1 INTRODUCTION

1.1 BACKGROUND

The Guangzhou-Shenzhen-Hong Kong Express Rail Link (XRL) is a cross-boundary transport infrastructure project providing high speed rail services between HK and Guangzhou and a connection to the national high-speed passenger rail network serving major mainland cities outside the Guangdong province. The XRL preliminary design was completed in December 2008 and the first gazetted drawings (G.N. 8022 of Nov 2008) were issued in November 2008. The MTR Corporation Limited (MTRC) has then decided to proceed with the Detailed Design of the XRL commencing in January 2009.

XRL construction is planned from Dec 2009 to 2014 / 2015. Excavation by blasting will be generally ongoing from 2011 to mid 2013.

The XRL Scheme consists of an underground terminus in West Kowloon, approximately 26 km of tunnels from the terminus to the mainland boundary near Huang Gang. After crossing the boundary, the Mainland section of the high-speed railway runs north for a further 116 km to Guangzhou. Trains on the Hong Kong section are intended to operate at speeds up to 200 kph.

Referring to *Chapter 2* of the EIA, the selection of construction methods has been optimised to minimise, as far as possible, the use of explosives depending on the type of material to be excavated. The breakdown per excavation method is approximately:

- Tunnel Boring Machine (TBM) (specially designed for soft soil excavation): ~8.5 km;
- Cut and Cover: ~2.0 km; and
- Drill and Blast: ~15 km.

As shown above, a substantial length of the XRL tunnels and adits (approximately 15 km) will be excavated in rock. A significant amount of explosives will be required for the construction of rock caverns, tunnels and adits.

To enable a timely delivery of explosives to site and in order to meet the proposed construction work programme, two Explosives Storage Magazines (Magazines) are required. The purpose of the Magazines is to maintain progress rates for construction activities, ie to meet multiple blasts per day and also act as a buffer in case of delivery interruptions by Mines Division (Mines Division) 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 Mines will deliver explosives and initiation devices (detonators) to the Magazine on a daily basis and these will be withdrawn by the contractors as required.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 magazines or directly to sites is under Mines' responsibility and falls outside the scope of this EIA.

The appointed contractors of MTRC will transport explosives in Mines Division licensed trucks to be operated by the contractors, from the Magazine to a particular construction site for daily or twice-daily blasts depending on the requirements for construction. Generally, the quantity of explosives that can be transported in any 3rd party contractor's truck is limited by the Mines Division to maximum 200kg.

The explosives to be stored and transported from the magazines to the construction sites will include detonators, detonating cord 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-197/2008* for this project (EIA Study Brief). *Section 3.4.2* of the EIA Study Brief requires that, if there is overnight storage of explosives magazine and the storage location is in close vicinity to populated areas, and/or Potentially Hazardous Installation site, the Applicant shall carry out hazard assessment.

ERM-Hong Kong, Limited (ERM) was commissioned by MTRC to undertake the Hazard to Life Assessment for the storage and transport of explosives during the XRL Construction Stage 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 of the EIA Study Brief are shown below.

Figure 1.1 EIA Study Brief – Hazard to Life Requirements

3.4.2 Hazard to Life

3.4.2.1 If the Project will use explosives (of Cat. 1 Dangerous Goods and/or prepared from Cat. 7 Dangerous Goods), the Applicant shall describe the statutory/licensing requirements with respect to explosives under the Dangerous Goods Ordinance (Cap. 295). The Applicant shall also document any guidelines and/or advice obtained from relevant departments/ authorities on the proposed transport and storage of explosives for the blasting activities.

3.4.2.2 If there is overnight storage of explosives magazine and the storage location is in close vicinity to populated areas and/or Potentially Hazardous Installation site, 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) Identify and assess practicable and cost-effective risk mitigation measures.

The methodology to be used in the hazard assessment should be consistent with previous studies having similar issues.

3.4.2.3 If the railway alignment passes through the consultation zone (CZ) of WSD Water Treatment Works (e.g. Shek Lei Pui Water Treatment Works) and/or any other potentially hazardous installation(s) associated with gas as defined in the Gas Safety Ordinance (Cap. 51), and there is above ground works within the CZ during the construction or operational phase of this project, the Applicant shall carry hazard assessment as follows :

(i) Identify hazardous scenarios associated with:

(a) the on-site transport, storage and use of chlorine at the Water Treatment Works; and/or

(b) the on-site transport, storage and processing of gas as defined in the Gas Safety Ordinance (Cap.51) at the potentially hazardous installation(s); and then determine set(s) of relevant scenarios to be included in Quantitative Risk Assessment(s) (QRA);

(ii) Execute respective QRA for each of the works and installation(s) with 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 The methodology to be used in the hazard assessment should be consistent with previous studies having similar issues. hazard to life stipulated in Annex 4 of the TM; and;

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

The methodology to be used in the hazard assessment should be consistent with previous studies having similar issues.

