by means other than fire are as follows:

- Dropping of explosives during handling (for the detonators only); and
- Crushing of explosives under the wheels of vehicles during loading or off-loading (for detonators and detonating cord only).

The detonators supplied are packaged within plastic separating strips, such that the initiation of a single detonator will not propagate to the adjacent detonator. Packaged in this manner the detonators are classified as Class 1.4B Explosives. The total mass of detonators is negligible in terms of explosive mass.

5.4 ACCIDENTAL INITIATION ASSOCIATED WITH TRANSPORTATION FROM THE MAGAZINE

Cartridged emulsion, cast boosters and detonating cord will be transported within the same truck in the same compartment.

In accordance with the vehicle cargo specifications, the cargo will be designed to minimise all sources of local stimulus and as such will require a significant crash impact and/or a fire to cause a concern to the explosive load. As reported in the ACDS study (ACDS, 1995), a low speed traffic accident is not likely to cause a concern to the explosive load. Conservatively, such an event is still considered possible in this study but with a lower probability (ERP, 2009). Based on the review with explosives experts, the energy required to detonate PETN or emulsion based explosives is one order of magnitude higher (based on bullet tests) than NG. Since NG was considered as the basis for determining the probability of imitation under impact conditions in previous studies (assessed at 0.001), this probability can be reduced by one order of magnitude based on impact energy consideration (ERP, 2009).

The response of the explosive load to an accidental fire would depend on the time and possibility to full fire development on the vehicle (typically 5 - 10 minutes) and the amount of heat transferred to the load. In the case of emulsion, if isolated from detonating cord, based on accident statistics, it may take at least another 30 minutes for the explosive to reach critical conditions. This time may be considerably reduced for mixed loads of cartridged emulsion, cast boosters and detonating cord; however, no accurate time could be predicted from detonating cord transport accident data (ERP, 2009).

In this project, the behaviour of explosives as transported was considered to be similar to the XRL study (ERM, 2009), for which, the explosive properties were reviewed with assistance from experts in the explosives industry (ERP, 2009). The review was based on the current knowledge on the explosive properties taking into account recent knowledge on explosive behaviour under thermal stimulus as well as worldwide accident experience. The expert panel considered in detail what might happen in situations where an emulsion explosive load suffers a thermal stimulus (which could be via heat transfer or direct fire impingement). The main findings for emulsion based explosives are quoted below.

"The radical change in explosive properties at higher temperatures compared to the original emulsion must be taken into account. At high temperatures (> melting point), emulsion explosives would lose water content which may result in a refined explosive (small droplet/ crystal size Ammonium Nitrate). This could lead to a thermal explosion, deflagration or detonation and the probability of 0.1 may not therefore be applicable to emulsion. Also, some limited accident statistics have some bearing on this hazard scenario: these accidents may include a combination of both thermal and mechanical stimuli, which would likely have resulted in explosion or detonation. The consensus was that the probability of an explosion for the case of an emulsion was less than 0.5 but further refinement of this upper estimate would require additional data and more detailed analysis." (ERP, 2009).

This is consistent with recent accident experience as described in the next section.

On the subject of detonating cord (PETN based), there is no accident data directly relevant for PETN. The properties of detonating cord (PETN based) was reviewed by experts (ERP, 2009) by comparison with other commercial explosives such as NG-based blasting explosives, Plastic Explosives, etc. taking particularly care to exclude mixed load where the load was mixed with significantly more sensitive items such as detonators and safety fuses to offer a valid comparison for PETN. The review was based on accident events reported in the EIDAS which had an explosion confirmed to be caused by a fire event. The review showed that for incidents involving explosives with properties comparable to detonating cord (PETN based) a fire resulted in explosion in roughly 50% of the cases. Most of the cases involved dynamite known to be more sensitive than detonating cord (PETN based). The data set reviewed contained a number of uncertainties. In particular, for incidents which did not result in explosion, the degree of explosive involvement in fire is uncertain in a few cases. There could also be the presence of other factors which could have contributed to the explosion. On the other hand, it is likely that a number of fire incidents which did not result in explosion do not appear in the database. The panel concluded that a probability of 0.5 would be more appropriate for PETN based explosives.

5.5 REVIEW OF INCIDENTS

This section presents a review of reported safety incidents involving explosives (in industrial/commercial applications). Records were retrieved mainly from the UK Health and Safety Executive's (UK HSE's) Explosives Incidents Database Advisory Service (EIDAS), US Mine Safety and Health Administration (MHSA) and Western Australia's Department of Consumer and Employment Protection (DOCEP). The records provided are also supplemented with information obtained from various sources. Analyses of accident data are provided in the following sections.

For the purpose of this study, incidents were sorted according to the following categories to highlight causative factors to the incidents:

- Incidents involving storage of explosives; and
- Explosive transport incidents.

Further analysis has been performed for other types of explosives (e.g. NG based explosives, ANFO, Plastic (C4), etc.) as relevant for the Frequency Assessment part of this Hazard to Life Assessment.

5.5.1 *Explosives Storage Incidents*

In the UK a study of the risks associated with explosives manufacture and storage was undertaken based on the 79 major incidents identified during the period from 1950 to 1997 (Merrifield, 1998). A total of 16 major incidents were attributed to the storage of explosives. Thirteen (13) incidents related to the storage of gunpowder, ammunition, nitroglycerine, and fireworks. A further incident occurred in 1970 involved the storage of detonators and was attributed to corrosion of the detonators themselves. The remaining two (2) incidents related to the storage of blasting explosives in 1954 and 1964. One of these incidents involving blasting explosives was attributed to malicious activity, whilst the cause of the remaining incident in 1954 was not identified.

Based on the above study, and on the hazards of the explosive materials, it is apparent that the protection of explosives from malicious human activity, and the elimination of possible ignition sources are critical to maintaining storage facilities. From a review of the above records, some of the identified initiating causes of accidents in storage facilities are listed below:

- Impact;
- Friction;
- Overheating;
- Electrical effects (lightning/static discharges);
- Sparks;
- Spontaneous reactions; and
- Malicious action/mishandling.

Avoidance of incidents in the storage area can only be assured by maintaining good housekeeping practice, eliminating potential ignition sources and allocating safe and secure storage space for explosives.

However, not all of these causes are applicable to the types of explosives used in the Project. These are further discussed in *Section 6.1.2*.

5.5.2 *Explosives Transport Incidents*

In Hong Kong, there has not been any road transport related incidents on vehicles carrying explosives with significant consequences, i.e. fire and explosion. In September 2010, a minor incident involving a Mines Division Truck occurred on Queens Road West. The crash impact was not significant and the integrity of the explosives was not affected. The incident did not result in fire or explosion and therefore does not contribute towards the truck accident explosion frequency assumed in the frequency assessment.

The international experience of incidents involving the transport of explosives on the road has therefore been reviewed in detail.

A review of international incident databases indicates that the EIDAS database contains most of the worldwide incidents associated with the transport of commercial explosives. The incidents which were reported from 1950 to 2008 were scrutinised.

The EIDAS database identified one emulsion related transport incident in which a tyre fire on a truck spread to the emulsion load, which eventually detonated producing a substantial crater. However, there were no casualties as the truck crew had time to evacuate to a safe distance before the explosion occurred. Other than this incident, there have been a number of other incidents involving mixed cargoes of emulsion or water-gel carried with other types of explosives. One such event was the 1989 '*Peterborough* incident', involving a vehicle carrying Cerium fuseheads, detonators, NG-based explosives and water-gel (Peterborough, 1989). The explosion was initiated by fire and explosion from a box of Cerium fusehead combs destined for a local fireworks manufacturer. The combs were in unauthorised and unsafe packages. This incident initiated enactment of more stringent safety guidelines in the UK, specifically the Road Transport (Carriage of Explosives) Regulations of 1989, which came into force just 3-months after the incident.

Australia is a significant user and transporter of explosives, consuming approximately 900,000 tonnes of explosives per year (approximately 8% of the world's consumption of explosives). Of this total, approximately 3,000 tonnes (0.3%) is non-bulk explosives (boosters or cartridged emulsion) based on industry estimates. Western Australia consumes approximately 30% of Australia's explosives and publishes accident data (DOCEP). Within the data recorded by DOCEP, there was one accident reported: a vehicle carrying blasting explosive and detonators overturned (DOCEP, 2001). No ignition (i.e. no fire or explosion) occurred. In the 1990s there were several accidents in Western Australia involving ammonium nitrate or Ammonium Nitrate Emulsion (UN3375) (UN Class 5 Dangerous Goods, used as a precursor for manufacturing explosives). All three incidents involved articulated vehicles overturning with no fire or explosion. None of these incidents are directly comparable to the situation in Hong Kong where explosives vehicles are not articulated. In the EIDAS database, two fire incidents involving explosive delivery trucks were recorded in 1998 and 2007 in Australia, however none of these incidents resulted in fatality or injury.

In the US, explosives transport has a good safety record. In a recent study released by the National Institute of Occupational Safety and Health (NIOSH, 2008), analysis of data from 1998 to 2006 revealed that accidents related to the transport of explosives and ammonium nitrate used in mining and construction have resulted in only 5 major injuries, 11 minor injuries, and no fatalities. The safe history of explosives and ammonium nitrate transport is attributed to diligent efforts by government, labour and industry.

Other pertinent statistics could be summarised below:

- There have not been any known transport related explosions involving purely packaged emulsion, hence, accident data has been examined for other types of explosives having similar properties to bulk emulsion although they may be subject to different explosion mechanisms;

- There have been numerous accidents involving crash impact and even with more sensitive explosives such as nitroglycerine based explosives, there are no reported instances of explosion following a crash impact for either nitroglycerine based explosives, or less sensitive explosives such as PETN and emulsion. Amongst those incidents, several have resulted in truck overturn or significant scenarios but no explosion occurred purely due to the shock impact (October 2008 (US), August 2008 (US), July 2008 (US), May 2008 (Spain), etc.); and

- There have been only six reported transport related accidents involving emulsion (June 2004 in Russia and March 2007 in Chile) and bulk ANFO (which would behave like emulsion in a fire condition) (April 1959 in USA, August 1998 in Canada, December 1998 in Australia and September 2007 in Mexico). All of these are reported in the EIDAS database and listed in *Table 5.2* Each of these six accidents were caused by a vehicle fire (50% crash related) and most of them led to explosion. Although a high probability (nearly 100%) exists based on accident statistics, the actual probability is less including the number of potentially unreported incidents and at least four known burning tests in Canada, Sweden and Norway in which burning is known to have occurred instead of explosion.

A summary of transport fire incidents involving unmixed loads of ammonium nitrate based commercial explosives is shown in *Table 5.2*.

Table 5.2 Summary of Transport Fire Incidents Involving Unmixed Loads of Ammonium Nitrate Based Commercial Explosives

Date	**Country**	**Type of Explosives**	**Type of Event**	**Cause**
Apr 1959	USA	ANFO	Explosion	Vehicle Fire
Aug 1998	Canada	ANFO	Explosion	Vehicle Crash/ Collision
Dec 1998	Australia	ANFO	Explosion	Vehicle Fire
Jun 2004	Russia	Emulsion	Explosion	Vehicle Fire
Mar 2007	Chile	Emulsion	Fire	Vehicle Crash/ Collision
Sep 2007	Mexico	ANFO	Explosion	Vehicle Crash/ Collision

It is also relevant to note the experience of cartridged emulsion disposal, reported in the EIDAS database, in burning grounds in controlled burning grounds conditions (typically involving maintenance of separation distances, controlled fire, and in many cases removal of the explosives from their package), where, although the causes may have potentially included contamination i.e. mixing explosives with other materials e.g. waste copper, five events are known to have led to explosions. It is however difficult to correlate these events to transport or storage conditions under uncontrolled fire conditions with potential confinement. It is also worth noting that a number of explosive packages have been disposed by way of burning in which no explosion occurred. However, the information is scattered and the number of such events could not be determined to estimate a probability of explosion.

It is also worth noting a high number (over 20) of known pumping accidental explosions associated with emulsions or slurries which occurred in combination of overheating and confinement (high pressure) (ISEE, 1996).

5.6 SCENARIOS FOR HAZARD ASSESSMENT

The following hazardous scenarios were identified:

5.6.1 *Proposed Magazine*

A Magazine site typically contains more than one explosive store. Tai Lam Explosives Magazine Site, for example, have 2 stores in total. Within each store, explosives and detonators are stored in segregated compartments. The stores are designed with separation and enclosed walls so that initiation of the contents of one store will not affect other stores. The internal separation distances between the Magazine stores meet the safety distances requirements from the UK Explosives Regulations 2014. Therefore, the study considers the possibility to initiate adjacent store's explosives due to escalation or domino effects to be negligible compared to the overall explosion frequency of the Magazine. The analysis considers the scenario to be the detonation of the full contents of each store. This, together with accidents involving the delivery trucks leads to the following scenarios that were considered in the assessment:

- Detonation of a full load of explosives on a delivery truck within the magazine access road; and
- Detonation of the full quantity of explosives within a store; or a series of stores.

The explosives transport within the Magazine site has conservatively considered the maximum load and the maximum delivery frequency throughout the project as a simplification. In addition, in cases where the explosives trucks are allowed to load explosives at the same time, it was simplistically and conservatively assumed that an accidental explosion of one truck load can lead to domino effects to the other trucks resulting in a potential 2 fold increase in truck load explosion frequency for a Magazine with 2 stores.

The explosive loads considered are listed in Table 5.3. The detonator explosive load has been considered in the total explosive load.

Table 5.3 Explosives Storage Quantities

Magazine Site	Mass of Explosive per Site (kg)(1,2)	No. of Detonators per Site (No.) (3)	TNT Equivalent per Site (kg) (4)	No. of Stores	TNT Equivalent per Store (kg)
Tai Lam	800	3800	934	2	467

Notes:

1 Assuming the worst case storage scenario, in which the store contains 40% detonating cord, 60% cartridged emulsion; number of detonators based on a typical pull length of 5 m and face area of 125 m^2 (extracted from the Project blasting programme)

2 Detonating cord are made of PETN

3 Each detonator contains about 0.9g of PETN

4 1 kg of cartridged emulsion equals 0.96 kg of TNT, 1kg of cast boosters equals 1.3 kg of TNT and 1 kg of PETN equals 1.4 kg of TNT

5.6.2 *Transport of Explosives*

Hazardous scenarios considered for the transport of explosives are:

- Accidents involving explosives delivered and transferred from the Magazine to each delivery point from the gate of the Magazine to the gate of the blasting face.

Explosion of the detonator load during transport is not quantified for the following reasons:

- Detonators will be transported on a separate truck within the same convoy; and

- Detonator packages will be classified as UN 1.4B or UN 1.4S (articles which present no significant hazard outside their packaging). Packaged in such a way, the consequences potentially leading to fatalities will be limited to remain within the explosive truck boundaries. The UK HSE has estimated the consequences for small quantities of explosives in workrooms. For a detonator load of less than 200 g per trip to be transported in HKLTH, an accidental explosion will lead to approximately 1% chance of eardrum rupture at a distance of 3.5 metres; approximately 50% chance of eardrum rupture at 1.5 metres. Persons in very close proximity to the explosion (e.g. holding the explosives) would almost certainly be killed (HSE, Explosion of Small Quantities of Explosives).

The drill and blast activities for the Project will be carried out over a 24 month period during which the explosive load requirement and delivery frequency is expected to vary (see *Section 2.5*). Risks, however, are defined on a per year basis and represent one year construction programme; the base case scenario for the Hazard to Life Assessment was therefore defined to cover different risk levels and possible construction programme deviations throughout the project period.

5.6.3 *Scenarios Considered in the Assessment*

A Base Case and a Worst Case were considered in the risk assessment; the assessed scenarios are summarised in the following tables.

Table 5.4 Scenarios Considered in the Base Case Assessment

Tag	Scenario	Explosives Load (TNT eqv. kg)	No. of Trips per year	Remarks
Storage of Explosives				
01	Detonation of full load of explosives in one store in the Tai Lam Explosives Magazine Site	467	-	Store capacity is 400 kg
02	Detonation of full load of explosives in one contractor truck on the access road within Tai Lam Explosives Magazine Site boundary	206	2100	
Transport of Explosives				
03	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam Explosives Magazine site to Mid-Ventilation Adit delivery point	206	450	
04	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam Explosives Magazine site to North Portal delivery point	206	570	
05	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam Explosives Magazine site to South Portal delivery point	206	1080	

Table 5.5 Scenarios Considered in the Worst Case Assessment

Tag	Scenario	Explosives Load (TNT eqv. kg)	No. of Trips per year	Remarks
Storage of Explosives				
01	Detonation of full load of explosives in one store in the Tai Lam Explosives Magazine Site	467	-	Store capacity is 400 kg
02	Detonation of full load of explosives in one contractor truck on the access road within Tai Lam Explosives Magazine Site boundary	206	2520	
Transport of Explosives				
03	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam Explosives Magazine site to Mid-Ventilation Adit delivery point	206	540	
04	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam Explosives Magazine site to North Portal delivery point	206	684	
05	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam Explosives Magazine site to South Portal delivery point	206	1296	

6 FREQUENCY ASSESSMENT

6.1 STORAGE OF EXPLOSIVES

6.1.1 *Explosion in Contractor's Collection Truck within the Magazine Site*

The risk associated with accidental explosion during transportation within the Magazine site was assessed using the same methodology as described for explosive transport, which will be discussed in detail in *Section 6.2* and is consistent with the approach considered in the SCL Study (ERM, 2011) and XRL Study (ERM, 2009). The base frequency for accidental explosion during transport has been taken as 7.69×10^{-10}/km for normal roads, and the same frequency has been assumed while the Contractor's truck is onsite at the magazine. For cases where several explosives trucks are allowed to operate within the Magazine site, this frequency has been multiplied by the number of stores to account for potential domino effects (refer to *Section 5.6.1*). This is considered conservative accounting for low speeds, lack of other vehicles and hence low collision probability. The lengths of the magazine access roads and the number of trips considered are provided in *Table 6.1*.

Table 6.1 ***Length of Magazine Access Roads (within the Magazine Sites) and Number of Trips Considered***

Magazine Site	Route Length (km)	Total Number of Deliveries (/year)
Tai Lam	0.196	2100

6.1.2 *Explosive Magazine Explosion*

In this analysis, the following possible causes of accidental initiation have been considered. Each is discussed in further detail below.

Table 6.2 ***Potential Causes of Accidental Initiation in the Magazine***

Generic causes (included in base frequency)
Explosion during manual transfer from store to contractor's collection truck
Lightning strike
Fixed wing aircraft crash onsite
Hill /vegetation fire
Earthquake
Escalation (explosion of one Magazine storeroom triggers another)
Other site specific considerations

Generic Causes

A base frequency of 1×10^{-4} /yr for the Magazine site has been taken for generic causes of explosion during storage in the Magazine site based on the UK historical records (Merrifield, 1998) as detailed in the WIL Study (ERM, 2008). An analysis of the UK explosive storage experience shows that all explosions in UK magazines (other than military stores and ordnance factories) were caused by one of the following:

- unstable explosive material caused by product degradation, corrosion, and contamination;
- escalation of an external incident, e.g. fire; or
- malicious acts, e.g. vandalism or attempted theft.

The explosives types to be used in the Project are stable and less likely to undergo initiation due to degradation or impact. However, the explosives stored in this project are detonator sensitive, and hence the detonators are to be stored and transported separately, within a dedicated chamber in the Magazine.

The magazine is protected from external fire due to the location of explosives inside a concrete or brick wall building and the provision of fire fighting measures (described in *Section 2.3.2*), and therefore the probability of initiation due to external fire is considered to be lower than that implicit in the UK HSE event frequency.

Hence, it is considered that the most significant causative event that leads to an explosion within the magazine is that posed by malicious activities, such as vandalism or robbery. The magazine is provided with a comprehensive security system as elaborated in a previous section (*Section 2.3.2*) and thus the possibility of vandalism may be reduced.

The installation of fire fighting measures within the magazine store will reduce the probability of initiation due to fire. The proposed security system will also reduce the frequency of initiation of an explosion due to vandalism or robbery. Nevertheless, this conservative figure of 1×10^{-4} for the Magazine site per year was retained to represent all generic causes of explosion that are common to nearly all magazines. Other causes such as on-site transportation and aircraft impact will vary between sites and have therefore been addressed separately.

Explosion during Manual Transfer from Store to Contractor's Truck

Since transfer of explosive from the store to the truck or vice versa will be carried out manually without involving any tools susceptible to initiate explosives, mishandling is deemed to be the only cause leading to an explosion. There is no significant cause of explosive mishandling identified specific to the project magazine compared to international practice; hence risks due to manual transfer are taken to be covered in the generic failure causes.

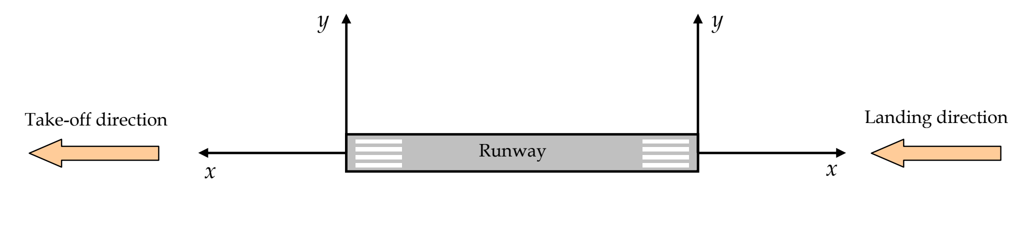
Lightning Strike

The magazine will be protected with lightning conductors to safely earth direct lightning strikes. The potential for a lightning strike to hit the facility and cause a detonation of explosives is therefore deemed to be unlikely although possible. Given that lightning protection will be provided for each store, lightning strike does not present an additional risk compared to the risk considered as part of the base frequency estimation in the UK. Explosive initiation due to lightning strikes is taken to be covered by the generic failure frequency.