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*

The hazard to life assessment under this section of the EIA, addresses, in particular, the following:

- Storage of explosives at the proposed magazines (cartridged emulsion, detonating cord and detonators) including handling of explosives within the magazine sites; and
- Transport of Explosives to the delivery points.

The scope of the study concerns the transport of explosives (cartridged emulsion, detonating cord and detonators) from the magazines to the construction sites.

Detonators are used in relatively small quantities and transported separately. Bulk emulsion and/or Ammonium nitrate – fuel oil (ANFO) will be used in this project as the blasting explosive. Cartridged emulsion will be used to initiate the blasting explosive.

Bulk emulsion (unsensitised) is not classified as an explosive substance (ie Category 1 Dangerous Good) in Hong Kong (it is classified as Category 7 Dangerous Good, ie strong supporters of combustion) until sensitized within the blast holes at the excavation face, and hence is out of the scope of this study. ANFO, if used in this project, will be produced at the construction site by mixing an oxidizing substance ie Ammonium nitrate, classified as Category 7 Dangerous Good, with fuel oil. Although ANFO is classified as an

explosive (Class HD 1.1D under United Nation Classification), it will not be transported to the construction site as such and hence falls outside the scope of this study.

To be consistent with West Island Line Project (ERM 2008), the risks associated with transport of explosives are limited to the delivery by contractor trucks up to the blasting sites boundaries and exclude the manual transportation from trucks.

With reference to the study brief clause 3.4.2.3, there is no work area within the consultation zone of the PHIs under which the alignment is passing through. Based on this, the PHI assessment is not considered applicable for this hazard to life assessment.

The hazard to life assessment presented in this section relates to the storage and handling of explosives during the construction phase of the project. There will be no explosives handled during the operational phase of the project.

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 XRL construction phase 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 measures to demonstrate compliance with the EIAO TM Criteria.

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 temporal factors.

The maximum level of off site individual risk should not exceed 1 in 100,000 per year, ie $1x10^{-5}$ 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 1.2*. 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.

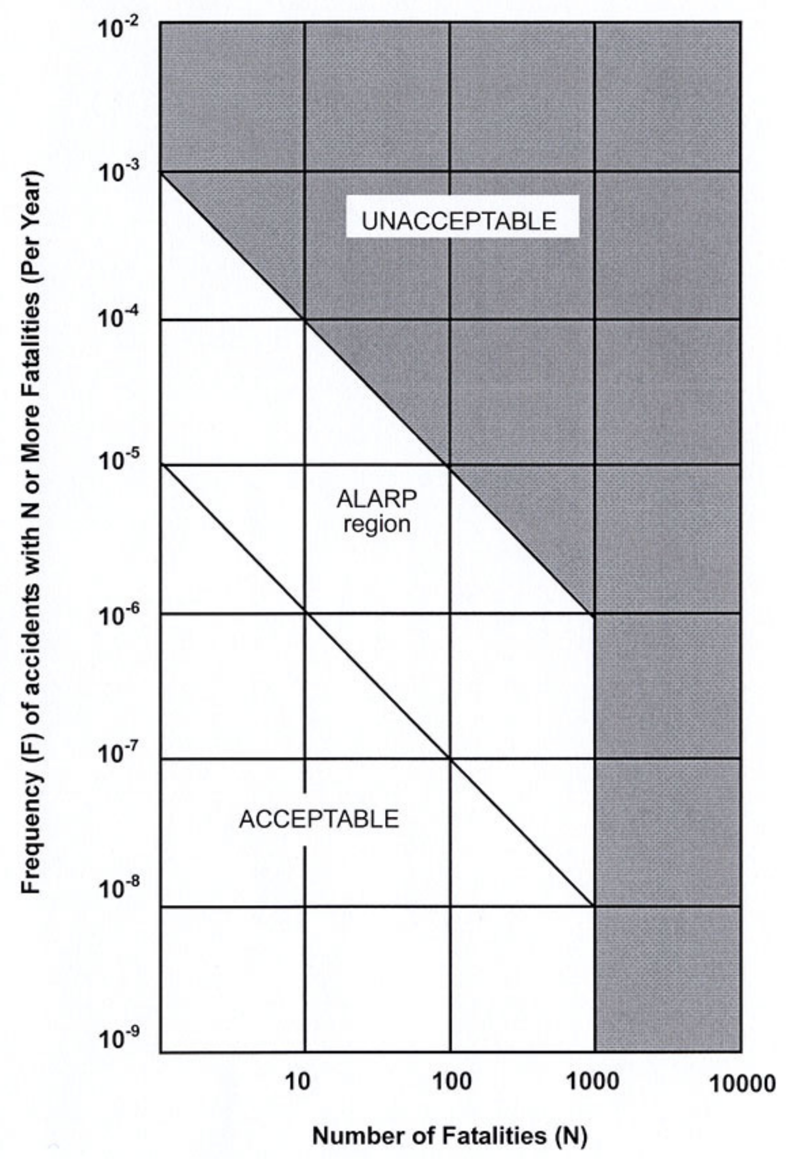
The risk guidelines incorporate a special requirement (as seen in *Figure 1.2*), that no hazardous scenario shall cause more than 1,000 fatalities. If so, the risks are deemed 'unacceptable' and need to be reduced regardless of the cost.