Fixed Wing Aircraft Crash

The probability of a civilian aeroplane crashing onsite can be estimated using the HSE methodology (Byrne, 1997). The same model has been used in previous assessments of aircraft accidents (ERM, 2006). The model takes into account specific factors such as the target area of the proposed site and its longitudinal (*x*) and perpendicular (*y*) distances from the airport runway thresholds of the Hong Kong International Airport (*Figure 6.1*).

Figure 6.1 ***Aircraft Crash Coordinate System***



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

$$F_T(x,y) = \frac{(x+0.6)}{1.44} e^{\frac{-(x+0.65)}{1.2}} \left[\frac{46.25}{\sqrt{2\pi}} e^{-0.5(125y)^2} + 0.9635 e^{-4.1|y|} + 0.08 e^{-|y|} \right] \qquad (3)$$

for $x > -0.6$ km

Equations 2 and *3* are valid only for the specified range of *x* values, as defined in *Figure 6.1* for take-offs and landings. If *x* lies outside this range, the impact probability is zero.

National Transportation Safety Board (NTSB) data for fatal accidents in the US involving scheduled airline flights during the period 1992-2011 show a downward trend with recent years showing a rate of about 8.5×10^{-8} per flight. However, only 18.7% of accidents are associated with the approach to landing, 14.0% are associated with take-off and 4.7% are related to the climb phase of the flight (NTSB, 2006). The accident frequency for the approach to landings hence becomes 1.6×10^{-8} per flight and for take-off/climb 1.6×10^{-8} per flight. The Civil Aviation Department (CAD) reports an annual number of flights at Chek Lap Kok is about 380,000.

Chek Lap Kok has 2 runways, but with take-offs and landings from each direction, the runway designations are 07L, 07R, 25L and 25R. Half the plane movements are taking-offs (190,000 per year) and half are landings (190,000 per year). Assuming each runway is used with equal probability, the frequency of crashes at the Magazine site may be calculated as summarised in *Table 6.3*. The footprint area of each store and associated sand mound is estimated at 120 m^2, suggesting a target area of 240 m^2 for the 2 stores at Tai Lam Explosive Magazine.

From *Table 6.3,* the combined frequencies of all take-off and landing crashes amount to much less than 10^{-9} per year for the Magazine site. The risk of aircraft crash is therefore negligible compared to the risks considered in this project.

Table 6.3 Airplane Crash Frequencies

Magazine Site	Distance from Runway Threshold (km)				Crash Frequency (/km²/yr)*					Magazine Store Area (m²)	Impact Frequency (/yr)
	07L/25R		**07R/25L**		**07L**	**25R**	**07R**	**25L**	**Total**		
	x	*y*	*x*	*y*	**Take-off**	**Landing**	**Take-off**	**Landing**			
Tai Lam	12.5	7.5	12.5	9	5.3×10^{-12}	4.7×10^{-10}	1.2×10^{-12}	6.4×10^{-10}	1.1×10^{-9}	240	2.7×10^{-13}

* Take-offs to the west on runways 25L/R, and landings from the west on runways 07L/R will not contribute to the crash frequencies impacting on the Magazine site

Hill/Vegetation Fires

Hill/vegetation fires are relatively common in Hong Kong, and could potentially occur near the Magazine site. Recent statistics for these fires in Hong Kong country parks have been reviewed. Although the magazine is not actually located in a country park, some of the surrounding terrain and vegetation is similar to those typically found in country parks**.** According to Agriculture, Fisheries and Conservation Department (AFCD) statistics, the average number of hill fires is 32.4 per year during the five years 2008-2012 (range: 16 to 49). The area affected by fire each year is available from AFCD annual reports for 2009-2013 (*Table 6.4*). These are compared to the total area of country parks in Hong Kong of 44004 - 44239 Ha.

Averaging the data for the 5-year period suggests that 1% of vegetation areas are affected by fire each year, or equivalently, the frequency of a hill fire affected a specific site is 0.01 per year.

Table 6.4 Hill Fire Data for Hong Kong

Year	Area Affected (Ha)	Country Park Area (Ha)	% of Total Country Park Affected
2012	79	44239	0.18
2011	27	44239	0.06
2010	897	44239	2.03
2009	275	44004	0.62
2008	501	44004	1.14

With respect to the explosive magazine design, the land within the compound will be cleared of vegetation to remove combustible materials (see *Section 2.3.2*). The magazine, referring to *Section 2.3.2*, will be constructed from fire resistance materials such as bricks, cement rendering and steel doors. The ground surface will be made of either concrete or stone to prevent fire ingress to explosive stores. Since the magazine will be protected from fire by design, together with other fire-fighting measures in place, the chance of explosive initiation due to hill fire will be much lower than the generic explosion frequency and will be at no greater risk than other explosive magazines worldwide. Thus the generic explosion frequency is considered to include hill fire scenarios.

Earthquake

Studies by the Geotechnical Engineering Office (GEO Report 65) and Civil Engineering Services Department (GCO, 1991) conducted in the last decades indicate that Hong Kong SAR is a region of low seismicity. The seismicity in Hong Kong is considered similar to that of areas of Central Europe and the Eastern areas of the USA. As Hong Kong is a region of low seismicity, an earthquake is an unlikely event. The generic failure frequencies adopted in this study are based on historical incidents that include earthquakes in their cause of failure. Since Hong Kong is not at disproportionate risk from earthquakes compared to similar explosive magazines worldwide, it is deemed appropriate to use the generic frequencies without adjustment. There is no need to address earthquakes separately as they are already included in the generic failure rates.

Escalation

Referring to the WIL study (ERM, 2008), it is not considered possible that an explosion within one magazine store will directly initiate an explosion within an adjacent store (i.e. leading to mass explosion). This is based on the results obtained from the Ardeer Double Cartridge (ADC) test for cartridged emulsion that show that beyond a separation distance of 2 cartridge diameters the consequence of a detonation are not able to propagate. Therefore the direct propagation by blast pressure wave and thermal radiation effects of an explosion within one store initiating an explosion within the adjacent store is not considered. However, the ground shock induced from an explosion may cause damage within the adjacent stores leading to subsequent explosion.

Explosive stores are made of substantial brickwork surrounded by earth mounds between each store. Referring to a previous assessment (ERM, 2008), a building can withstand a vibration level lower than 229 mm/s without significant structural damage.

Ground vibration distances R can be assessed using the formula

$$A = K\, Q^{d}\, R^{-b}$$

where

A is the vibration threshold (mm/s)
Q is the mass of explosive detonated.
$K = 1200$, $d = 0.5$, $b = 1.2$.

The above equation applies to explosives fully coupled with hard rock as typically found in Hong Kong. The magazine store building will provide some confinement which would result in explosion energy being transmitted through the ground by ground shock effects due to the direct contact of explosives with the ground. The WIL study (ERM, 2008) defines a methodology for assessing the ground shock effects in underground explosive stores. Although the criteria for underground store of the DoD 6055.9-STD will not be reached given the thickness of the walls, the same approach is conservatively adopted to evaluate the ground shock effects in the absence of other relevant correlation. This gives a K value circa 200 ± 10%for the Project considering the amount of explosives to be stored in each storeroom at the Magazine site.

Applying the above equation and the ground coupling correlation of the WIL study (ERM, 2008), the maximum ground vibration generated from detonating of 467 kg TNT equivalent explosive is calculated at 155 mm/s for a separation of 16 m which is less than 229mm/s . Hence, this study considers the possibility to initiate adjacent store's explosives due to escalation or domino effect to be negligible compared to the overall explosion frequency.

Other Site Specific Considerations

It is assessed that model aircraft (aeroplanes and helicopters) operating from the enthusiasts' club airfield adjacent to the Tai Lam site are too light, and carry too little fuel, to cause any consequence on impact.

Conclusion on Accidental Initiation in the Magazine

All external hazards make either negligible additional contribution to the risks or are deemed to be already included in the generic frequency of 10^{-4} per year.

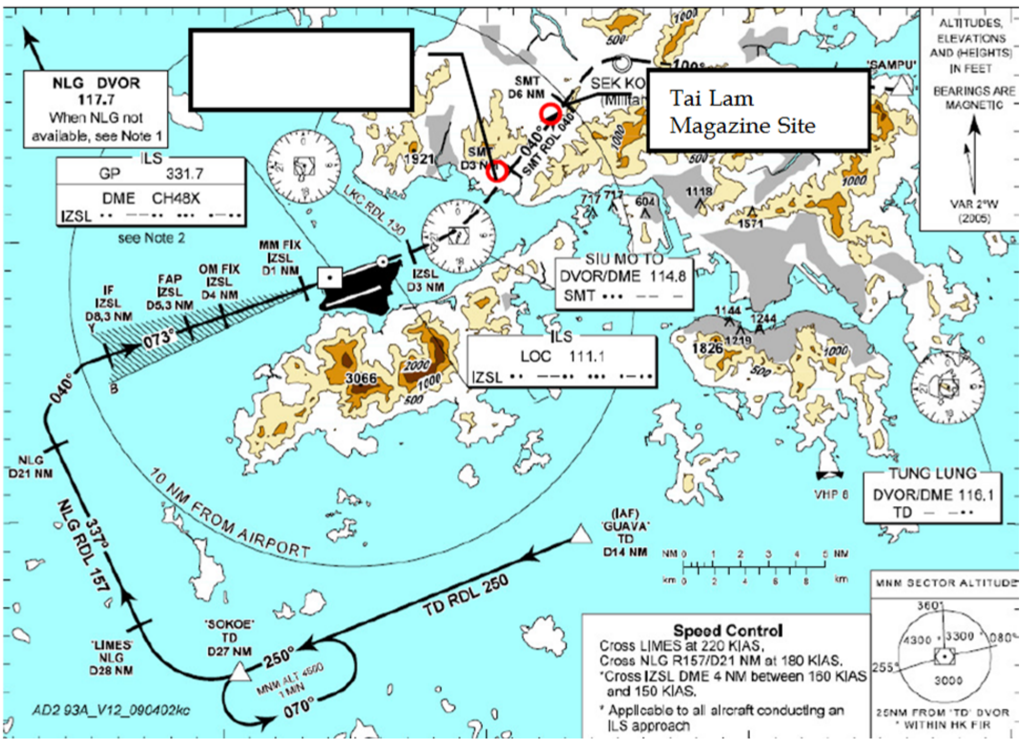
6.1.3 *Impact on Air Traffic near the Tai Lam Site*

The proposed Tai Lam Explosives Magazine site will be located about 5 km away respectively from the regular arrival paths 25L/25R, departure paths 07L/07R (North), 07L/07R (South) and 25L/25R at Hong Kong International Airport (*Figure 6.2* and *Figure 6.3*). These distances are far beyond the maximum impact area of fragments generated in an explosion.

Figure 6.2 Arrival Flight Paths of Hong Kong International Airport

Figure 6.3 Departure Flight Paths of Hong Kong International Airport

Figure 6.4 Missed Approach Flight Path



Impact on Regular Arrival and Departure Flight Paths

Both the regular arrival and departure flight paths are more than 2 km from Tai Lam Explosives Magazine Site. This distance is far beyond the maximum impact zone of fragments generated in the event of an explosion. Any incident at the Magazine site, therefore, will not have any impact on normal flights at Chep Lap Kok.

Impact on Missed Approach Flight Paths

Based on information provided by the Civil Aviation Department (CAD), planes that miss the approach to runway 07L will climb to 5000 ft on a heading that passes over the Tai Lam Explosives Magazine Site (*Figure 6.4*). The altitudes of planes are expected to be about 600m above the Tai Lam Explosives Magazine Site. This is regarded as a lower limit given the distance from the airport and climb gradients of 2.5% to 3.7% (152 – 225 ft/nm). Also, some planes would not be at runway level when they abort a landing but may begin the climb out earlier in the approach so would already have some altitude.

To estimate the risk of fragments affecting an aircraft, it is necessary to assess the magazine explosion frequency, the airplane presence factor and the probability of significant damage leading to a crash.

The explosion frequency is $1x10^{-4}$ per year for the Tai Lam Explosives Magazine Site. During the 12 month period from January 2014 to December 2014, based on information provided by the CAD, there were a total of 291 missed approaches recorded at the airport and about 61% of landings take place on runway 07L. This gives about 177 missed approaches per year for runway 07L that may pass over the Magazine site. The maximum fragment range for an explosion from a magazine is reported to be less than 600m (Moreton 2002). The effects diameter for affecting an aircraft is therefore taken to be 1.2km. This is a little conservative since it assumes the hazard range at >200m altitude will be the same as that as ground level. Assuming an aircraft flies at a speed of about 300km/h, the transit time for crossing this distance is 14 seconds. The presence factor for 270 missed approaches per year may therefore be calculated as 177 x 14 / (365 x 24 x 3600) = $7.9x10^{-5}$. Although the missed approach flight path is close to the Magazine site, there will be some variation in horizontal and vertical position of planes. It is assumed that 50% of aircraft will be out of range horizontally, and 50% will be out of range vertically. If a plane is within range, it is conservatively assumed that it will be struck by a fragment with probability of 1. This gives a probability of impact by fragments from an explosion at the magazine of $10^{-4} \times 7.9x10^{-5} \times 0.25 = 2.0\times10^{-9}$ per year.

In the event that an aircraft were hit by a fragment, the crash of the aircraft is not inevitable. The fragment would need to have sufficient energy to penetrate the skin of the aircraft and cause damage to critical components. The target area of these critical components such as engines, hydraulic lines, control surfaces etc. will likely constitute a small fraction of an aircraft's total projected cross-sectional area. Also, given the redundancy in aircraft equipment such as the presence of multiple engines, the probability that fragment damage would be severe enough to lead to a crash before the plane could return safely to the airport is considered to be small. A value of 10% is assumed. This gives a crash frequency for aircraft, caused by an explosion at a magazine, to be 2.0×10^{-10} per year.

The probability for Tai Lam Explosives Magazine will be even lower given its great distance from the airport. It is concluded that the risk of magazine explosions impacting on aircraft is negligible, i.e. $< 10^{-9}$ per year.

6.2 *TRANSPORT OF EXPLOSIVES*

A deflagration or detonation explosion is a possible accidental outcome which may occur during the transportation of explosives from the magazine to the worksites. The causes of potential accidental explosion during transportation have been identified in the WIL QRA study (ERM, 2008), which was based on the DNV study (DNV, 1997) and to a great extent on the ACDS study (ACDS, 1995) and its associated frequency assessment reported by Moreton (Moreton, 1993).

Accidental explosion can be caused by spontaneous fire (non-crash fire), fire after a vehicle crash (crash fire) and impact initiation in crash (crash impact) or spontaneous explosion during the normal condition of transport which may occur if the cargo load contains 'unsafe explosives'.

- Non-crash fire:
  This cause category includes any explosion instance where the explosive load has been subject to thermal stimulus which was not the result of a vehicle collision. Events in this category, not only include instances where the explosive load is directly engulfed in the fire but also events where thermal stimulus occurs by ways of heat conduction and convection;

- Crash fire:
  This cause category is similar to the non-crash fire category but only concerns fires resulting from a vehicle collision;

- Crash impact:
  This cause category includes all instances of vehicle collisions with a sufficient energy to significantly affect the stability of the explosive and which could have the potential to cause an accidental explosion; and

- Spontaneous explosion ('unsafe explosive'):
  The term 'unsafe explosive' originates from the ACDS study (ACDS, 1995). It includes explosions, during conditions of normal transport, resulting from breach of regulations caused by badly packaged, manufactured, and/or 'out-of-specification' explosives.

For crash and non-crash fires, explosive initiation requires a fire to start, the fire to spread to the explosives load and initiation to occur once the load is engulfed by the fire for a period of time.

Based on the Hazard Identification section of this report, explosive initiation due to impact is considered possible but unlikely. It would first require, as demonstrated by bullet impact tests (Holmberg), a significant mechanical (impact) energy which is unlikely to be encountered in a transport accident scenario. Even in the case of a significant mechanical (impact) energy, as demonstrated by the accident records and drop test data (ACDS, 1995), an explosion would be unlikely. Scenarios in this report include direct initiation events of the explosive load due to impact or secondary events resulting in explosives being spilt onto the road which could subsequently initiate due to indirect impact. For both scenarios, the initiating event requires, as mentioned above, a significant crash impact leading to the loss of integrity of the load compartment and/or a significant mechanical energy affecting the explosive load.

6.2.1 *Explosive Initiation Frequency During Transport as Used in Previous Hong Kong Studies*

The basic event frequencies derived in previous Hong Kong studies for road accidents were based on those derived in the ACDS study (ACDS, 1995) for assessing the risks related to the transport of explosives (commercial and non-commercial) in ports. The basic event frequencies were subsequently adjusted in the DNV study (DNV, 1997) to address the risk associated with the transport of commercial explosives by Mines Division Medium/Heavy Goods Vehicle (M/HGV) trucks. Subsequent studies undertaken in Hong Kong including the WIL study (ERM, 2008), Ocean Park Development study (Maunsell, 2006) and Penny's Bay Rail Link study (ERM, 2001) studies adopted the frequencies derived for the M/HGV Mines Division trucks based on the DNV study (DNV, 1997) and applied them to the transport of explosives in pick-up truck type Light Goods Vehicles (LGV) operated by contractors from the relevant magazine to the worksites.

Accounting for the safer nature of the explosives to be transported nowadays in Hong Kong and the existing regulations in place, the WIL study (ERM, 2008) proposed a refined approach for the assessment of the explosion frequency associated with the transport of 'unsafe explosives'. Although such events are considered extremely unlikely for the types of explosives used in Hong Kong, it has not been possible to completely rule out their occurrence. As such, the assumption that the assessed frequency of explosion will be doubled as used in the ACDS study (ACDS, 1995) has been dismissed for the particular types of explosives transported in Hong Kong and replaced, instead, by an overall frequency increase by 1% (i.e. a factor of 1.01 was applied to the overall frequency). The details of the approach are presented in the WIL study report (ERM 2008).

The frequency components for transport of explosives has been re-assessed in detail as part of the XRL study (ERM, 2009) given the current knowledge on the explosives' properties, vehicle incident frequencies provided by the Transport Department and Fire Services Department and specific design features applicable for the project such as:

- Light Goods Vehicle (LGV) pick-up type truck for explosive delivery;

- Recent Hong Kong Transport Department statistics;
- Hong Kong specific vehicle fire data;
- Specific Hong Kong explosive delivery truck design feature;
- Specific Hong Kong explosive delivery truck operation; and
- Revised knowledge of explosives properties.

The revised frequency parameters for transport of explosives are summarised in the following sections. The historical background for the derivation of each frequency component are presented in the XRL study (ERM, 2009) report.

Initiation Probability on Significant Impact

Based on the review with explosives experts, the energy required to detonate PETN or emulsion based explosives is one order of magnitude higher (based on bullet tests) than nitroglycerin (NG) based explosives. Since NG was considered as the basis for determining the probability of initiation under impact conditions in the ACDS study (ACDS, 1995) (assessed at 0.001), a reduction factor of 0.1 was applied based on impact energy consideration (ERP, 2009), giving the overall initiation on impact probability taken as 0.0001.

Probability of Explosive Response to Fire

The initiation of explosives in the DNV study (DNV, 1997) was assessed as 0.1 for any fire involvement. This value was based on the ACDS study (ACDS, 1995), which was derived from an expert judgement for heat insensitive explosive group which included a variety of explosives. In the XRL study (ERM, 2009), the proportion of detonating cord and cartridged emulsion differs from the previous projects. The sensitivity of the explosive load to fire and impact has therefore been reviewed. Based on the experts' knowledge (ERP, 2009) and experience on PETN and sensitised emulsion, the probability that the explosive melts and detonates once the fire impacts on the load is more likely than what was initially assumed in the ACDS study (ACDS, 1995) given the recent transport accident experience and the known properties of mixed explosives used. In the absence of further test data on transported explosives, a probability of 0.5 has been taken in the XRL study (ERM, 2009) to more appropriately represent the mix of explosive loads as applicable in the study. The same 0.5 is used in the current study.

Frequency of Non-crash Fire – Explosives Subject to Thermal Stimulus

Referring to the expert panel review (ERP, 2009) a thermal stimulus is sufficient to cause an explosion of the explosive load based on updated knowledge on explosive properties. The non-crash fire frequency (i.e. 1.30×10^{-9} /km) was then derived specifically for Hong Kong conditions based on goods vehicle data provided by the Transport Department in 2007 and Fire Services Department data on causes of fire call incidents in Hong Kong between 2004 and 2008. This update in the XRL study (ERM, 2009) reflects the most common causes of fires occurring on motor vehicles in Hong Kong, giving a lower fire incident rate compared to UK data (1.4 x 10^{-9}/km).

Vehicle Involvement Rate

In previous studies undertaken in Hong Kong including the WIL EIA (ERM, 2008), Ocean Park Develop (Maunsell, 2006) and DNV QRA (DNV, 1997) studies, they adopted the frequencies derived for the M/HGV to account for Hong Kong situation based on the relevant HK HGV to UK HGV reportable vehicle collision involvement. Since specific LGV pick-up type trucks will be used in the project, a review of the Hong Kong accident data and vehicle involvement rate for LGVs was carried out based on the data published by the Transport Department between 2003 and 2007.

Explosive Initiation Frequency for Different Types of Road

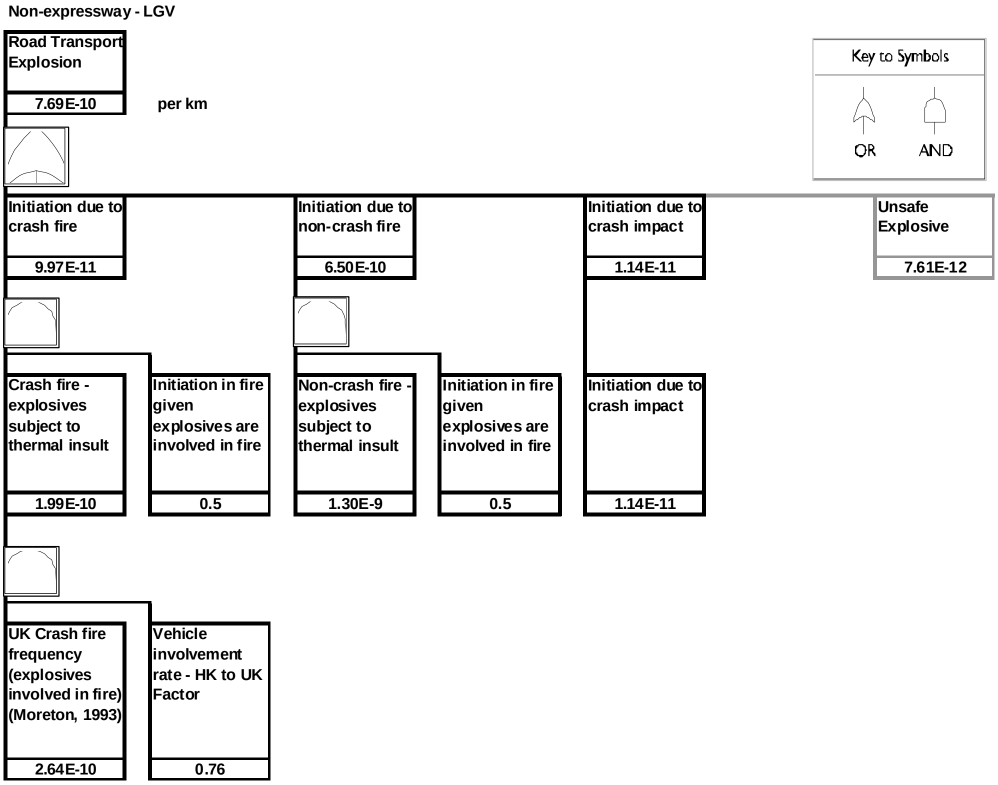
Since the vehicle impact speed and the accident involvement rate on highway/ major roads and non-highway are significantly different, different sets of explosive initiation frequencies for Expressway and Non-expressway have been derived during explosive transport to reflect the road conditions along the transport routes.

The components of the explosive initiation fault tree adopted in the XRL QRA (ERM, 2009) as well as their individual probabilities are shown in *Table 6.5* and the fault tree models for the road transport explosion are shown in *Figure 6.5* and *Figure 6.6*. The frequencies of explosives initiation during road transport were therefore estimated at 6.87 x10^{-10}/km on expressway and 7.69 x10^{-10}/km on other road sections considering an additional 1% increase for "unsafe explosives" (i.e. a factor of 1.01), as justified in the WIL QRA (ERM, 2008).

Table 6.5 Explosives Initiation Fault Tree Inputs from the XRL QRA (ERM, 2009)

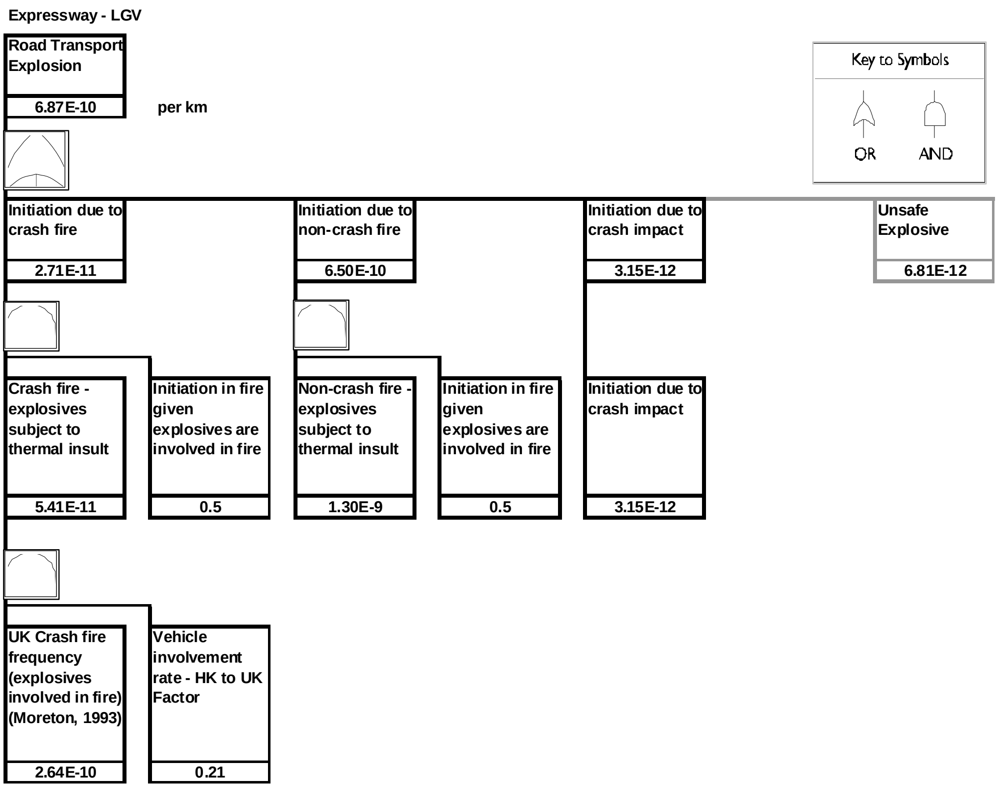
Event	Event type	Value
Vehicle crash (on expressway)	Frequency	1.27 x10^{-7} /km
Vehicle crash (on non-expressway)	Frequency	4.68 x10^{-7} /km
Crash fire (on expressway)	Frequency	5.41 x10^{-11} /km
Crash fire (on non-expressway)	Frequency	1.99 x10^{-10} /km
Non-crash fire	Frequency	1.30 x10^{-9} /km
Explosives initiation in fire	Probability	0.5
Explosives initiation in impact	Probability	0.0001

Figure 6.5 Explosives Initiation Fault Tree for Non-Expressway – Road Transport Events from the XRL QRA (ERM, 2009)



Note: Vehicle involvement rate – HK to UK factor was calculated by dividing the crash frequency of 4.7E-7 per year by the UK frequency of 6.2E-7 per year (see discussion of *Section 6.2.2* in the XRL QRA (ERM, 2009).

Figure 6.6 Explosives Initiation Fault Tree for Expressway – Road Transport Events after the XRL QRA (ERM, 2009)



Note: Vehicle involvement rate – HK to UK factor was calculated by dividing the crash frequency of 1.3E-7 per year by the UK frequency of 6.2E-7 per year (see discussion of *Section 6.2.2* in the XRL QRA (ERM, 2009).

6.2.2 *Transport Explosion Frequency for the Project*

The Hazard to Life Assessment study for Project has been performed based on the explosive initiation frequencies derived in the XRL study (ERM, 2009) for the transport of explosives and the specific explosive transport vehicle design and operation to be used as part of the Project. This approach is consistent with previous studies. The explosives initiation fault tree models for the road transport events for non-expressway and expressway are presented in *Figure 6.5* and *Figure 6.6* respectively. The expressway explosion rate of 6.87 x 10^{-10} per km has been applied to the Yuen Long Highway, San Tin Highway, and Fanling Highway sections while the non-expressway explosion rate of 7.69 x 10^{-10} per km has been applied to other road sections.

7 CONSEQUENCE ASSESSMENT

7.1 GENERAL

Explosives present a hazard to both property and people. This hazard manifests itself in the following ways:

- blast and pressure wave;
- flying fragments or missiles;
- thermal radiation; and
- ground shock.

In the case of bulk explosions, the most damage is usually caused by the blast effects. However, for small detonations, fragmentation is the most significant effect and thermal radiation is only of interest in low speed deflagrations.

Three modes of injury can result to people when exposed to blast effects:

- Primary;
- Secondary; and
- Tertiary effects.

Primary effects involve the direct effects of the blast upon sensitive human organs such as the ears and lungs. Compared with secondary and tertiary effects, considerable overpressures are required for fatalities to occur, and consequently people need to be fairly close to the scene of the explosion for primary effects to be significant.

Secondary effects are associated with building collapse or the impact of debris and fragments from damaged building structures and the vehicle or container in which the explosives are held. Predicting injury and fatality levels due to fragments/debris from high explosives is particularly difficult.

Tertiary blast injuries may occur with whole body impacts, when people are displaced or swept away, or due to the violent movement of internal organs within the body. For people outdoors, tertiary effects are dominant.

Thus, for the cartridged emulsion to be transported and stored for this project, the blast effects will be of most concern. Also of interest are the detonators used to initiate these explosives. However, provided these are kept within their original packaging they will only explode 'one-at-a time', and will not present a mass explosion hazard. Packaged in this way, the detonators may be classified as UN Class 1.4 S.

7.2 PHYSICAL EFFECT MODELLING

7.2.1 *Blast and Pressure Wave for Explosion*

The consequence models used for the assessment of the probability of fatality due to blast and pressure waves, are based on the most recent UK Explosive Storage and Transport Committee (ESTC) model defined in the HSC publication (ESTC, 2000). This model has been previously used in the SCL study (ERM, 2011) and XRL study (ERM, 2009) and considers all the effects associated with an above ground explosion including fireball, overpressure, flying debris, broken glass, structural damage etc.

People Indoors

The ESTC indoor model is based on the analysis of casualty data collated from records of a number of major incidents involving accidental explosion. The data on which the model is constructed does not distinguish between those killed by the blast and those killed by fragments. It is assumed that blast effects were the cause of most of the fatalities recorded in these incidents but the model implicitly makes some allowance for fragment effects. The probability of fatality for persons located inside conventional buildings for various quantities of explosives can be estimated by:

$$\log_{10} P = 1.827 - 3.433\log_{10} S - 0.853(\log_{10} S)^2 + 0.356(\log_{10} S)^3 \qquad \text{for } 3 < S < 55$$

Where $S = R / Q^{1/3}$

P is the probability of death, R is the range in metres, and Q is the explosive charge mass in kg (TNT equivalent mass).

In this study, the indoor consequence model has been assumed to be also applicable to the population present in vehicles.

People Outdoors

The outdoor model is based on a review of the available literature on primary and tertiary blast effects:

$$P = \frac{e^{(-5.785S + 19.047)}}{100} \qquad \text{for } 2.5 < S < 5.3$$

The distance to 1%, 3%, 10%, 50% and 90% fatality contours were used in the modelling.

7.2.2 *Flying fragments or missiles*

Fatality due to flying fragments or missiles due to explosion is considered in the ESTC model; therefore, no separate model for debris is considered.

7.2.3 *Thermal Radiation*

The initiation of an explosion will result in thermal radiation from a fireball as the explosives initiate. There are relatively few published models in the literature for high explosive fireballs, or those that may result from a cartridged emulsion detonation. Models that are available describe the fireball duration and diameter based on TNT or similar explosives e.g. nitroglycerine, PETN, etc. Radiation effects are generally considered to be a concern for explosives classified as HD 1.3. For the purpose of this study, it is assumed that the fireball correlations are applicable to cartridged emulsion containing ammonium nitrate, fuel oil and aluminium powder.

The diameter and duration of a fireball from a high explosive are given in Lees (1996):

$$D = 3.5\, M^{0.333}$$

$$t_d = 0.3\, M^{0.333}$$

where D is the fireball diameter (m)
M is the mass of the explosive (kg), TNT equivalent
t_d is the duration of the fireball (seconds).

For the largest explosive mass of 467 kg (initiation of an entire store contents), a fireball radius of 13.5 m is predicted with a duration of 2.3 seconds.

The surface emissive power (E_f) can then be calculated from the equation:

$$E_f = \frac{f_s M \Delta H_r}{4\pi r_{fireball}^2 t_d}$$

Where ΔH_r is the heat released from the explosive (kJ/kg), which is approximately 4.01 MJ/kg for cartridged emulsion. M is the mass of explosive (kg) and f_s is the fraction of the heat that is radiated, a conservative value of 0.4 is taken. This gives a surface emissive power of the fireball of 141 kW/m^2.

The heat flux received by a receptor at some distance from the fireball is estimated from:

$$q'' = E_f . F_{view} \tau_a$$

Where E_f is the surface emissive power of the fireball, which is either estimated using the previous equation or is an assumed maximum value. F_{view} is the view factor, and τ_a is the atmospheric transmissivity.

For a vertical surface the view factor can be calculated from:

$$F_{view} = \frac{X (r_{fb})^2}{\left(X^2 + r_{fb}^2\right)^{3/2}}$$

Where X is the distance measured along the ground from the object to a point directly below the centre of the fireball. This distance must be greater than the radius of the fireball, because actual development of the fireball often involves an initial hemispherical shape, which would engulf nearby receptors. Additionally, as the fireball lifts off the ground, the distance to near field receptors changes significantly. This means that the radiation estimates in the near field are of questionable accuracy.

At very large distances, the above equation for the view factor reduces to:

$$F_{view} = \left(\frac{r}{X}\right)^2$$

The atmospheric transmissivity, τ_a, reflects the proportion of radiation that is adsorbed by the water vapour and the carbon dioxide present in the atmosphere. A correlation for the estimation of transmissivity was published by F.D. Wayne (1991):

$$\tau_a = 1.006 - 0.01171\log_{10}\left(X_{H_2O}\right) - 0.02368\left[\log_{10}\left(X_{H_2O}\right)\right]^2 - 0.03188\log_{10}\left(X_{CO_2}\right) + 0.001164\left[\log_{10}\left(X_{CO_2}\right)\right]^2$$

where

$$X_{H_2O} = \frac{2.165 P_w^o RHd}{T}$$

$$X_{CO_2} = \frac{273d}{T}$$

RH is the relative humidity and is assumed to be 85% for Hong Kong. P_w^o is the vapour pressure of water at atmospheric temperature T, and d is the distance to the fireball surface, or path length.

The probit equation for fatalities due to thermal radiation is proposed by Eisenberg (Lees, 1996):

$$\Pr = -14.9 + 2.56 \ln L$$

Where L is the thermal dose or load defined as $L = t\, I^{4/3}$, I is the thermal radiation flux (kW/m^2), t is the exposure duration and Pr is the probit that is related to probability of fatality.

The thermal dose units corresponding to 1%, 50%, and 90% fatality levels are 956, 2377, and 3920 s.(kW/m^2)$^{4/3}$ respectively. These broadly match with the 1000, 1800 and 3200 TDU levels reported by the UK HSE Safety Report Assessment Guides (HSE HFLs) for the same fatality levels. Applying the HSE thermal dose criteria limits for a fireball of duration 2.3 s, indicates that the incident radiation fluxes to cause these fatality levels are estimated as 95, 148, and 228 kW/m^2.

Comparing these with the fireball surface emissive power of 140 kW/m^2, shows that these levels of thermal flux will only be realised when in very close proximity to the fireball. Therefore, it can be concluded that a fireball from the initiation of cartridged emulsion within the storage magazine will not pose an off-site hazard. It is generally the case that the thermal hazards from an explosives detonation event are of less concern than the blast and fragment hazards. Therefore, the hazards from a fireball are not considered further in this assessment.

7.2.4 *Ground Shock*

The detonation of solid phase materials liberates energy by a rapid chemical reaction process, which produces and sustains a shock wave in the material. The high temperatures and pressure associated with the shock wave causes almost instantaneous reaction in the material. This reaction produces high pressures and temperatures in the expanding gas. In the case of rock excavation, it is this pressure that crushes surrounding rock when the explosive material is placed in a drill hole for blasting.

In areas where the explosive material is less confined, the pressure will be reduced due to the increased volume into which the gases can expand. If the degree of confinement is reduced, eventually the pressure will cease to crush the rock, but instead will cause rock fractures or cracking. If the level of confinement is reduced further, the pressure will cease to fracture the rock and the energy will propagate through the rock as an elastic wave causing the rock particles to vibrate. The degree of vibration of the rock particles decreases with increasing distance from the blast. However, the vibration of the rock particles can cause damage and structural failure to buildings if sufficiently strong (USBM 656).

Considering the fact that in this project explosive transport and storage will be carried out aboveground with much less confinement than that of rock excavation, this aspect of consequence should not be of much concern compared to the hazards posed by the overpressure wave and debris generated (modelled by the ESTC model). A comparison of 1% fatality impact distance calculated by ground vibration model and ESTC model are provided in *Table 7.1* and the results show the effect of ground vibration are less significant than that of air shockwave and debris.

Table 7.1 ***Blast Effect Distances for 1% Fatality Probability from Detonation of 467 kg TNT Equivalence of Explosive***

Consequence	**Receiver's Location**	**Effect Radius (m)**
Shockwave and debris - ESTC model	Indoor	70.8
	Outdoor	25.0
Ground shock – Object falling threshold (PPV = 100 mm/s)	Indoor / outdoor close by a structure	23.0

In addition, excessive ground vibration may lead to slope failure and create a secondary hazards. Based on the effect thresholds defined in the previous assessment, the weakest slope with factor of safety (FOS) of 1.1 can be damaged in 0.01% chance with a peak particle velocity (PPV) of 90 mm/s.

The effect radius of 90mm/s was calculated as 25.1 m for detonation of 467 kg TNT equivalence of explosives, which correspond to the maximum quantity of explosive (TNT equivalent) to be stored in each magazine store. From *Table 4.9,* all the slopes are too far away to be affected or too far away to affect any population or roads. Therefore, the hazards from a ground shock are not considered further in this assessment.

7.3 RESULTS OF CONSEQUENCE ASSESSMENT

The consequence results for each transport and storage scenario are summarised in *Table 7.2* and *Table 7.3.* Consequence distances for the storage scenarios (no. 1 -2) may be compared to the separation distances specified in the magazine designs, as follows: public footpaths must be at least 54 m away (vehicle routes must be further); buildings must be at least 183m away. Thus, the design separation distances substantially exceed the 1% fatality distance and hence no significant risk of fatality due to explosive storage is expected.

Table 7.2 ***Summary of Results for Base Case Consequence Scenarios***

No.	Scenario	TNT eqv. kg	Fatality Prob.	*Indoor*	*Outdoor*
				Impact Distance (m)	Impact Distance (m)
Storage of Explosives					
01	Detonation of full load of explosives in one store in Tai Lam Explosives Magazine site	467	90%	23.9	19.1
			50%	27.6	19.9
			10%	40.9	22.0
			3%	54.7	23.6
			1%	70.8	25.0
02	Detonation of full load of explosives in one contractor truck on the access road within the Tai Lam Explosives Magazine site boundary	206	90%	18.2	14.6
			50%	21.1	15.2
			10%	31.2	16.8
			3%	41.6	18.0
			1%	53.6	19.1
Transport of Explosives					
03	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam Explosives Magazine site to Mid-Ventilation Adit delivery point	206	90%	18.2	14.6
			50%	21.1	15.2
			10%	31.2	16.8
			3%	41.6	18.0
			1%	53.6	19.1
04	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam Explosives Magazine site to North Portal delivery point	206	90%	18.2	14.6
			50%	21.1	15.2
			10%	31.2	16.8
			3%	41.6	18.0
			1%	53.6	19.1
05	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam site to South Portal delivery point	206	90%	18.2	14.6
			50%	21.1	15.2
			10%	31.2	16.8
			3%	41.6	18.0
			1%	53.6	19.1

Table 7.3 Summary of Results for Worst Case Consequence Scenarios

No.	Scenario	TNT eqv. kg)	Fatality Prob.	*Indoor* Impact Distance (m)	*Outdoor* Impact Distance (m)
Storage of Explosives					
01	Detonation of full load of explosives in one store in Tai Lam Explosives Magazine site	467	90%	23.9	19.1
			50%	27.6	19.9
			10%	40.9	22.0
			3%	54.7	23.6
			1%	70.8	25.0
02	Detonation of full load of explosives in one contractor truck on the access road within the Tai Lam Explosives Magazine site boundary	206	90%	18.2	14.6
			50%	21.1	15.2
			10%	31.2	16.8
			3%	41.6	18.0
			1%	53.6	19.1
Transport of Explosives					
03	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam Explosives Magazine site to Mid-Ventilation Adit delivery point	206	90%	18.2	14.6
			50%	21.1	15.2
			10%	31.2	16.8
			3%	41.6	18.0
			1%	53.6	19.1
04	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam Explosives Magazine site to North Portal delivery point	206	90%	18.2	14.6
			50%	21.1	15.2
			10%	31.2	16.8
			3%	41.6	18.0
			1%	53.6	19.1
05	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam site to South Portal delivery point	206	90%	18.2	14.6
			50%	21.1	15.2
			10%	31.2	16.8
			3%	41.6	18.0
			1%	53.6	19.1

7.4 SECONDARY HAZARDS

7.4.1 *Property Damage*

As mentioned previously the Hong Kong Model Engineering Club periodically flies model aircrafts at a site about 300 m from the Magazine. The distance of the entrance of the club to the magazine is about 200 m, which is outside the 183 m specified in the requirements. The 200 m also substantially exceeds the 1% fatality distance.

7.4.2 *Impacts on Slopes and Boulders*

Along the transport route, there are some slopes close to the road, in particular along some sections of Fan Kam Road. There is a possibility that an explosion on a road vehicle may trigger a landslide or a boulder fall. This is regarded as a secondary hazard. The impact of this hazard in terms of potential consequences was evaluated using the approach adopted in the XRL study (ERM, 2009). It was found that any landslide and boulder fall event will impact the same area along the road that is already affected by the primary explosion consequences. Hence, no significant additional fatality will occur.

7.4.3 *Potential Impact to Sensitive Facilities along the Explosives Delivery Routes*

Two sensitive facilities, WSD Au Tau Water Treatment Works (ATWTW) and Tai Po Tau Water Treatment Works (TPTWTW), which are Potentially Hazardous Installations (PHIs), are located more than 450 m and 650 m respectively away from the nearest transport routes (Route Option R1). This is well outside the 100 m impact zone of the explosives truck and hence not considered further.