Application of Criteria

Making reference to other studies which involved the transportation of explosives in Hong Kong (ERM 2008 , Maunsell 2006), 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. Injures 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 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, MTRC staff or its contractors have not been included in the assessment.

Figure 1.2 Societal Risk Criteria in Hong Kong



2 PROJECT DESCRIPTION AND BASIS FOR THE ASSESSMENT

2.1 PROJECT OVERVIEW

The Guangzhou-Shenzhen-Hong Kong Express Rail Link (XRL) is a cross-boundary transport infrastructure project providing high speed rail services between HK and Guangzhou and a connection to the national high-speed passenger rail network serving major mainland cities outside the Guangdong province.

The project comprises approximately 26km of tunnel from the Huang Gang Ventilation Shaft (HGV) north of the Boundary between the Shenzhen Special Economic Zone (SEZ) and the Hong Kong Special Administrative Region to a terminus station in West Kowloon. In addition, the project includes seven stand-alone ventilation buildings, two ventilation adits and six ventilation shafts, an Emergency Rescue Station, a series of stabling sidings with an integrated first line maintenance facility and other associated buildings and facilities. The entire XRL alignment within Hong Kong will be constructed in tunnel except the sub-surface Emergency Rescue Station (ERS), the at-grade Shek Kong Stabling Sidings (SSS) and the seven Ventilation Buildings (VB) which will be built above ground. The proposed XRL alignment and work areas are shown in *Figure 2.1*.