8 *RISK SUMMATION*

8.1 *OVERVIEW*

The Consultants' in-house software has been used for risk calculation and summation. This integrates the risks associated with the Magazine site with those from the transport of explosives to the worksites, including the risks to other road users, nearby buildings and outdoor population.

The base case considered a realistic construction scenario. The individual risk and societal risk results are shown below.

A Worst Case was also considered to address potential changes in the construction programme due to construction uncertainties. The societal risk results for this worst case scenario are also shown for comparison purposes.

8.2 *RISK MEASURES*

The two types of risk measures considered are societal and individual risks.

8.2.1 *Societal Risk*

Societal risk is defined as the risk to a group of people due to all hazards arising from a hazardous installation or activity. The simplest measure of societal risk is the Rate of Death or Potential Loss of Life (PLL), which represents the predicted equivalent fatalities per year:

$$\text{PLL} = f_1N_1 + f_2N_2 + f_3N_3 + \ldots + f_nN_n$$

where f_i is the frequency and N_i the number of fatalities for each hazardous outcome event.

Societal risk can also be expressed in the form of an F-N curve, which represents the cumulative frequency (F) of all event outcomes leading to N or more fatalities. This representation of societal risk highlights the potential for accidents involving large numbers of fatalities.

8.2.2 *Individual Risk*

Individual risk may be defined as the frequency of fatality per individual per year due to the realisation of specified hazards. Individual Risk may be derived for a hypothetical individual present at a location 100% of the time or a named individual considering the probability of his presence etc. (the latter case being known as Personal Individual Risk).

8.3 SOCIETAL RISK

8.3.1 *Potential Loss of Life*

Table 8.1 and *Table 8.6* below show the PLL values for the storage of explosives at the Magazine site and the transport of explosives to the blasting sites. As expected, the Worst Case (PLL = 8.10×10^{-4}/year, 1.56×10^{-3}/year, 9.40×10^{-4}/year) imposes a higher risk than the Base Case (PLL = 6.75×10^{-4}/year, 1.30×10^{-3}/year, 7.83×10^{-4}/year).

The proposed magazine storage site (Tai Lam Explosives Magazine Site) has negligible contribution (i.e. in a magnitude of 1×10^{-9}) to the overall risks since it is located in a remote area with no permanent population nearby.

The variation in contributions to the overall risk due to the different routes can be explained by

- the different route lengths;
- the differences in road traffic and pavement population density;
- the differences in nearby building population density and proximity;
- the differences in explosive loads to the different worksites; and
- the number of trips according to the blasting programme.

Therefore, in the case of minor modifications to the delivery routes, as long as the routes maintain similar characteristics in terms of length and its surroundings (e.g. population density, proximity, etc.), the overall risk will not be significantly impacted.

Table 8.1 *PLL for Base Case Route Option R1*

Case: Base Case	PLL (per year)	Contribution (%)
Storage of Explosives		
Tai Lam Explosives Magazine Site	9.03E-09	0.001%
Transport of Explosives		
Tai Lam Explosives Magazine Site to Mid-Ventilation Adit	1.68E-04	24.90%
Tai Lam Explosives Magazine Site to North Portal	2.13E-04	31.55%
Tai Lam Explosives Magazine Site to South Portal	2.94E-04	43.55%
Total	**6.75E-04**	**100.00%**

Table 8.2 *PLL for Base Case Route Option R2*

Case: Base Case	PLL (per year)	Contribution (%)
Storage of Explosives		
Tai Lam Explosives Magazine Site	9.03E-09	0.001%
Transport of Explosives		
Tai Lam Explosives Magazine Site to Mid-Ventilation Adit	2.83E-04	21.83%
Tai Lam Explosives Magazine Site to North Portal	3.58E-04	27.61%
Tai Lam Explosives Magazine Site to South Portal	6.56E-04	50.55%
Total	**1.30E-03**	**100.00%**

Table 8.3 *PLL for Base Case Route Option R3*

Case: Base Case	PLL (per year)	Contribution (%)
Storage of Explosives		
Tai Lam Explosives Magazine Site	9.03E-09	0.001%
Transport of Explosives		
Tai Lam Explosives Magazine Site to Mid-Ventilation Adit	1.73E-04	22.04%
Tai Lam Explosives Magazine Site to North Portal	2.18E-04	27.84%
Tai Lam Explosives Magazine Site to South Portal	3.93E-04	50.12%
Total	**7.83E-04**	**100.00%**

Table 8.4 *PLL for Worst Case Route Option R1*

Case: Worst Case	PLL (per year)	Contribution (%)
Storage of Explosives		
Tai Lam Explosives Magazine Site	9.03E-09	0.001%
Transport of Explosives		
Tai Lam Explosives Magazine Site to Mid-Ventilation Adit	2.02E-04	24.90%
Tai Lam Explosives Magazine Site to North Portal	2.56E-04	31.55%
Tai Lam Explosives Magazine Site to South Portal	3.53E-04	43.55%
Total	**8.10E-04**	**100.00%**

Table 8.5 *PLL for Worst Case Route Option R2*

Case: Worst Case	PLL (per year)	Contribution (%)
Storage of Explosives		
Tai Lam Explosives Magazine Site	9.03E-09	0.001%
Transport of Explosives		
Tai Lam Explosives Magazine Site to Mid-Ventilation Adit	3.40E-04	21.83%
Tai Lam Explosives Magazine Site to North Portal	4.30E-04	27.61%
Tai Lam Explosives Magazine Site to South Portal	7.87E-04	50.55%
Total	**1.56E-03**	**100.00%**

Table 8.6 *PLL for Worst Case Route Option R3*

Case: Worst Case	PLL (per year)	Contribution (%)
Storage of Explosives		
Tai Lam Explosives Magazine Site	9.03E-09	0.001%
Transport of Explosives		
Tai Lam Explosives Magazine Site to Mid-Ventilation Adit	2.07E-04	22.04%
Tai Lam Explosives Magazine Site to North Portal	2.62E-04	27.84%
Tai Lam Explosives Magazine Site to South Portal	4.71E-04	50.12%
Total	**9.40E-04**	**100.00%**

8.3.2 *F-N Curves*

Figure 8.1, *Figure 8.2* and *Figure 8.3* show the overall F-N curves for explosives storage and transport combined. These include the Tai Lam Explosives Magazine Site and the associated transport routes to the 3 worksites.

The Base Case represents the risks associated with the expected blasting programme, whereas the Worst Case has considered a 20% increase in the number of deliveries for the three worksites. It can be seen that for both cases the risks lie in the ALARP region.

Figure 8.1 ***F-N Curve for Storage and Transport of Explosives (Route Option R1)***

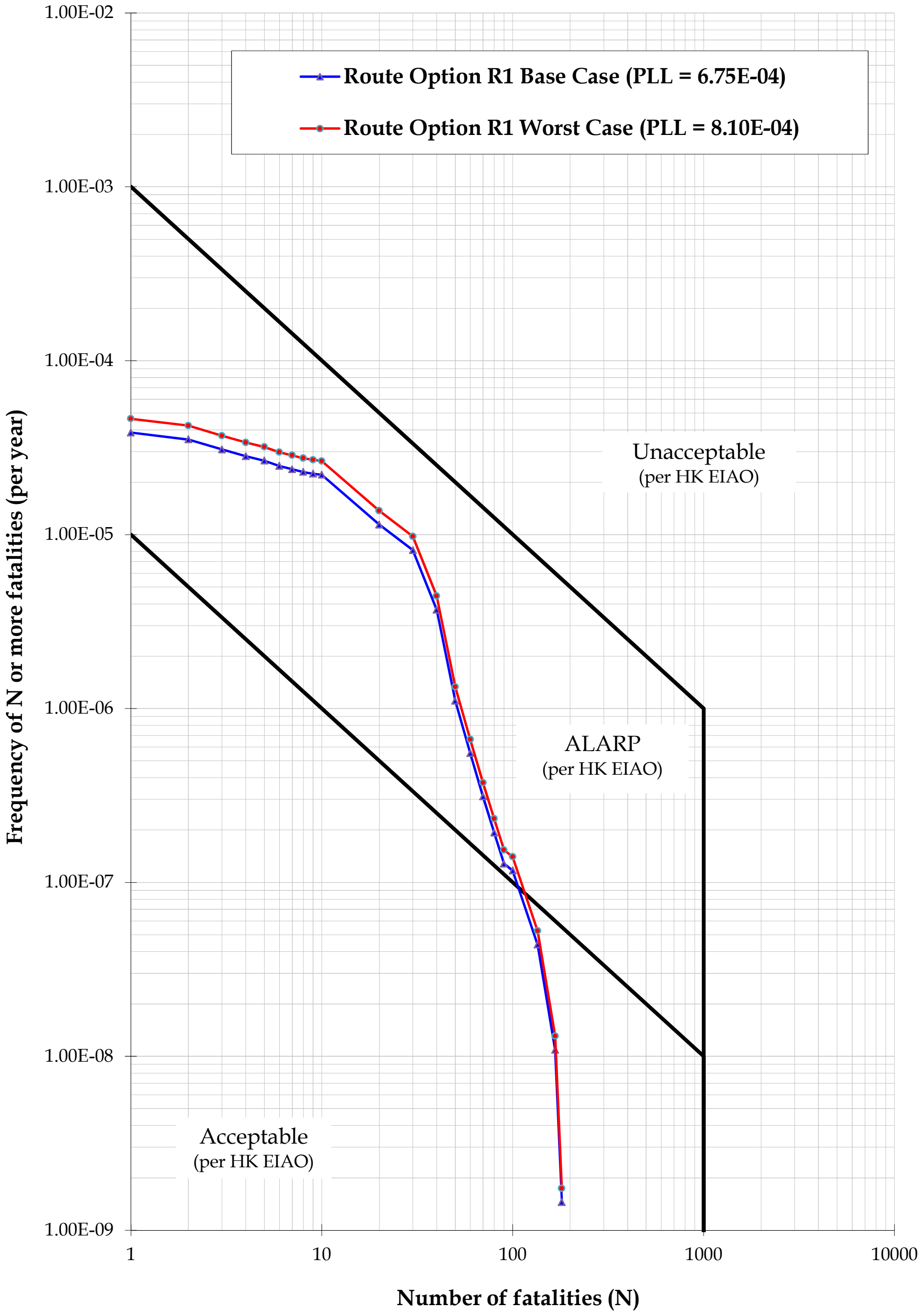


Figure 8.2 F-N Curve for Storage and Transport of Explosives (Route Option R2)

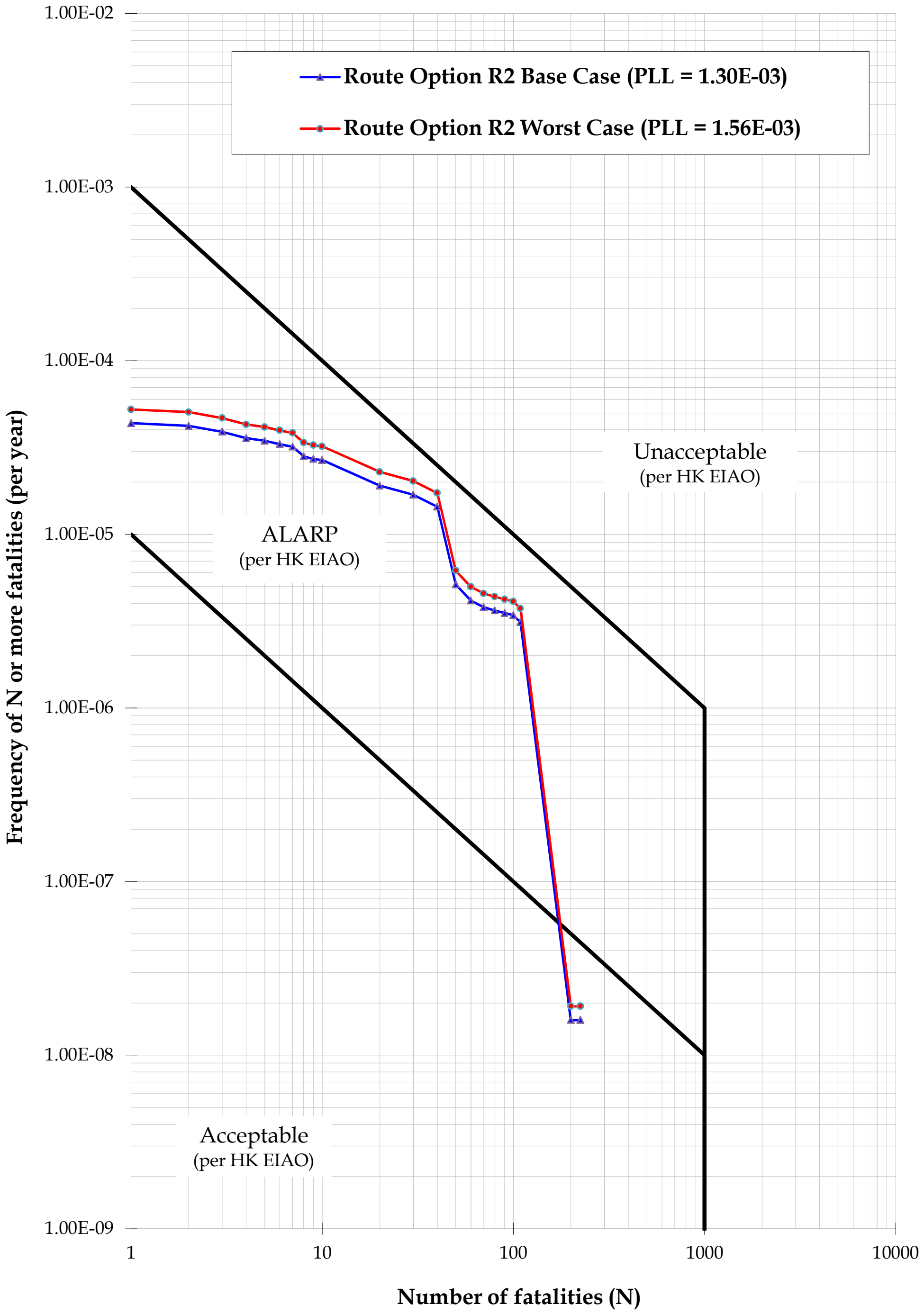


Figure 8.3 F-N Curve for Storage and Transport of Explosives (Route Option R3)

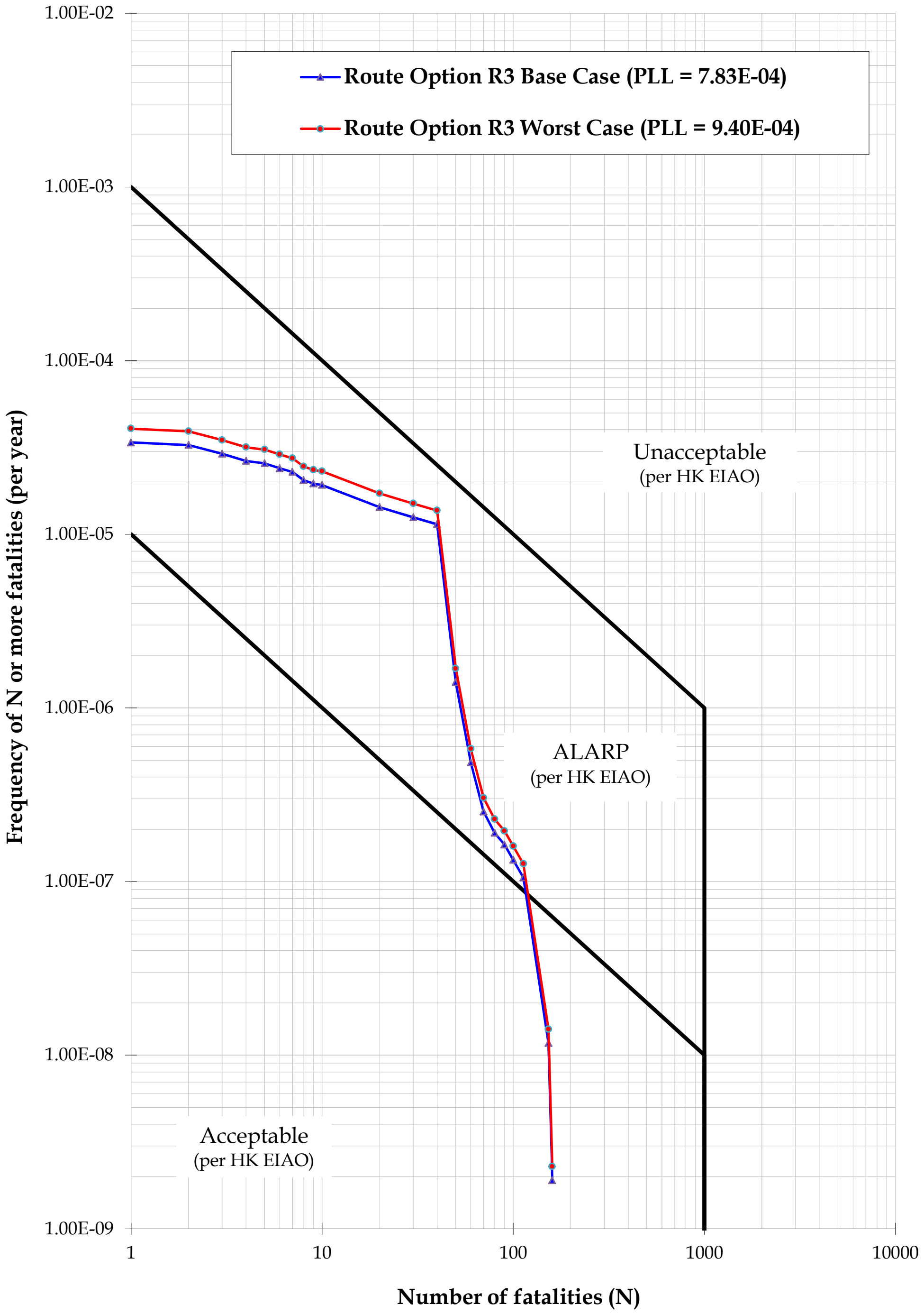


Figure 8.4, Figure 8.5 and *Figure 8.6* show the F-N curves for the Base Case with a breakdown by storage and transport. It can be seen that risks from the Magazine are negligible compared to transport risks. This is consistent with the comments made in relation to the PLL. Population in the vicinity of the Magazine site is very low and hence the societal risks are small.

Figure 8.7, Figure 8.8 and *Figure 8.9* provide a breakdown by population types for the Base Case scenario. As expected, the highest risks are associated with other road users and this dominates the overall F-N curve, high percentages of the PLL is related to population in vehicles. Scenarios involving high numbers of fatalities are also related to fatalities in buildings close to the road. This is particularly noticeable towards the end of the delivery route to Mid-Ventilation Adit and North Portal that passes through non-expressway roads close to residential and commercial buildings with high population densities.

The F-N curves show risks in the ALARP region and therefore mitigation measures need to be considered to reduce the risks. This is assessed in *Section 9*.

It is important to note that conservative measures have been taken into account when calculating the total risk:

- The 200 kg load assumed for each delivery trip in the calculation represents the maximum load – in reality the load is significantly less; and
- The number of delivery trips used in the calculations represents the maximum amount of delivery trips.

Figure 8.4 F-N Curve for the Base Case with Breakdown by Storage and Transport (Route Option R1)

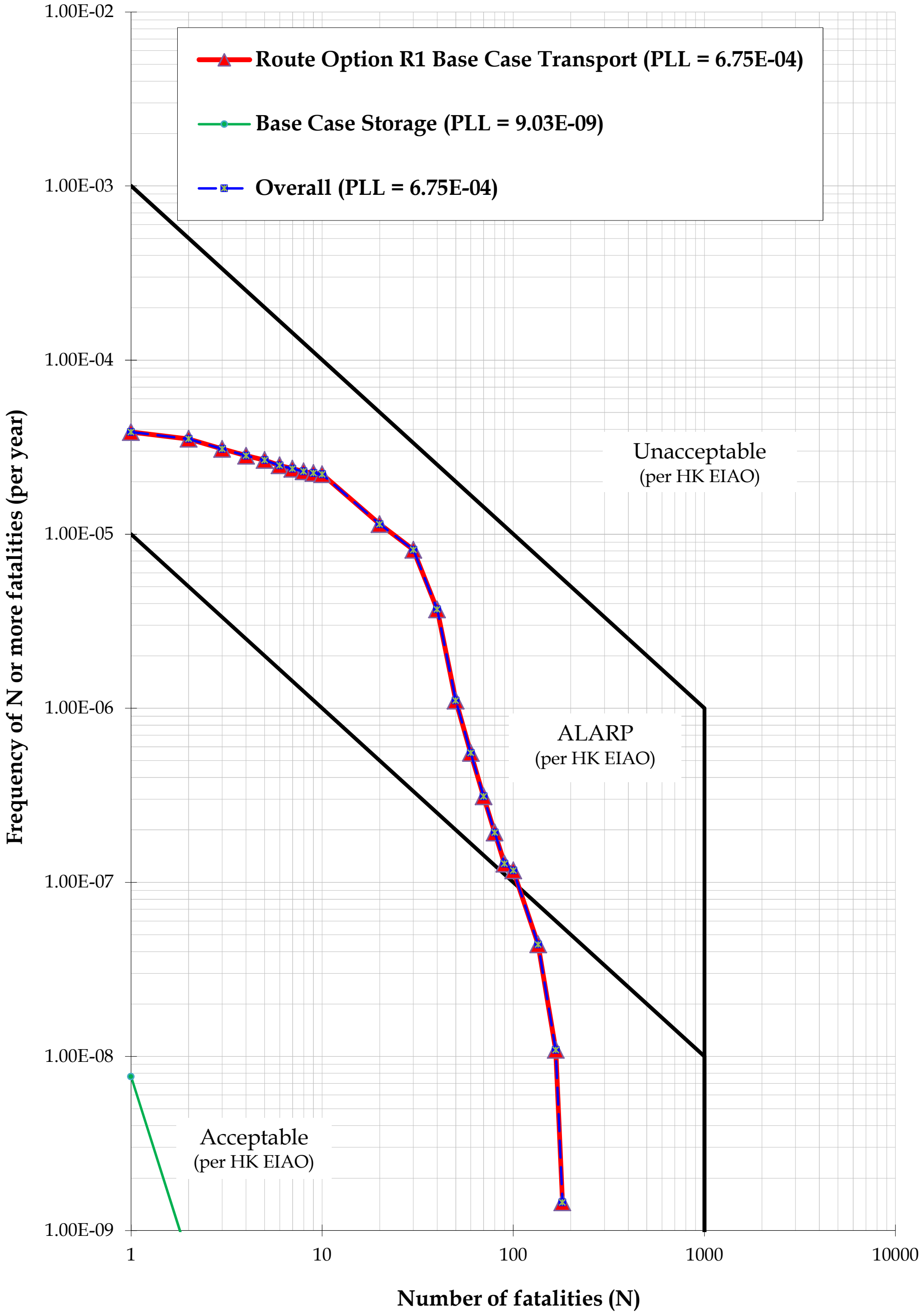


Figure 8.5 F-N Curve for the Base Case with Breakdown by Storage and Transport (Route Option R2)

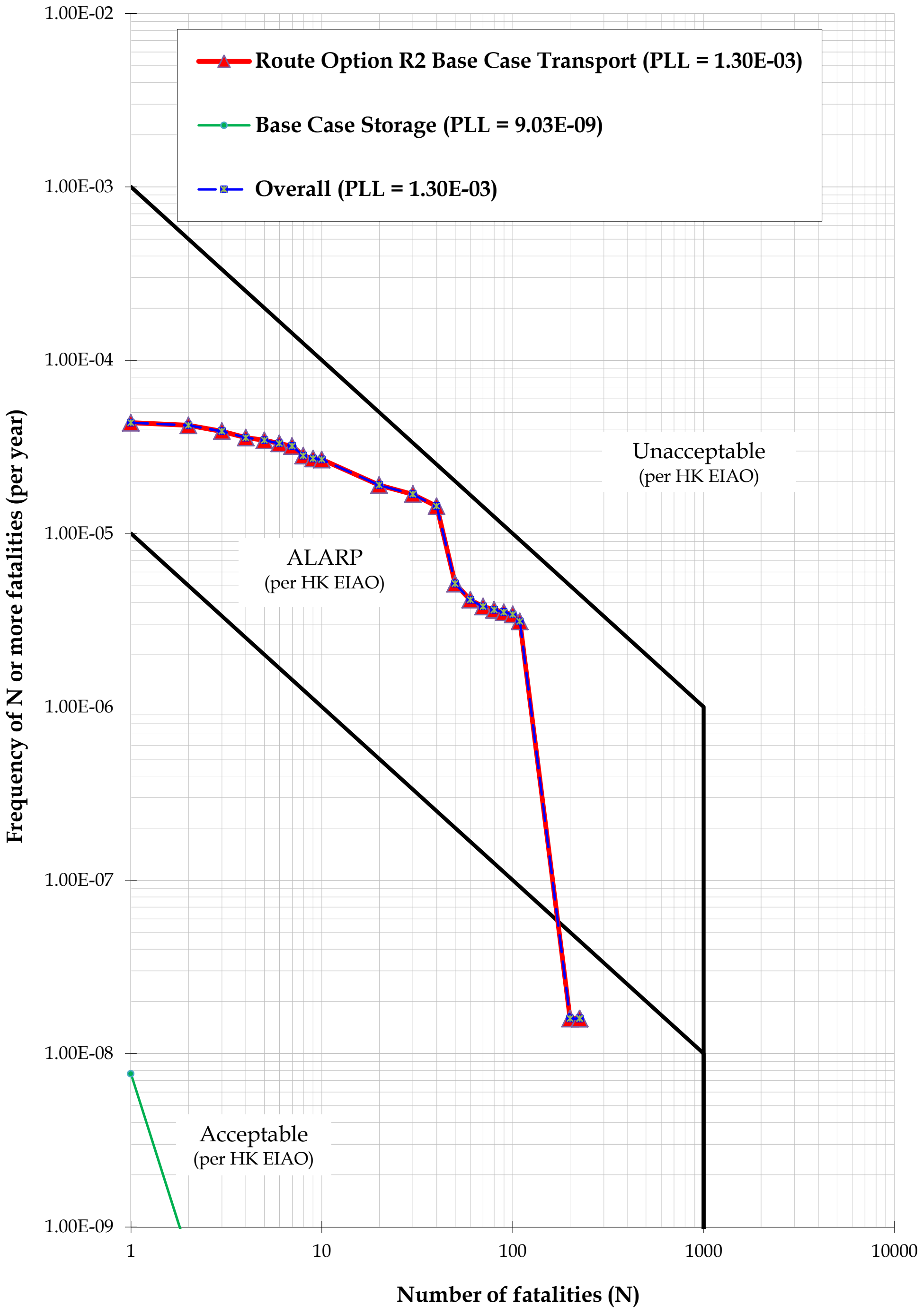


Figure 8.6 F-N Curve for the Base Case with Breakdown by Storage and Transport (Route Option R3)

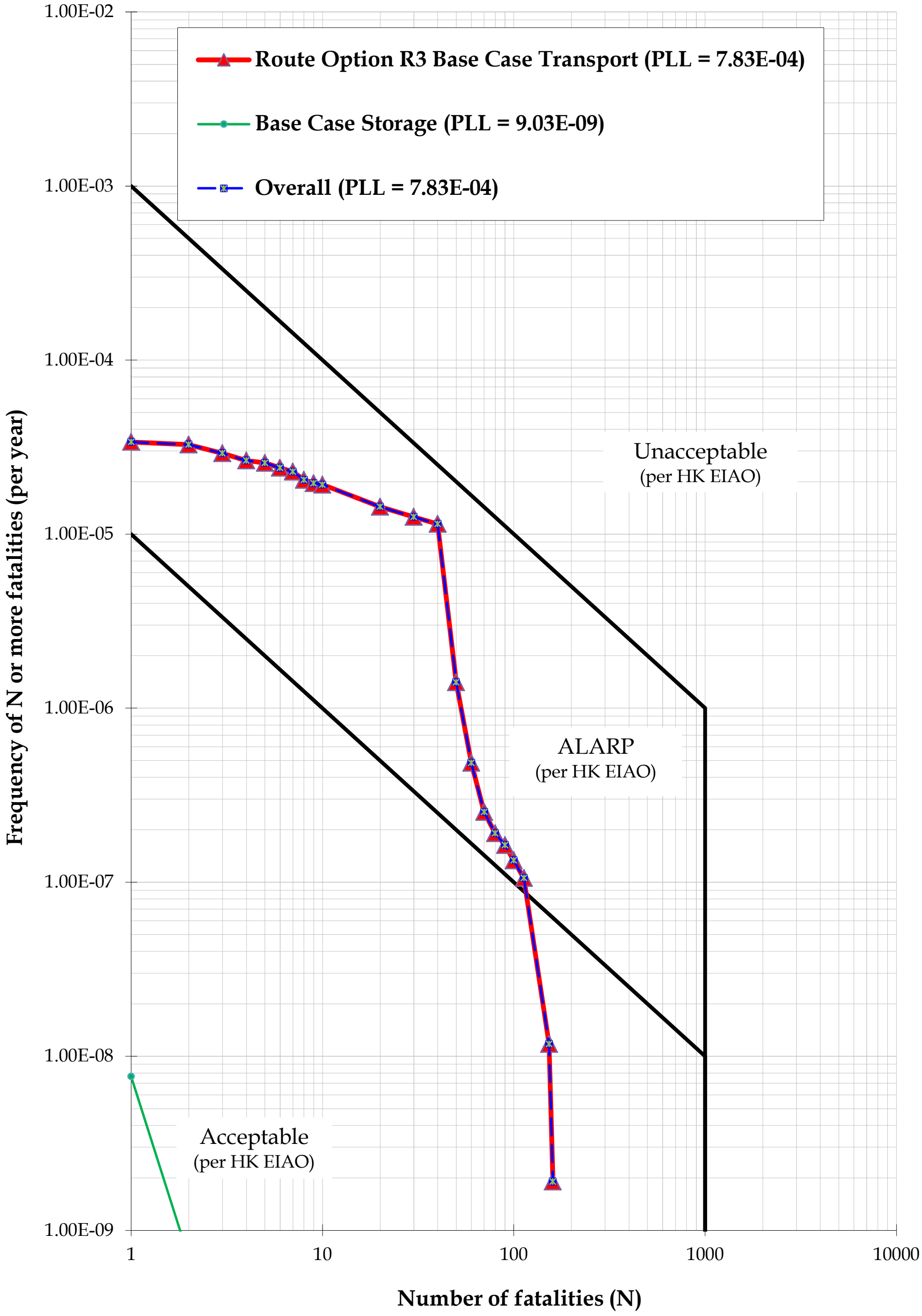
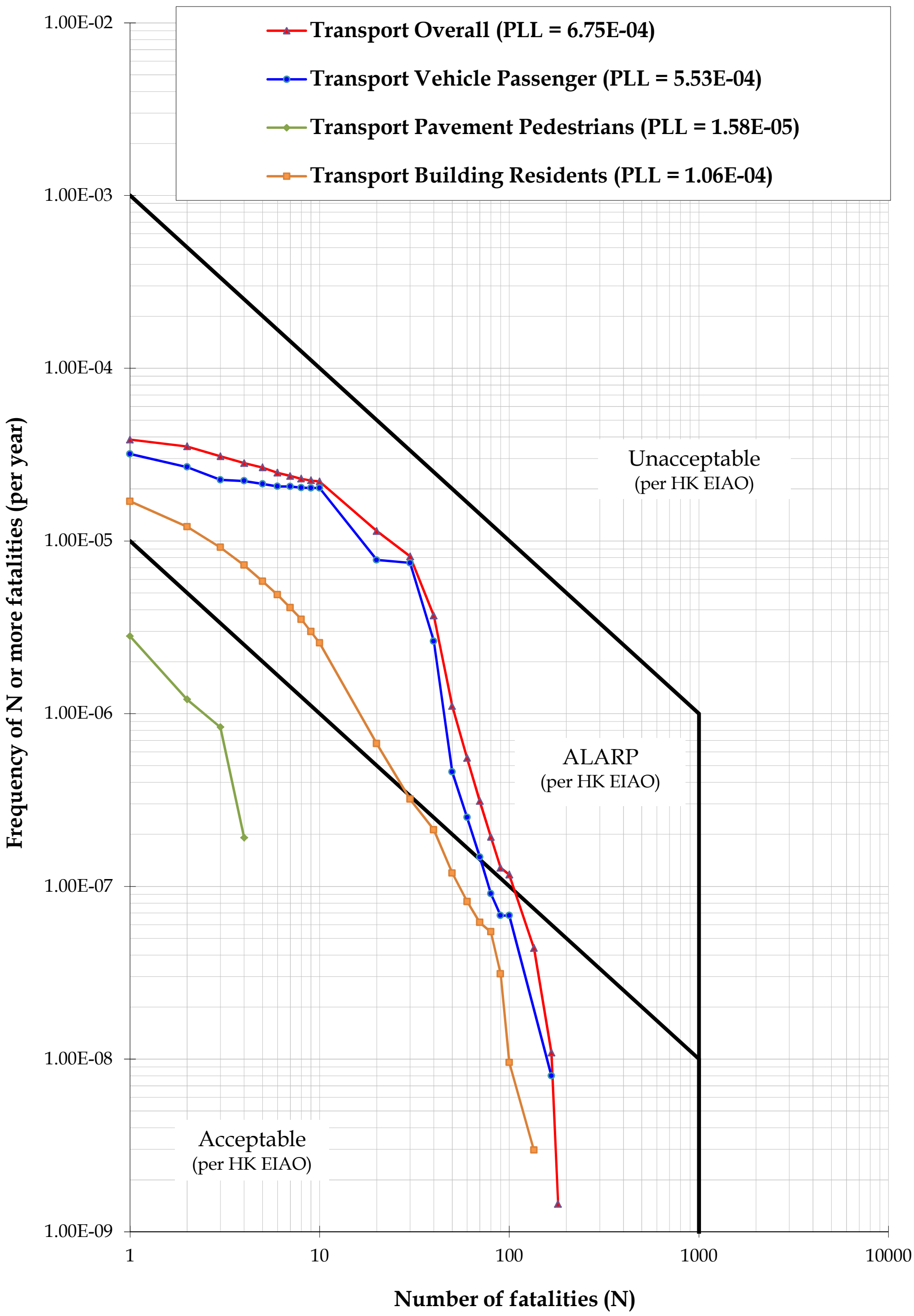
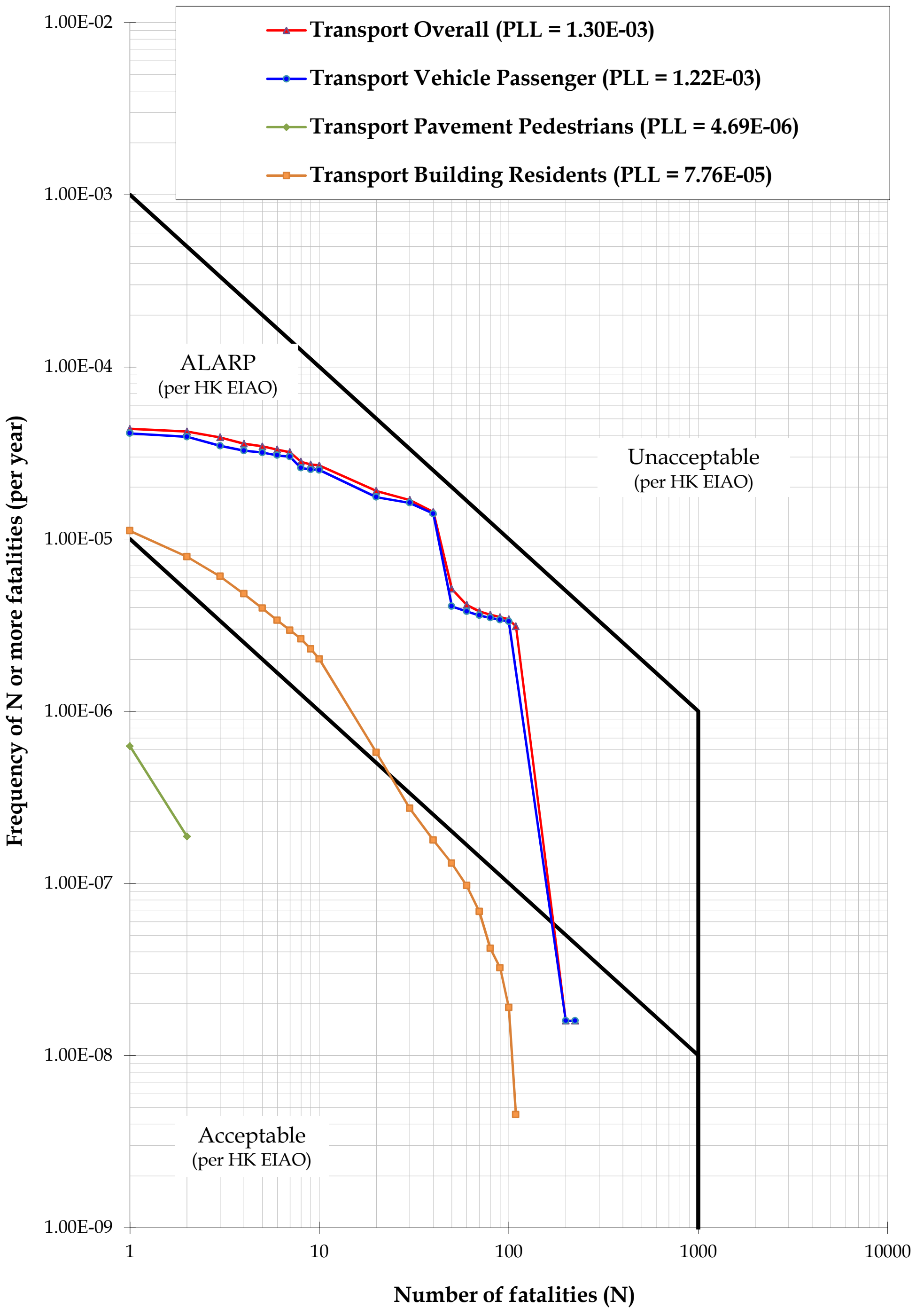


Figure 8.7 F-N Curve for the Base Case with Breakdown by Population Type (Route Option R1)



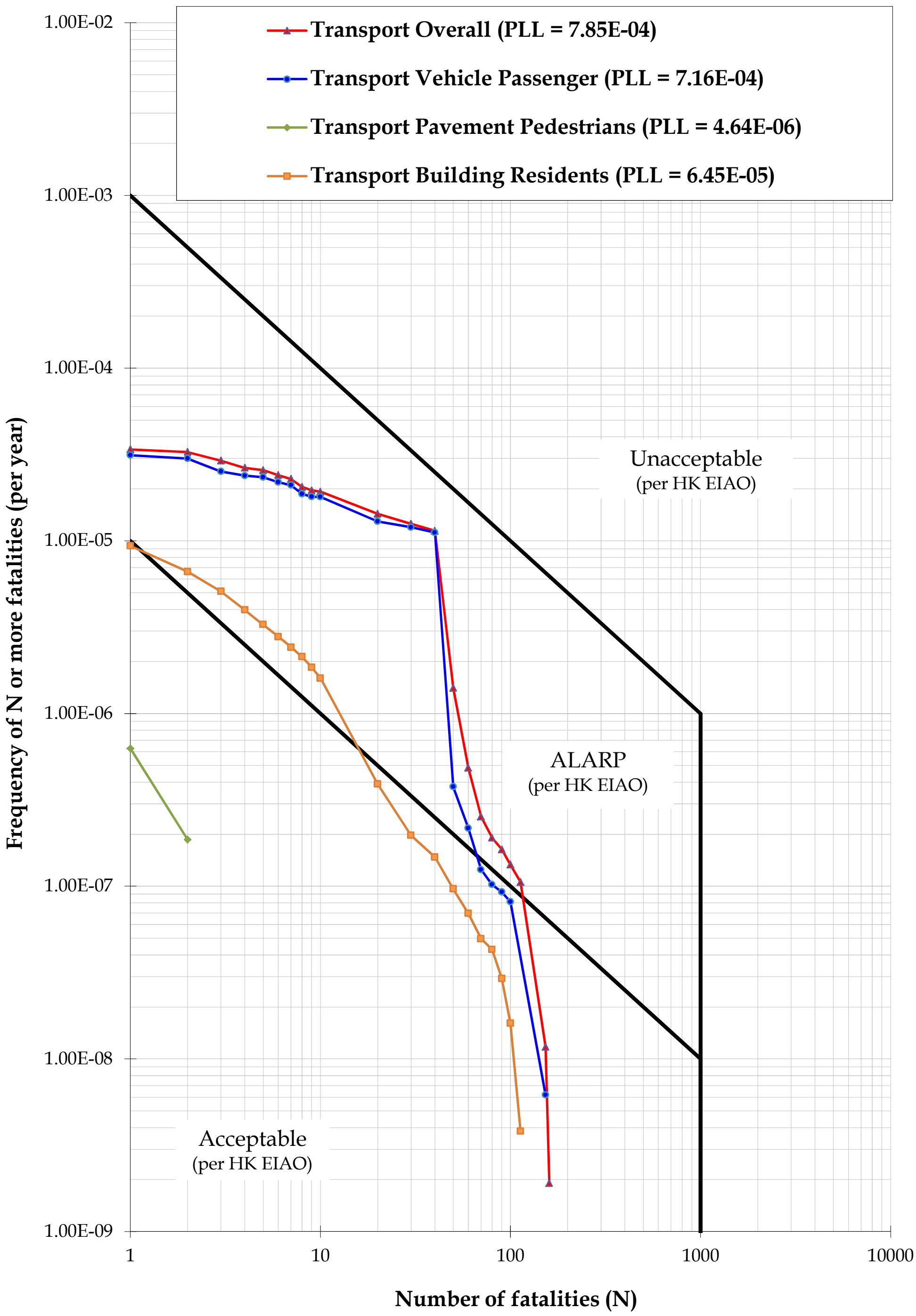
Note: The frequency of N= 1 of more fatalities per year is lower for pavement and building population groups since such population groups are outside the hazard range of the explosion for a large portion of the route. Vehicle passengers above refer to general members of the public on the roads but not the explosives truck crew.

Figure 8.8 *F-N Curve for the Base Case with Breakdown by Population Type (Route Option R2)*



Note: The frequency of N= 1 of more fatalities per year is lower for pavement and building population groups since such population groups are outside the hazard range of the explosion for a large portion of the route. Vehicle passengers above refer to general members of the public on the roads but not the explosives truck crew.

Figure 8.9 *F-N Curve for the Base Case with Breakdown by Population Type (Route Option R3)*



Note: The frequency of N= 1 of more fatalities per year is lower for pavement and building population groups since such population groups are outside the hazard range of the explosion for a large portion of the route. Vehicle passengers above refer to general members of the public on the roads but not the explosives truck crew.

8.4 INDIVIDUAL RISK

The individual risk (IR) for each section of the transport routes are listed in *Table 8.7*. The same data are shown graphically in *Figure 8.10, Figure 8.11* and *Figure 8.12*. The IR summation takes into account that some road sections are common to several transport routes; the IR is roughly proportional to the frequency of explosives trucks travelling along the road. The IR results presented below represent the maximum individual risk occurring on the road in the same lane as the explosives delivery truck. It can be seen that the maximum IR is about 1.8×10^{-7} per year. This is a low risk when compared to Hong Kong Risk Guidelines which require the offsite IR from a fixed installation to be below 10^{-5} per year. The low values of IR are due to the fact that the risk at any given fixed location along the route is transitory.