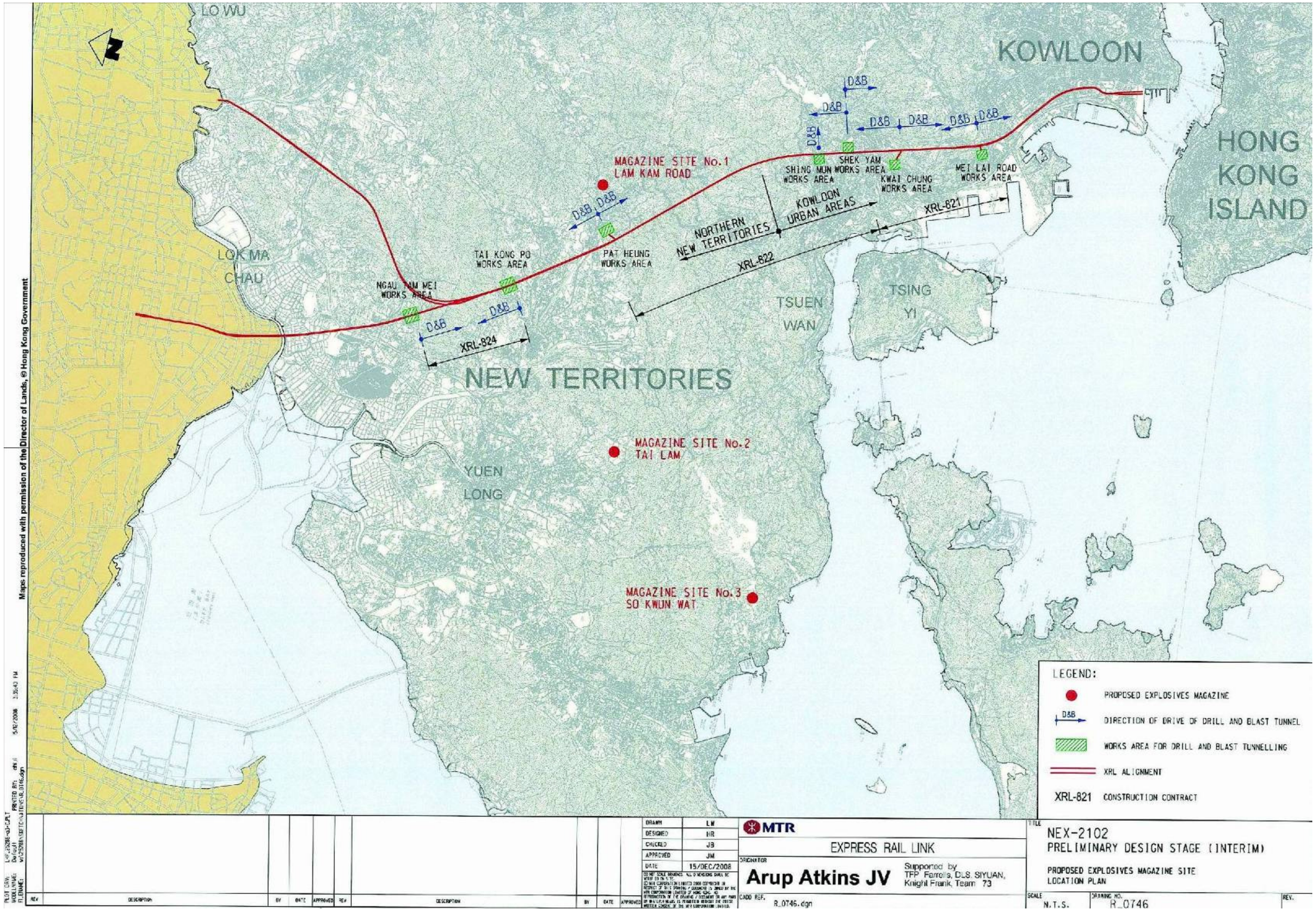
XRL construction is planned for Dec 2009 to 2014 / 2015. Excavation by blasting will be ongoing generally from 2010 to mid 2013.

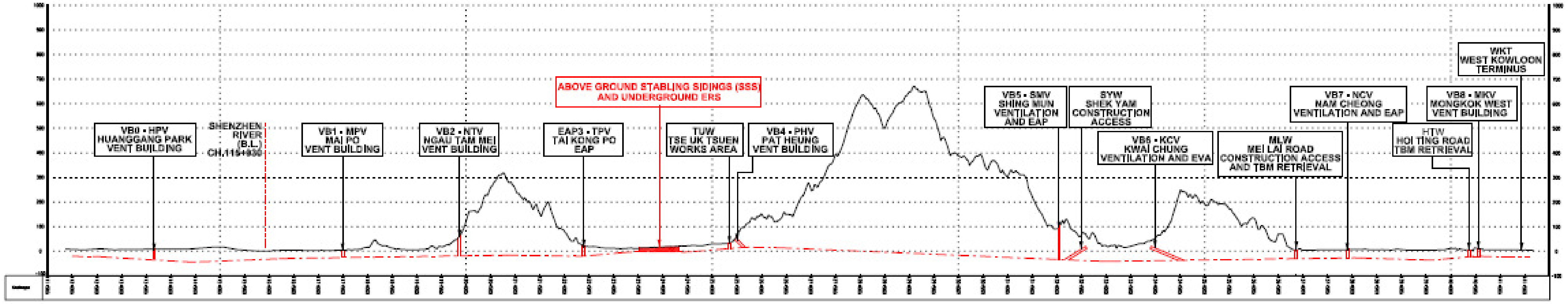
It is recognised that, from a risk point of view, blasting is not a desirable construction method; however, due to impracticability in using other techniques, blasting is required for some sections of the alignment. The selection of construction methods for the tunnels is detailed in Working Paper No. 6 - Interim Preliminary Design Alignment (MTRC 1) and Deliverable No. D2.4 - Value Engineering Report No. 1 (MTRC 2). Details of the construction method, including the location and production rate are provided in Deliverable No. D3.17 – Final Works Programme (MTRC 3).