Table 8.7 Maximum Individual Risk for Each Section of the Transport Routes from Tai Lam Explosives Magazine Site (Base Case)

Section ID	Description	Maximum IR (per year)
Route R1a (Route Option R1: Tai Lam Explosives Magazine Site – Mid-Ventilation Adit)		
Road R1a1	Access road towards Tai Shu Ha Rd West	8.98E-08
Road R1a2	Tai Shu Ha Road West 1	8.78E-08
Road R1a3	Tai Shu Ha Road West 2	1.08E-07
Road R1a4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	1.13E-07
Road R1a5	Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)	8.63E-08
Road R1a6	Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)	7.30E-08
Road R1a7	Castle Peak Road (Yuen Long) (Pok Oi Int - Kam Tin Rd)	7.90E-08
Road R1a8	Kam Tin Rd (Castle Peak Rd (Yuen Long) - Kam Sheung Rd western junction)	7.82E-08
Road R1a9	Kam Tin Bypass	7.82E-08
Road R1a10	Kam Tin Rd (Kam Sheung Rd western junction - Fan Kam Rd)	8.04E-08
Road R1a11	Fan Kam Rd (Kam Tin Rd - Castle Peak Rd)	7.53E-08
Road R1a12	Po Kin Rd (Fan Kam Rd - Pak Wo Rd)	4.87E-08
Road R1a13	Pak Wo Rd (Po Kin Rd - Slip rd to So Kwun Po Int)	4.05E-08
Road R1a14	Pak Wo Rd (Slip rd to So Kwun Po Int - Yu Tai Rd)	3.73E-08
Road R1a15	Pak Wo Rd (Yu Tai Rd - Pak Wo Rd RA)	3.84E-08
Road R1a16	Pak Wo Rd (Pak Wo Rd RA - Wah Ming Rd)	3.81E-08
Road R1a17	Pak Wo Rd (Wah Ming Rd - Wai Ming St)	3.80E-08
Road R1a18	Pak Wo Rd (Wai Ming St - Yat Ming Rd)	3.80E-08
Road R1a19	Pak Wo Rd (Yat Ming Rd - Wo Hop Shek Int)	6.90E-08
Road R1a20	Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd)	1.09E-07
Road R1a21	Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd) 2	7.15E-08
Road R1a22	Jockey Club Rd (Lok Yip Rd - Sha Tau Kok Rd)	3.94E-08
Road R1a23	Sha Tau Kok Rd (Lung Yeuk Tau) (Jockey Club Rd - Lok Yip Rd)	3.78E-08
Road R1a24	Sha Tau Kok Rd (Lung Yeuk Tau) (Lok Yip Rd - Luen Shing St)	3.77E-08
Road R1a25	Sha Tau Kok Rd (Lung Yeuk Tau) (Luen Shing St - On Kui St)	3.74E-08
Road R1a26	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Lau Shui Heung Rd)	3.90E-08
Road R1a27	Lau Shui Heung Rd (Sha Tau Kok Rd - Po Kat Tsai Rd)	3.84E-08
Road R1a28	Po Kat Tsai Road (Lau Shui Heung Rd - Site)	1.97E-08

Section ID	Description	Maximum IR (per year)
Route R1b (Route Option R1: Tai Lam Explosives Magazine Site – North Portal)		
Road R1b1	Access road towards Tai Shu Ha Rd West	8.98E-08
Road R1b2	Tai Shu Ha Road West 1	8.78E-08
Road R1b3	Tai Shu Ha Road West 2	1.08E-07
Road R1b4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	1.13E-07
Road R1b5	Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)	8.63E-08
Road R1b6	Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)	7.30E-08
Road R1b7	Castle Peak Road (Yuen Long) (Pok Oi Int - Kam Tin Rd)	7.90E-08
Road R1b8	Kam Tin Rd (Castle Peak Rd (Yuen Long) - Kam Sheung Rd western junction)	7.82E-08
Road R1b9	Kam Tin Bypass	7.82E-08
Road R1b10	Kam Tin Rd (Kam Sheung Rd western junction - Fan Kam Rd)	8.04E-08
Road R1b11	Fan Kam Rd (Kam Tin Rd - Castle Peak Rd)	7.53E-08
Road R1b12	Po Kin Rd (Fan Kam Rd - Pak Wo Rd)	4.87E-08
Road R1b13	Pak Wo Rd (Po Kin Rd - Slip rd to So Kwun Po Int)	4.05E-08
Road R1b14	Pak Wo Rd (Slip rd to So Kwun Po Int - Yu Tai Rd)	3.73E-08
Road R1b15	Pak Wo Rd (Yu Tai Rd - Pak Wo Rd RA)	3.84E-08
Road R1b16	Pak Wo Rd (Pak Wo Rd RA - Wah Ming Rd)	3.81E-08
Road R1b17	Pak Wo Rd (Wah Ming Rd - Wai Ming St)	3.80E-08
Road R1b18	Pak Wo Rd (Wai Ming St - Yat Ming Rd)	3.80E-08
Road R1b19	Pak Wo Rd (Yat Ming Rd - Wo Hop Shek Int)	6.90E-08
Road R1b20	Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd)	1.09E-07
Road R1b21	Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd) 2	7.15E-08
Road R1b22	Jockey Club Rd (Lok Yip Rd - Sha Tau Kok Rd)	3.94E-08
Road R1b23	Sha Tau Kok Rd (Lung Yeuk Tau) (Jockey Club Rd - Lok Yip Rd)	3.78E-08
Road R1b24	Sha Tau Kok Rd (Lung Yeuk Tau) (Lok Yip Rd - Luen Shing St)	3.77E-08
Road R1b25	Sha Tau Kok Rd (Lung Yeuk Tau) (Luen Shing St - On Kui St)	3.74E-08
Road R1b26	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 1	3.90E-08
Road R1b27	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 2	3.63E-08
Route R1c (Route Option R1: Tai Lam Explosives Magazine Site – South Portal)		
Road R1c1	Access road towards Tai Shu Ha Rd West	8.98E-08
Road R1c2	Tai Shu Ha Road West 1	8.78E-08
Road R1c3	Tai Shu Ha Road West 2	1.08E-07
Road R1c4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	1.13E-07
Road R1c5	Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)	8.63E-08
Road R1c6	Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)	7.30E-08
Road R1c7	Castle Peak Road (Yuen Long) (Pok Oi Int - Kam Tin Rd)	7.90E-08
Road R1c8	Kam Tin Rd (Castle Peak Rd (Yuen Long) - Kam Sheung Rd western junction)	7.82E-08
Road R1c9	Kam Tin Bypass	7.82E-08
Road R1c10	Kam Tin Rd (Kam Sheung Rd western junction - Fan Kam Rd)	8.04E-08
Road R1c11	Kam Tin Rd (Fan Kam Rd - Kam Sheung Rd eastern junction)	7.48E-08
Road R1c12	Lam Kam Rd (Kam Sheung Rd - Lam Kam Rd Int)	4.09E-08
Road R1c13	Lam Kam Rd (Lam Kam Rd Int - Tai Wo Service Rd W)	4.04E-08
Road R1c14	Tai Wo Service Rd W (Lam Kam Rd Int - Kau Lung Hang	4.14E-08

Section ID	Description	Maximum IR (per year)
	FO)	
Road R1c15	Tai Wo Service Rd W (Kau Lung Hang FO - Wo Hing Rd)	4.42E-08
Road R1c16	Unnamed road (Wo Hing Rd - Pak Wo Rd)	7.59E-08
Road R1c17	Jockey Club Rd (Wo Hop Shek Int - Lok Yip Rd)	1.09E-07
Road R1c18	Slip Rd (Jockey Club Rd - Fanling Highway)	7.60E-08
Road R1c19	Fanling Highway (Wo Hop Shek Int - Kau Lung Hang Lo Wai)	1.09E-07
Road R1c20	Tai Wo Service Rd East (Slip rd from Fanling Highway - Road to Site 1)	4.84E-08
Road R1c21	Road to Site 1 (Tai Wo Service Rd East - Road to Site 2)	4.98E-08
Road R1c22	Road to Site 2 (Road to Site 1 - Site)	4.31E-08
Route R2a (Route Option R2: Tai Lam Explosives Magazine Site – Mid-Ventilation Adit)		
Road R2a1	Access road towards Tai Shu Ha Rd West	9.09E-08
Road R2a2	Tai Shu Ha Road West 1	8.80E-08
Road R2a3	Tai Shu Ha Road West 2	1.83E-07
Road R2a4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	1.12E-07
Road R2a5	Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)	8.74E-08
Road R2a6	Shap Pat Heung Interchange (Shap Pat Heung Road - Yuen Long Highway)	1.40E-07
Road R2a7	Yuen Long Highway (Shap Pat Heung Int - Tong Yan San Tsuen Int)	1.58E-07
Road R2a8	Connecting road from Tong Yan San Tsuen Int to Long Tin Road	1.25E-07
Road R2a9	Long Tin Road (Tong Yan San Tsuen Int - Castle Peak Rd (Ping Shan))	1.30E-07
Road R2a10	Connecting road from Long Tin Road North Bound to South Bound	8.06E-08
Road R2a11	Long Tin Road (Castle Peak Rd (Ping Shan) - Tong Yan San Tsuen Int)	1.25E-07
Road R2a12	Connecting road from Long Tin Rd to Tong Yan San Tsuen Int	1.16E-07
Road R2a13	Yuen Long Highway (Tong Yan San Tsuen Int - Shap Pat Heung Int)	1.63E-07
Road R2a14	Yuen Long Highway (Shap pat Heung Int - Nr Tsing Long Highway)	1.50E-07
Road R2a15	Yuen Long Highway (to San Tin Highway 1)	7.10E-08
Road R2a16	Yuen Long Highway (to San Tin Highway 2)	7.02E-08
Road R2a17	San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)	7.12E-08
Road R2a18	San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)	7.06E-08
Road R2a19	Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)	7.52E-08
Road R2a20	Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)	7.42E-08
Road R2a21	So Kwun Po Rd (Fanling Highway - So Kwun Po Rd Int)	7.45E-08
Road R2a22	So Kwun Po Rd (So Kwun Po Rd Int - Jockey Club Rd)	3.84E-08
Road R2a23	Ma Sik Rd (Jockey Club Rd - Tin Ping Rd)	3.80E-08
Road R2a24	Ma Sik Rd (Tin Ping Rd - Fan Leng Lau Rd)	3.83E-08
Road R2a25	Ma Sik Rd (Fan Leng Lau Rd - Luen Chit St)	3.81E-08
Road R2a26	Ma Sik Rd (Luen Chit St - Wo Tai St)	3.73E-08
Road R2a27	Ma Sik Rd (Wo Tai St - Sha Tau Kok Rd (Lung Yeuk Tau))	4.11E-08
Road R2a28	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Lau Shui Heung Rd)	3.90E-08
Road R2a29	Lau Shui Heung Rd (Sha Tau Kok Rd - Po Kat Tsai Rd)	3.82E-08
Road R2a30	Po Kat Tsai Road (Lau Shui Heung Rd - Site)	2.00E-08
Route R2b (Route Option R2: Tai Lam Explosives Magazine Site – North Portal)		
Road R2b1	Access road towards Tai Shu Ha Rd West	9.09E-08

Section ID	Description	Maximum IR (per year)
Road R2b2	Tai Shu Ha Road West 1	8.80E-08
Road R2b3	Tai Shu Ha Road West 2	1.83E-07
Road R2b4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	1.12E-07
Road R2b5	Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)	8.74E-08
Road R2b6	Shap Pat Heung Interchange (Shap Pat Heung Road - Yuen Long Highway)	1.40E-07
Road R2b7	Yuen Long Highway (Shap Pat Heung Int - Tong Yan San Tsuen Int)	1.58E-07
Road R2b8	Connecting road from Tong Yan San Tsuen Int to Long Tin Road	1.25E-07
Road R2b9	Long Tin Road (Tong Yan San Tsuen Int - Castle Peak Rd (Ping Shan))	1.30E-07
Road R2b10	Connecting road from Long Tin Road North Bound to South Bound	8.06E-08
Road R2b11	Long Tin Road (Castle Peak Rd (Ping Shan) - Tong Yan San Tsuen Int)	1.25E-07
Road R2b12	Connecting road from Long Tin Rd to Tong Yan San Tsuen Int	1.16E-07
Road R2b13	Yuen Long Highway (Tong Yan San Tsuen Int - Shap Pat Heung Int)	1.63E-07
Road R2b14	Yuen Long Highway (Shap pat Heung Int - Nr Tsing Long Highway)	1.50E-07
Road R2b15	Yuen Long Highway (to San Tin Highway 1)	7.10E-08
Road R2b16	Yuen Long Highway (to San Tin Highway 2)	7.02E-08
Road R2b17	San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)	7.12E-08
Road R2b18	San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)	7.06E-08
Road R2b19	Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)	7.52E-08
Road R2b20	Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)	7.42E-08
Road R2b21	So Kwun Po Rd (Fanling Highway - So Kwun Po Rd Int)	7.45E-08
Road R2b22	So Kwun Po Rd (So Kwun Po Rd Int - Jockey Club Rd)	3.84E-08
Road R2b23	Ma Sik Rd (Jockey Club Rd - Tin Ping Rd)	3.80E-08
Road R2b24	Ma Sik Rd (Tin Ping Rd - Fan Leng Lau Rd)	3.83E-08
Road R2b25	Ma Sik Rd (Fan Leng Lau Rd - Luen Chit St)	3.81E-08
Road R2b26	Ma Sik Rd (Luen Chit St - Wo Tai St)	3.73E-08
Road R2b27	Ma Sik Rd (Wo Tai St - Sha Tau Kok Rd (Lung Yeuk Tau))	4.11E-08
Road R2b28	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 1	3.90E-08
Road R2b29	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 2	3.59E-08
Route R2c (Route Option R2: Tai Lam Explosives Magazine Site – South Portal)		
Road R2c1	Access road towards Tai Shu Ha Rd West	9.09E-08
Road R2c2	Tai Shu Ha Road West 1	8.80E-08
Road R2c3	Tai Shu Ha Road West 2	1.83E-07
Road R2c4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	1.12E-07
Road R2c5	Shap Pat Heung Road (Tai Shu Ha Road West 2 - Shap Pat Heung Interchange)	8.74E-08
Road R2c6	Shap Pat Heung Interchange (Shap Pat Heung Road - Yuen Long Highway)	1.40E-07
Road R2c7	Yuen Long Highway (Shap Pat Heung Int - Tong Yan San Tsuen Int)	1.58E-07
Road R2c8	Connecting road from Tong Yan San Tsuen Int to Long Tin Road	1.25E-07
Road R2c9	Long Tin Road (Tong Yan San Tsuen Int - Castle Peak Rd (Ping Shan))	1.30E-07
Road R2c10	Connecting road from Long Tin Road North Bound to South Bound	8.06E-08
Road R2c11	Long Tin Road (Castle Peak Rd (Ping Shan) - Tong Yan San Tsuen Int)	1.25E-07

Section ID	Description	Maximum IR (per year)
Road R2c12	Connecting road from Long Tin Rd to Tong Yan San Tsuen Int	1.16E-07
Road R2c13	Yuen Long Highway (Tong Yan San Tsuen Int - Shap Pat Heung Int)	1.63E-07
Road R2c14	Yuen Long Highway (Shap pat Heung Int - Nr Tsing Long Highway)	1.50E-07
Road R2c15	Yuen Long Highway (to San Tin Highway 1)	7.10E-08
Road R2c16	Yuen Long Highway (to San Tin Highway 2)	7.02E-08
Road R2c17	San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)	7.12E-08
Road R2c18	San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)	7.06E-08
Road R2c19	Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)	7.52E-08
Road R2c20	Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)	7.42E-08
Road R2c21	Fanling Highway (So Kwun Po Int - Wo Hop Shek Int)	7.30E-08
Road R2c22	Fanling Highway (Wo Hop Shek Int - Kau Lung Hang Lo Wai)	4.04E-08
Road R2c23	Tai Wo Service Rd East (Slip rd from Fanling Highway - Kau Lung Hang FO)	4.43E-08
Road R2c24	Road to Site 1 (Tai Wo Service Rd East - Road to Site 2)	4.69E-08
Road R2c25	Road to Site 2 (Road to Site 1 - Site)	4.32E-08
Route R3a (Route Option R3: Tai Lam Explosives Magazine Site – Mid-Ventilation Adit)		
Road R3a1	Access road towards Tai Shu Ha Rd West	8.62E-08
Road R3a2	Tai Shu Ha Road West 1	8.83E-08
Road R3a3	Tai Shu Ha Road West 2	1.10E-07
Road R3a4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	1.14E-07
Road R3a5	Shap Pat Heung Road (Tai Tong Rd - Shap Pat Heung Interchange)	8.72E-08
Road R3a6	Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)	7.14E-08
Road R3a7	Yuen Long Highway	6.99E-08
Road R3a8	Yuen Long Highway (to San Tin Highway 1)	6.99E-08
Road R3a9	Yuen Long Highway (to San Tin Highway 2)	7.05E-08
Road R3a10	San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)	6.88E-08
Road R3a11	San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)	7.02E-08
Road R3a12	Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)	7.00E-08
Road R3a13	Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)	7.04E-08
Road R3a14	So Kwun Po Rd (Fanling Highway - So Kwun Po Rd Int)	6.95E-08
Road R3a15	So Kwun Po Rd (So Kwun Po Rd Int - Jockey Club Rd)	3.78E-08
Road R3a16	Ma Sik Rd (Jockey Club Rd - Tin Ping Rd)	3.73E-08
Road R3a17	Ma Sik Rd (Tin Ping Rd - Fan Leng Lau Rd)	3.79E-08
Road R3a18	Ma Sik Rd (Fan Leng Lau Rd - Luen Chit St)	3.78E-08
Road R3a19	Ma Sik Rd (Luen Chit St - Wo Tai St)	3.69E-08
Road R3a20	Ma Sik Rd (Wo Tai St - Sha Tau Kok Rd (Lung Yeuk Tau))	4.07E-08
Road R3a21	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Lau Shui Heung Rd)	4.13E-08
Road R3a22	Lau Shui Heung Rd (Sha Tau Kok Rd - Po Kat Tsai Rd)	3.63E-08
Road R3a23	Po Kat Tsai Road (Lau Shui Heung Rd - Site)	2.02E-08
Route R3b (Route Option R3: Tai Lam Explosives Magazine Site – North Portal)		
Road R3b1	Access road towards Tai Shu Ha Rd West	8.62E-08
Road R3b2	Tai Shu Ha Road West 1	8.83E-08
Road R3b3	Tai Shu Ha Road West 2	1.10E-07
Road R3b4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	1.14E-07
Road R3b5	Shap Pat Heung Road (Tai Tong Rd - Shap Pat Heung	8.72E-08

Section ID	Description	Maximum IR (per year)
	Interchange)	
Road R3b6	Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)	7.14E-08
Road R3b7	Yuen Long Highway	6.99E-08
Road R3b8	Yuen Long Highway (to San Tin Highway 1)	6.99E-08
Road R3b9	Yuen Long Highway (to San Tin Highway 2)	7.05E-08
Road R3b10	San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)	6.88E-08
Road R3b11	San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)	7.02E-08
Road R3b12	Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)	7.00E-08
Road R3b13	Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)	7.04E-08
Road R3b14	So Kwun Po Rd (Fanling Highway - So Kwun Po Rd Int)	6.95E-08
Road R3b15	So Kwun Po Rd (So Kwun Po Rd Int - Jockey Club Rd)	3.78E-08
Road R3b16	Ma Sik Rd (Jockey Club Rd - Tin Ping Rd)	3.73E-08
Road R3b17	Ma Sik Rd (Tin Ping Rd - Fan Leng Lau Rd)	3.79E-08
Road R3b18	Ma Sik Rd (Fan Leng Lau Rd - Luen Chit St)	3.78E-08
Road R3b19	Ma Sik Rd (Luen Chit St - Wo Tai St)	3.69E-08
Road R3b20	Ma Sik Rd (Wo Tai St - Sha Tau Kok Rd (Lung Yeuk Tau))	4.07E-08
Road R3b21	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 1	4.13E-08
Road R3b22	Sha Tau Kok Rd (Lung Yeuk Tau) (Ma Sik Rd - Site) 2	3.64E-08
Route R3c (Route Option R3: Tai Lam Explosives Magazine Site – South Portal)		
Road R3c1	Access road towards Tai Shu Ha Rd West	8.62E-08
Road R3c2	Tai Shu Ha Road West 1	8.83E-08
Road R3c3	Tai Shu Ha Road West 2	1.10E-07
Road R3c4	Tai Kei Leng Road (Tai Shu Ha Road West 2 - Shap Pat Heung Rd)	1.14E-07
Road R3c5	Shap Pat Heung Road (Tai Tong Rd - Shap Pat Heung Interchange)	8.72E-08
Road R3c6	Yuen Long Highway (Shap Pat Heung Int - Pok Oi Int)	7.14E-08
Road R3c7	Yuen Long Highway	6.99E-08
Road R3c8	Yuen Long Highway (to San Tin Highway 1)	6.99E-08
Road R3c9	Yuen Long Highway (to San Tin Highway 2)	7.05E-08
Road R3c10	San Tin Highway (Tsing Long Highway - Fairview Park Boulevard)	6.88E-08
Road R3c11	San Tin Highway (Fairview Park Boulevard - Lok Ma Chau Rd)	7.02E-08
Road R3c12	Fanling Highway (Lok Ma Chau Rd - Fan Kam Rd)	7.00E-08
Road R3c13	Fanling Highway (Slip rds to & from Fan Kam Rd Int - Slip rds to & from So Kwun Po Int)	7.04E-08
Road R3c14	Fanling Highway (So Kwun Po Int - Wo Hop Shek Int)	6.78E-08
Road R3c15	Fanling Highway (Wo Hop Shek Int - Kau Lung Hang Lo Wai)	3.71E-08
Road R3c16	Tai Wo Service Rd East (Slip rd from Fanling Highway - Kau Lung Hang FO)	4.74E-08
Road R3c17	Road to Site 1 (Tai Wo Service Rd East - Road to Site 2)	4.98E-08
Road R3c18	Road to Site 2 (Road to Site 1 - Site)	4.39E-08

Figure 8.10 Maximum IR for the Delivery Routes from Tai Lam Explosives Magazine Site (Base Case Route Option R1)

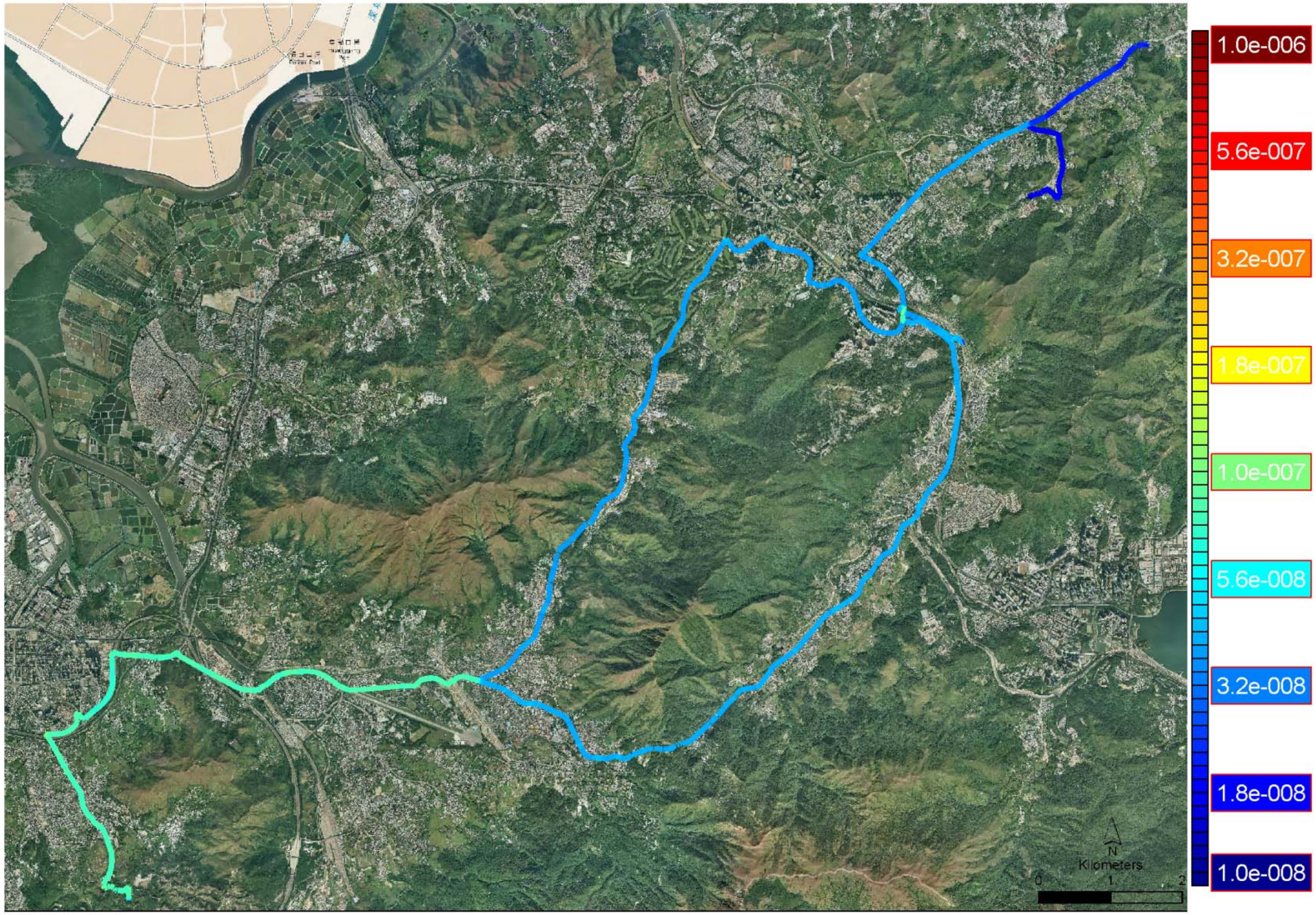


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Figure 8.11 Maximum IR for the Delivery Routes from Tai Lam Explosives Magazine Site (Base Case Route Option R2)

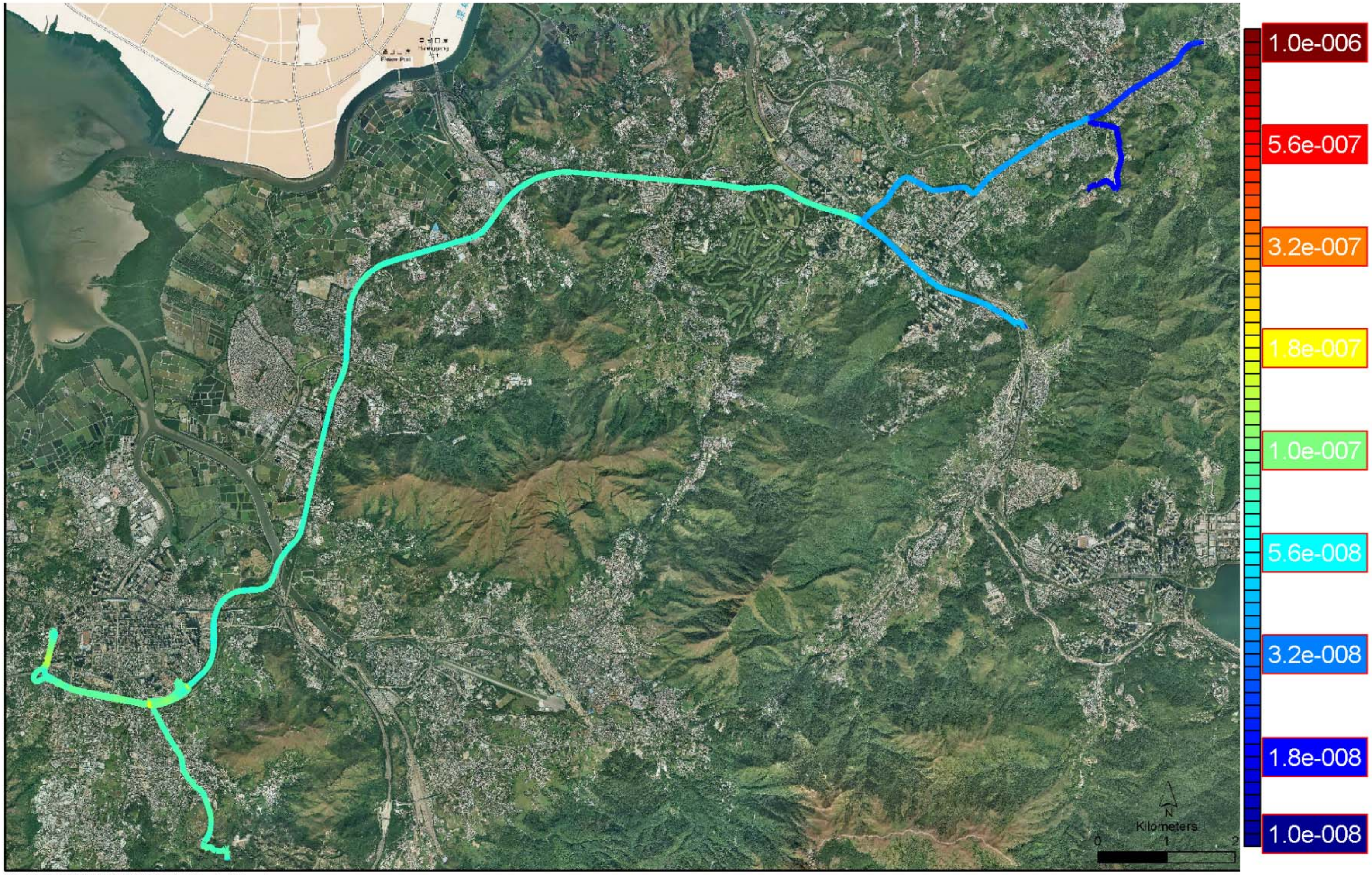

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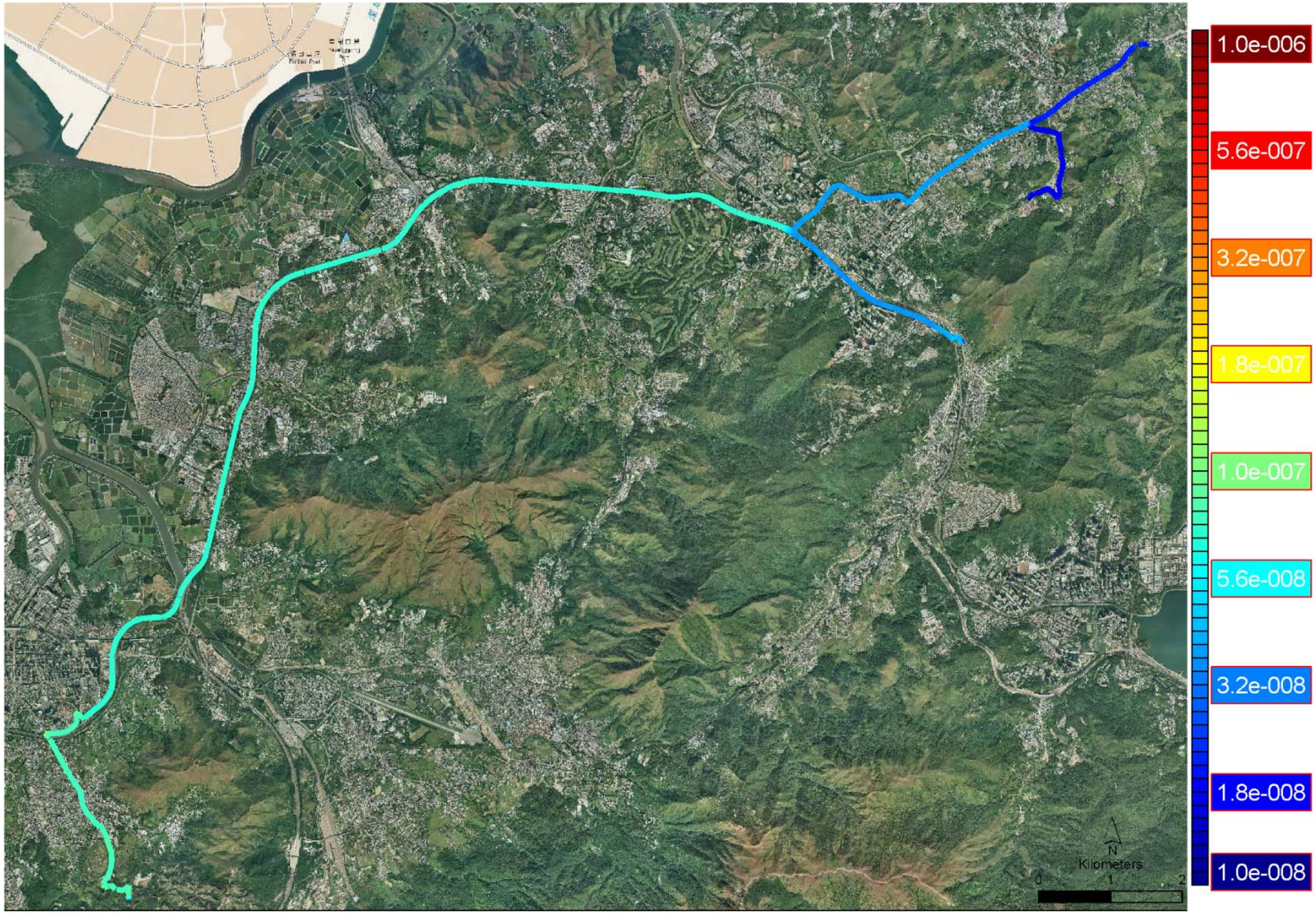
Figure 8.12 Maximum IR for the Delivery Routes from Tai Lam Explosives Magazine Site (Base Case Route Option R3)

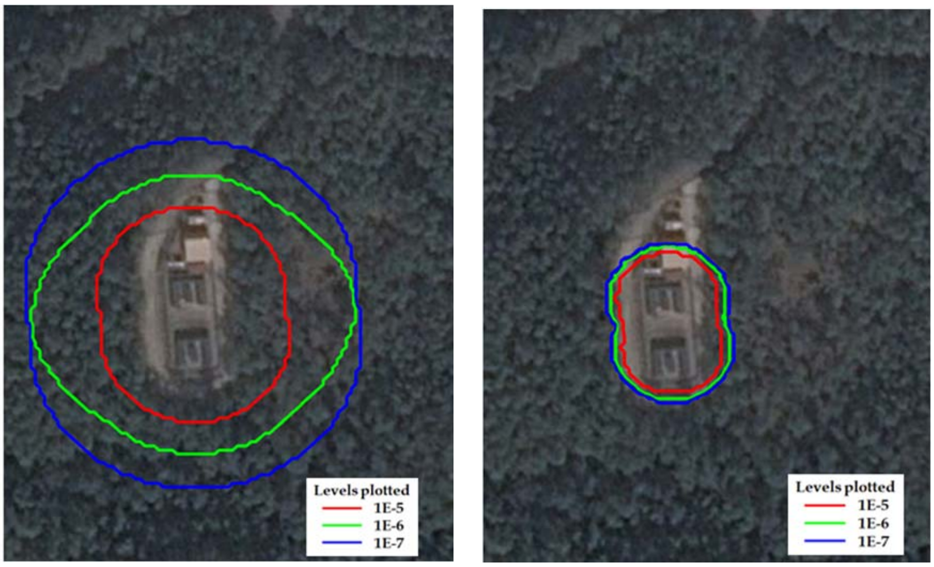


CT\0247534\Mxd\Route_AP.mxd

For the storage magazine, individual risk contours have been plotted and overlaid on plot layouts for Tai Lam Explosives Magazine site (*Figure 8.13*). IR contours (assuming a risk exposure factor of 100%) have been presented for both outdoor and indoor populations, with the 10^{-5} per year contour extending offsite in both cases. Persons indoors experience higher risks due to breaking windows and risk of building collapse. However, there are no buildings or structures nearby that lie within these contours and hence the outdoor contours are more appropriate. The maximum IR is about 1×10^{-4} per year considering the base frequency used in the analysis for explosion. This however, neglects to take into account presence factors. The Magazine site is in a remote area and the 10^{-5} per year contours impact only on woodland areas where there is no continuous presence of people. The presence of people in these areas will be rare and only temporary leading to a very small presence factor. The most exposed population group will be people potentially present adjacent to the Magazine site fence. Such persons are not expected to be present more than 1% of the time. Therefore, no member of the public will be exposed to an IR of 10^{-5} per year. The actual risk to any individual will be much less than 10^{-5} per year and is deemed to be acceptable.

Figure 8.13 IR of the Tai Lam Explosives Magazine Site

Indoor ***Outdoor***



8.5 UNCERTAINTY ANALYSIS AND SENSITIVITY TESTS

The study is based on a number of assumptions as previously highlighted in various sections of this report.

A discussion on the uncertainties and sensitivity of the results is given below.

Explosion Consequence Model

The employed ESTC model, or any other established TNT explosion model, tends to overpredict the number of fatalities (or, probability of fatality for an individual) when compared to the actual fatalities in past incidents related to explosives. It can be seen that no recorded incident involving road transport had resulted in more than 12 fatalities even in urban locations, while from the assessment, the maximum fatalities due to road transport is estimated as about 100 - 300. There is some conservatism in the model although it is acknowledged that given the dense urban environment in Hong Kong, the fatalities estimated during transport of explosives may not be too conservative.

On the other hand, a number of recent research studies performed by the HSE in the UK, indicates that the ESTC models may underpredict the fatalities caused by flying glass in highly built-up areas. Despite this recent research, the ESTC models are still recommended as the best currently available.

Intervention of the Explosive Truck Crew

In certain circumstances it may be possible for the crew to control a fire developing on the vehicle by using onboard safety devices. Given the quantity and type of fire extinguishers, credit has been given in combination with the fire screen protection. The two events have been assumed to be dependent.

Similarly, if it is possible and safe to do so, given the low amount of explosives to be transported on the truck, it may be possible for the crew to secure the explosive load before the fire fully develops. However, given that a fire could fully develop and critical explosive temperature can be reached within a couple of minutes, no credit was given for people to escape as a conservative assumption.

Intervention of the Fire Service Department

Most likely, a fire would have already fully developed by the time the fire brigade arrives at the scene, in case of a fire incident involving an explosive vehicle. The intervention of the fire brigade would be limited to fight the fire from a safe distance, given the risk posed by the scenario, and to evacuate the area.

Regarding the evacuation, it may be possible to evacuate the accident zone surrounding the vehicle which would include vehicle occupants and people located on the pavement but evacuation of the buildings would be difficult.

For the purpose of this assessment, no or little credit has been given for the intervention of the fire brigade.

Escape and Evacuation

In certain circumstance it may be possible for people to escape from the scene of an accident by themselves before the occurrence of an explosion event. This is particularly true in the case of a fire accident, for example fire on a truck in which explosives cargo is not initially involved but is only affected after a period of gradual escalation. However, modelling such escape scenario would only reduce slightly the consequences and have minimum impact on the conclusion of this report. For the purpose of this study, no credit was given for people to escape as a conservative assumption.

Explosive Initiation under Thermal Stimulus

Although the potential consequences are known, there are still some uncertainties associated with the probability of explosion for an explosive load composed of a mix of cartridged emulsion, cast boosters and detonating cord when involved in a fire during transportation. The probability used in this report has been based on accident statistics applicable to ANFO which is seen as being more sensitive than emulsion and transported in a different manner. In absence of test data, this assumption may be conservative.

It is concluded that the risk assessment approach adopted in this study are on the conservative side, with the best available conservative consequence assessment ESTC model and omitting credits for risk reduction factors in accident failure scenarios and "good practice" mitigation measures.

9 ALARP ASSESSMENT

9.1 *RISK RESULTS AND APPROACH TO ALARP*

The Hazard to Life Assessment of the Project has assessed the risks arising from the proposed Magazine site in Tai Lam as well as the risks associated with the road transport from this site to the work areas. From *Section 8*, the risks posed by the storage and transport of explosives, for both base case and worst case, are in the ALARP region specified in EIAO-TM Annex 4.

The risk, in terms of PLL, associated with the Worst Case, estimated at 1.56×10^{-3} per year (Route Option R2) has been used for the purpose of the ALARP assessment. This approach is conservative.

The results imply that achievable risk reduction measures and / or any alternate practicable option should be explored for the project. From *Section 8* it was also found that the risk arising from explosive transport is much more significant than that of explosives storage; hence, the following assessment focuses on the transportation aspect of the explosives.

Where the risk falls into the ALARP region, the risks associated with each probable hazardous event should be reduced to a level 'as low as reasonably practicable'. This firstly requires the identification of 'practicable' risk reduction options regardless of their cost. A risk reduction option is considered 'practicable' if an engineering solution exists and can be implemented for the Project regardless of the cost without affecting the project construction programme. Secondly, the extent to which the risk should be reduced is usually measured as a trade-off between the risk reduction, i.e. the safety benefits, and the cost of the risk reduction measure. A mitigation option is considered 'reasonable' if the cost of implementing the option is not grossly disproportionate to the achieved safety benefits.

Risk mitigation measures may take the form of engineered measures, controls in the zones most impacted by the hazardous scenarios presented by this project, or operation and procedural controls.

The following section presents the approach and the outcome of the ALARP assessment.

9.2 *APPROACH TO ALARP ASSESSMENT*

The approach consists of identifying potential justifiable mitigation measures, assessing their practicability for this project and evaluating their cost and comparing with the safety benefits of implementing the measures. Combinations of mitigation measures are also considered.

Cost benefit analysis (CBA) is widely used in QRA studies to evaluate the cost-effectiveness of alternative measures and provide a demonstration that all reasonably practicable measures have been taken to reduce risks.

The safety benefits are evaluated as follows:

Safety Benefits = Value of Preventing a Fatality x Aversion Factor x Reduction in PLL value x Design life of mitigation measure

The Value of Preventing a Fatality (VPF) reflects the tolerability of risk by the society and therefore the monetary value that the society is ready to invest to prevent a fatality. For the purpose of this assessment and for consistency with previous studies, the Value of Preventing a Fatality is taken as HK$33M per person, which is the same figure as used in previous Hazard Assessment studies (derived from the UK ACDS (ACDS, 1995)) but updated to current prices.

Depending on the level of risk, the value of preventing a fatality may be adjusted to reflect people's aversion to high risks or scenarios with potential for multiple fatalities. The methodology for application of the 'aversion factor' follows that developed in the EPD's Technical Note on Cost Benefit Analysis (EPD, 1996), in which the aversion factor is calculated on a sliding scale from 1 (risks at the lower boundary of the ALARP region of the Risk Guidelines) up to a maximum of 20 (risks at the upper boundary of the ALARP region). The adjusted VPF using the aversion factor of 20 is HK$660M. This value is a measure of how much the society is willing to invest to prevent a fatality, where there is potential for an event to cause multiple fatalities.

The cost of implementing potential justifiable mitigation measures will be first of all checked against the Maximum Justifiable Expenditure. The Maximum Justifiable Expenditure will be estimated on the assumption that risk is reduced to zero. Mitigation measures considered justifiable will be further analysed considering the actual risk (PLL) reduction offered by the measure.

If the safety benefits are greater than the cost of implementation of a particular mitigation measure, the mitigation measure will be considered for implementation in this project; otherwise its cost would not be considered justifiable.

The cost of implementing the mitigation measures should include capital and operational expenditures but exclude any cost associated with design or design change.

It is recognised that it may not always be possible to quantify the cost-benefits of a particular measure. In some cases, a qualitative approach was adopted.

9.3 *MAXIMUM JUSTIFIABLE EXPENDITURE*

The maximum justifiable expenditure for this project is calculated as follows assuming a conservative aversion factor of 20:

Maximum Justifiable Expenditure

= Value of Preventing a Fatality x Aversion Factor x Maximum PLL value x Design life of mitigation measure

Maximum Justifiable Expenditure = HK$ 33M x 20 x 1.56E-3x (24/12)
= HK$ 2.1M

The design life of a mitigation measure is assumed as 2 years (Jan 2016 to Dec 2017, 24 months) based on the Project duration during which storage and transport of explosives will be involved.

For an 'achievable' mitigation measure to be potentially justifiable, its cost should be less than the Maximum Justifiable Expenditure.

9.4 *POTENTIAL JUSTIFIABLE MITIGATION MEASURES*

The approach considered the identification of options pertaining to the following broad categories:

- Options eliminating the need for a magazine or eliminating the risk;
- Options reducing significantly the quantities of explosives to be used such as the use of hard rock TBM or alternatives to cartridged emulsion;
- Options reducing significantly the distance run by contractors' explosives trucks such as closer Magazine site and alternative routes;
- Options reducing significantly the number of trips to be carried out by contractors' explosives trucks;
- Options considering improved explosives truck design; and
- Options considering better risk management systems and procedures.

Based on the review of the risk results and a series of brainstorming sessions with DHK and explosives specialists operating in this industry, the following options were selected as potential candidates for risk mitigation.

9.4.1 *Need for a Tunnel and Proposed Alignment*

This Explosive Storage and Transport Project serves the Liantang / Heung Yuen Wai Boundary Control Point Work in the north-eastern New Territories is a crucial development project to serve the cross-boundary goods vehicles and passengers travelling between Hong Kong (HK) and Shenzhen (SZ) East. The new BCP will connect with the Shenzhen Eastern Corridor and provide an efficient access across the border to the eastern part of Guangdong, including Shantou, Shanwei, Chaozhou, etc. and the adjacent provinces such as Fujian and Jiangxi. The Project will:

- reduce travelling time between HK and SZ East, facilitating future development in these areas and extending the economic hinterland of HK and SZ;

- re-distribute cross-boundary traffic in New Territories East and alleviate the frequent congestion at Man Kam To BCP, resulting in enhancement of the overall operational efficiency, handling capacity and quality of service for BCPs in New Territories East; and

- improve and enhance the overall transport network in New Territories East and provide a convenient access to the proposed Ping Che/Ta Kwu Ling New Development Area by the proposed connecting road linking up the new BCP with Fanling Highway.

The Liantang/Heung Yuen Wai Boundary Control Point Work is an approved project. Opting for any alternative alignment option will cost significantly more than the Maximum Justifiable Expenditure.

9.4.2 *Magazine Requirement and Selection*

Due to the 24 hour blasting requirements as described in *Section 2* and summarised in *Section 2.5.2*, it is not possible for Mines Division to deliver the required explosives quantities directly to all the works areas as this would limit the blasting to one blast per day. An explosives magazine is therefore required.

The alternative Magazine sites to Tai Lam have been considered by Dragages Hong Kong Limited but they are not available for the Project (*Table 9.1*). The existing Tai Lam Explosives Magazine (TLEM) is the best option considering the shortest transportation distance, stakeholders' acceptance situation and its availability with the blasting schedule of the project.

On-site magazines were also considered (at the Mid Ventilation Portal and North Portal). Dragages Hong Kong Limited had preliminary consultation with CEDD Mines Division. After review with the necessary site setups and subsequent application process, Mines Divisions advised that it would not be feasible in managing interfaces with adjacent construction activities, safety of the site could be compromised and match with the program of project.

The only practicable location for the Magazine site is therefore Tai Lam Explosives Magazine site. This site has been used as the basis for this Hazard to Life assessment.

Table 9.1 Potential Explosive Magazine sites Selection

Magazine Location	District Council	Work Project	Contractor	Storage Capacity	Shortest Distance from Nearby Facilities	Status in June 2014	Distance to Liantang 2 Site	Availability for Liantang 2 Site
Tai Shu Ha, Tai Lam (New Territories)	Yuen Long	Hong Kong Section of Guangzhou-Shenzhen-Hong Kong Express Rail Link (XRL)	Leighton (C822) and Kier/Kaden/ Ossa (C824)	0.8 tonnes	About 210m	In use by C824 until end of 2014	About 25km	Available. Closest Magazine to the construction site.
So Kwun Wat, Siu Lam (New Territories)	Tuen Mun	Hong Kong Section of Guangzhou-Shenzhen-Hong Kong Express Rail Link (XRL)	Leighton (C822) and Dragages (C821)	1.2 tonnes	About 230m	Under demolish stage and reinstate-ment	About 35km	Not Feasible. Longer routes and more district involved.
Chung Hom Shan (Hong Kong Island)	Southern	MTR South Island Line (East)	Leighton (C904) and Nishimatsu (C902)	0.8 tonnes	About 200m	In use by both contractor	N/A	Not Feasible due to transport constraint (transport of explosive through tunnel is prohibited)

Magazine Location	District Council	Work Project	Contractor	Storage Capacity	Shortest Distance from Nearby Facilities	Status in June 2014	Distance to Liantang 2 Site	Availability for Liantang 2 Site
Victoria Road (Hong Kong Island)	Central and Western	MTR West Island Line	Nishimatsu/ Gammon (C704)	2.4 tonnes	About 64m	Not in use	N/A	Not Feasible due to transport constraint (transport of explosive through tunnel is prohibited)
Tseung Kwan O - Area137 (New Territories)	Sai Kung	MTR Kwun Tong Line Extension and Shatin to Central Link	KTE 1001	2.5 tonnes	About 160m	In use by both contractor	About 50km	In use at least until 2018.

9.4.3 *Use of alternative methods of construction*

It is possible to construct hard rock tunnels with hard rock tunnel boring machines (TBMs). The TBMs used in this project are dedicated to soft rock soils applications. For constructing the tunnels solely based on TBMs, TBMs dedicated to hard rock soils should be procured. The cost of such machines will be in the order of several hundred millions of Hong Kong Dollars each which would be much higher than the Maximum Justifiable Expenditure.

In addition, different tunnel profiles will be required leading to the need to use explosives to enlarge the circular TBM driven tunnels. Such costs and programme are not included.

Finally, immediate availability of such TBMs for Hong Kong plus the additional blasting required for non-circular sectors renders the option not practicable since it could lead to several months of project delay.

This option is therefore neither practicable nor justifiable on a cost basis.

9.4.4 *Use of Alternative Routes*

Several route options have been analysed in this assessment. As described in Section 2.6.5, current road improvement work at Pok Oi Interchange imposes limitations to explosives delivery routes selection as identified at the Fourth Meeting of Traffic and Transport Committee under Yuen Long District Council on 24 July 2014 (Thursday). Based on the risk assessment results presented in Section 8, the following routes will be selected for this project:

- At early stage of this project with road improvement work at Pok Oi Interchange (expected to be completed in 2015 but may be delayed), Route Option R2 will be used. Route Options R1 and R3 are not feasible.

- After road improvement work at Pok Oi Interchange is completed, all three routes will be available for use. The Route Option with minimum transport risk, i.e. Route Option R1, will be used. Route Option R3 can only be used as a contingency alternative route in the event that Route Option R1 is infeasible due to road blockage by traffic accidents.

9.4.5 *Use of Different Explosive Types*

The emulsion family of explosives is considered as the safest type of explosive for blasting applications. No safety benefits will be obtained by selecting a different type of explosive.

The detonating cord in this project uses a PETN core with a melting point of around 140 degC. Different detonating cord technologies are available such as those using a RDX or HMX core with a slightly higher melting point

(210 degC and 276 degC). This may offer more time before an explosion occurs following a fire event. The time gained and risk reduction achieved by implementing these technologies would however be negligible for the purpose of this assessment. In addition, current Mines Division's Explosives approval register shows both RDX and HMX core Detonating Cords are not registered and commercially available in HK. This option is therefore not considered further.

9.4.6 *Use of Smaller Quantities of Explosives*

This project has already considered the minimum amount of explosives for transportation as it will transport, as far as possible, initiating explosives only. Bulk blasting explosives will be manufactured on site. This option is therefore not considered further.

9.4.7 *Safer Explosives Truck Design*

The design of the truck has been reviewed to identify potential improvements which could reduce the risk particularly of fire escalating to the load. The analysis has already assumed that the current specification followed for Mines trucks such as use of fire screen between cabin and the load will also be followed for the Contractor's trucks. The use of fire screen is adopted overseas, although mainly for trucks carrying much larger quantities of explosives, i.e. more than 200 kg. However, this measure has been recommended for the Contractor's trucks in this project, as an improvement measure.

Further improvements to the fire and crash protection features for the explosives trucks were reviewed but no account of such practices was found worldwide and the effectiveness of such risk reduction measures is also not known.

It is however possible to implement simple measures such as reducing the combustible load on the vehicle by using fire retardant materials wherever possible and limiting the fuel tank capacity. Since the safety benefits of such measures are difficult to evaluate quantitatively such measures have been included in the recommendation section of this report, but no credit taken in the analysis.

9.4.8 *Lower Frequency of Explosives Transport*

The frequency of explosives transport has been minimized, as far as possible, with the use of alternative methods of construction, such as soft ground TBMs, etc. It has also been minimized with the use of bulk emulsion. No further options have been identified. The possibility of reducing the frequency of explosive transport has not been evaluated further.

9.4.9 *Reduction of Accident Involvement Frequency*

It is possible to reduce the explosive accident probability through the implementation of a training programme for both the driver and his attendants, regular 'toolbox' briefing sessions, implementation of a defensive driving attitude, appropriate driver selection based on good safety record, and medical checks. Such measures are to some degree mandatory and therefore considered in the base case assessment. The actual recommended implementation of this option is given in the recommendations section of this report.

9.4.10 *Reduction of Fire Involvement Frequency*

It is possible to carry better types of fire extinguishers onboard the explosives trucks and with bigger capacities e.g. AFFF-type extinguishers.

Adequate emergency plans and training could also be provided to make sure the adequate fire extinguishers are used and attempts are made to evacuate the area of the incident or securing the explosive load if possible.

The actual recommended implementation of this option is given in the recommendations section of this report.

9.4.11 *Summary*

In summary, various options have been either recommended for implementation or assessed comparing the implementation cost with the maximum justifiable expenditure for the safety benefit gained.

By adopting the feasible explosives delivery routes with the lowest risk, the risk has been reduced as low as practicable considering the impact of road improvement work at Pok Oi Interchange. The risk will be further reduced by implementation of the other selected mitigation measures.

9.5 ALARP ASSESSMENT RESULTS

The evaluation of each option considered is summarised in *Table 9.2*.

Table 9.2 ALARP Assessment Results

Option Description	Practicability	Implementation Cost	Safety Benefits or Justifiable Expenditure	ALARP Assessment Result
Use of alternative methods of construction (TBMs)	Not Practicable	> HK$ 100M	HK$ 2.1M	Neither practicable nor justified.
Use of Magazines Closer to the Worksites	Not Practicable	-	-	Closest practicable Magazine site to the worksites has been selected.
Use of different explosive types (different types of detonating cord)	Pose some limitations.	HK$ 2.4M	No safety benefit	Not justified

Option Description	Practicability	Implementation Cost	Safety Benefits or Justifiable Expenditure	ALARP Assessment Result
Alternative Routes (at early stage of this project, during road improvement work at Pok Oi Interchange)	Not Practicable	-	-	Neither practicable nor justified.
Alternative Routes (after road improvement work at Pok Oi Interchange is completed)	Practicable	< HK$ 10k	Negative	Route Option R1 is the preferred option. Route Option R3 can only be used as a contingency alternative route.
Use of Smaller Explosives Quantities	Not Practicable	-	-	Neither practicable nor justified.
Safer explosive truck (reduced fire load)	Practicable	-	-	This option has been directly incorporated in recommendations.
Reduction of Accident Involvement Frequency (training programme etc.)	Practicable	-	-	This option has been directly incorporated in recommendations.
Reduction of Fire Involvement Frequency (better emergency response, extinguisher types etc.)	Practicable	-	-	This option has been directly incorporated in recommendations.

10 CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

A QRA has been carried out to assess the hazard to life issues arising from the storage and transport of explosives from Tai Lam Explosives Magazine site to the three blasting worksites.

The criterion of Annex 4 of the EIAO-TM for Individual Risk is met. The assessment results show that the societal risk lies within the ALARP region when compared to the criteria stipulated in the EIAO-TM. A detailed ALARP assessment has been undertaken considering a wide range of mitigation measures and the results show compliance with the ALARP principles provided that the following recommendations are followed.

A number of recommendations have been made to ensure that the requirements (including ALARP requirements) of the EIAO-TM will be met during the construction period (see *Section 10.2.1*). In additional some general recommendations have been made to minimise the risks further and in accordance with best practices (see *Section 10.2.2*).

10.2 RECOMMENDATIONS

10.2.1 *Recommendations for Meeting the ALARP Requirements*

Following the ALARP principles, the following recommendations are justified and should be implemented to meet the EIAO-TM requirements:

- The truck design should comply with the Requirements for Approval of an Explosives Delivery Vehicle (CEDD 2) and limit the amount of combustibles in the cabin. The fuel carried in the fuel tank should also be minimised to reduce the duration of any fire;

- The explosive truck accident frequency should be minimised by implementing a dedicated training programme for both the driver and his attendants, including regular briefing sessions and implementation of a defensive driving attitude. In addition, drivers should be selected based on good safety records and medical checks;

- The Contractor should as far as practicable combine the explosive deliveries for a given work area;

- Only the required quantity of explosives for a particular blast should be transported to avoid the return of unused explosives to the Magazine;

- Whenever practicable, a minimum headway between two consecutive truck convoys of 10 min is recommended;

- The explosive truck fire involvement frequency should be minimised by ensuring the implementation of a robust emergency response and training to make sure the adequate fire extinguishers are used correctly and attempts are made to evacuate the area of the incident or securing the explosive load if possible. All explosive vehicles should be equipped with the required amount and type of fire extinguishers and shall be agreed with Mines Division.

10.2.2 *General Recommendations*

The following general recommendations should also be considered for the storage and transport of explosives:

1. The security plan should address different alert security levels to reduce opportunity for arson / deliberate initiation of explosives. The corresponding security procedure should be implemented with respect to prevailing security alert status announced by the Government.

2. Emergency plans (i.e. magazine operational manual) should be followed and amended if necessary to address uncontrolled fire in the Magazine area and for transport. The case of fire near an explosives truck in jammed traffic should also be covered. Drills of the emergency plans should be carried out at regular intervals.

3. Adverse weather working guideline should be followed and amended if necessary to clearly define procedures for explosives transport during thunderstorms.

4. The Magazine storage quantities need to be reported on a monthly basis to ensure that the two day storage capacity is not exceeded.

Specific recommendations for storage and transport of explosives are given below.

10.2.3 *Storage of Explosives in Magazine Store*

The Magazine should be operated and maintained in accordance with Mines Division guidelines and appropriate industry best practice. In addition, the following recommendations should be implemented.

1. A suitable work control system should be followed and amended if necessary, such as an operational manual including Permit-to-Work system, to ensure that work activities undertaken during the operation of the Magazine are properly controlled.

2. There should be good house-keeping within the Magazine to ensure that combustible materials are not allowed to accumulate.

3. The Magazine shall be without open drains, traps, pits or pockets into which any molten ammonium nitrate could flow and be confined in the event of a fire.

4. The Magazine building shall be regularly checked for water seepage through the roof, walls or floor.

5. Caked explosives shall be disposed of in an appropriate manner.

6. Delivery vehicles shall not be permitted to remain within the secured fenced off Magazine store area.

7. Good housekeeping outside the Magazine stores to be followed to ensure combustibles (including vegetation) are removed.

8. A speed limit within the Magazine area should be enforced to reduce the risk of a vehicle impact or incident within the Magazine area.

9. Traffic Management should be implemented within the Magazine site, to ensure that no more than 1 vehicle will be loading/loaded at any time, in order to avoid accidents involving multiple vehicles within the site boundary.

10.2.4 *Transport of Explosives*

General Recommendations:

The following measures should also be considered for safe transport of explosives:

1. Detonators shall not be transported in the same vehicle with other Class 1 explosives. Separation of vehicles should be maintained during the whole trip.

2. Location for stopping and unloading from truck to be provided as close as possible to shaft, free from dropped loads, hot work, etc. during time of unloading.

3. Develop procedure to ensure that parking space on the site is available for the explosives truck. Confirmation of parking space should be communicated to truck drivers before delivery. If parking space on site cannot be secure, delivery should not commence.

4. Ensure lining is provided within the transportation box on the vehicle and in good condition before transportation.

5. Ensure that packaging of detonators remains intact until handed over at blasting site.

6. Emergency plan to include activation of fuel and battery isolation switches on vehicle when fire breaks out to prevent fire spreading and reducing likelihood of prolonged fire leading to explosion.

7. Use only experienced driver(s) with good safety records.

8. Ensure that cartridged emulsion packages are damage free before every trip.

9. Ensure that explosives will be offloaded and stored away from the railway protection area according to the MTRCL railway protection area plan.

Contractors Licenced Vehicle Recommended Safety Requirements:

- Battery isolation switch;
- Front mounted exhaust with spark arrestor;
- Fuel level should be kept as far as possible to the minimum level required for the transport of explosives;
- Minimum 1 x 9 kg water based AFFF fire extinguisher to be provided;
- Minimum 1 x 9 kg dry chemical powder fire extinguisher to be provided;
- Horizontal fire screen on cargo deck and vertical fire screen mounted at least 150 mm behind the drivers cab and 100 mm from the steel cargo compartment, the vertical screen shall protrude 150 mm in excess of all three (3) sides of the steel cargo compartment;
- Cigarette lighter removed;
- Two (2) battery powered torches for night deliveries;
- Vehicles shall be dedicated explosive transport vehicles and should be maintained in good operating condition;
- Daily checks on tires and vehicle integrity;
- Regular monthly vehicle inspections;
  - Fuel system
  - Exhaust system
  - Brakes
  - Electrics
  - Battery
  - Cooling system
  - Engine oil leaks
- Vehicle log book in which monthly inspections and maintenance requirements are recorded; and
- Mobile telephone equipped.

Recommended Requirements for the Driver of the Explosives Vehicle:

The driver shall:

- be registered by the Commissioner of Mines and must be over the age of 25 years with proven accident free records and more than 7 year driving experience without suspension;
- hold a Driving Licence for the class of vehicle for at least one (1) year;
- adopt a safe driving practice including having attended a defensive driving course;
- pass a medical check and be assessed as fit to drive explosives vehicles; and
- not be dependent on banned substances.

Some of the following requirements may also apply to the vehicle attendant(s).

The driver is required to attend relevant training courses recognised by the Commissioner of Mines. The training courses should include the following major subjects, but not limited to:

- the laws and Regulations relating to the transport of explosives;
- security and safe handling during the transport of explosives;
- training courses provided by the explosives manufacturer or distributor, covering the following:
    - explosives identification;
    - explosion hazards; and
    - explosives sensitivity.
    - the dangers which could be caused by the types of explosives;
    - the packaging, labeling and characteristics of the types of explosives;
    - the use of fire extinguishers and fire fighting procedures; and
    - emergency response procedures in case of accidents.

The driver should additionally be responsible for the following:

- The driver shall have a full set of Material Safety Data Sheets (MSDS) for each individual explosive onboard the vehicle for the particular journey;
- The MSDS and Removal Permit (where applicable) shall be produced to any officer of the Mines Division of CEDD upon request;

- A card detailing emergency procedures shall be kept on board and displayed in a prominent place on the drivers door;
- Before leaving the Magazine the driver together with and / or assisted by the shotfirer shall check the following:
    - Packaging integrity and labeling;
    - Check that the types and quantities of explosives loaded onto the vehicle are as stipulated in the Removal Permit(s);
    - Check that the explosive load does not exceed the quantities stated in the removal permit;
    - Check the condition and integrity of the cargo compartment or box;
    - Check that detonators are not loaded in the explosives cargo compartment and vice versa;
    - Check that the cargo is secured and cannot be damaged during the delivery;
    - Ensure that the appropriate placards and a red flag are displayed before leaving the Magazine;
    - Be competent to operate all equipment onboard the vehicle including fire extinguishers and the vehicle emergency cut-off switches;
    - Prohibit smoking when the vehicle is loaded with explosives;
    - When explosives are loaded, ensure the vehicle is not left unattended;
    - Be conversant with emergency response procedures.

Specific Recommended Requirements for the Explosives Vehicle Attendants:

- When the vehicle is loaded with explosives, it shall be attended by the driver and at least one (1) other person authorized by the Commissioner of Mines. The vehicle attendant shall:
    - Be the assistant to the driver in normal working conditions and in case of any emergency;
    - Be conversant with the emergency response procedures; and
    - Be competent to use the fire extinguishers and the vehicle emergency cut-off switches.
- One of the vehicle attendant(s) should be equipped with mobile phones and the relevant MSDS and emergency response plan.

10.2.5 ***Type of Explosives & their Disposal***

- Explosive Selection:
  - Cartridged Emulsions with perchlorate formulation should be avoided; and
  - Cartridged Emulsions with high water content should be preferred.

Disposal Recommendations:

If disposal is required for small quantities, disposal should be made in a controlled and safe manner by a Registered Shotfirer.

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