A substantial portion of the XRL tunnels and adits (approximately 15 km) will be excavated in rock. A significant amount of explosives will be required for the construction of rock caverns, tunnels and adits.

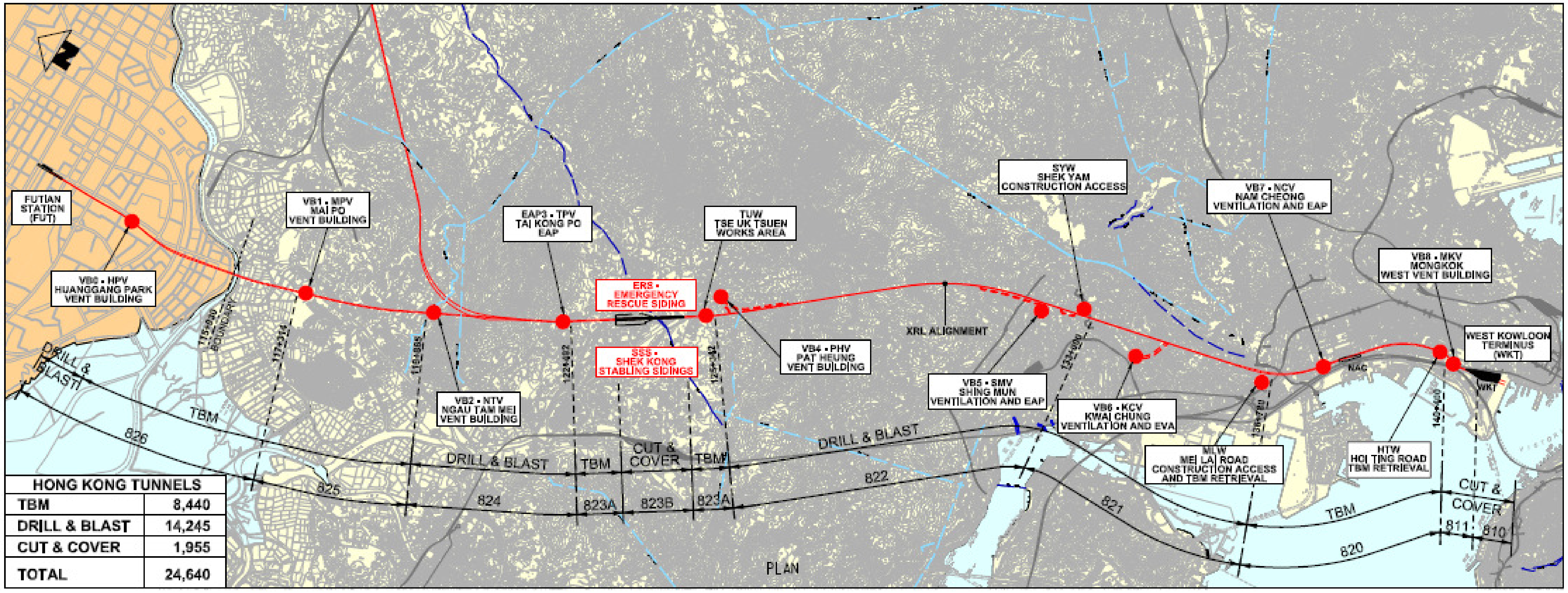
For the purposes of this study, the alignment is divided into two areas. The northern area contains those tunnels and associated structures for which excavation will be carried out from worksites within the northern New Territories. The southern area contains those tunnels and associated structures for which excavation will be carried out from worksites within the urban Kowloon areas. It is preferable that each area has its own explosives magazine in order to limit the travelling distances of explosive trucks from the Magazines to the underground worksites. This is particularly pertinent given explosives are not permitted to be transported within road tunnels.

Figure 2.1 XRL Proposed Alignment and Work Areas





ELEVATION



HONG KONG TUNNELS	
TBM	8,440
DRILL & BLAST	14,245
CUT & COVER	1,955
TOTAL	24,640

PLAN

DRAWN	LW
DESIGNED	TM
CHECKED	TM
APPROVED	TM
DATE	20/MAY/2009

MTR
EXPRESS RAIL LINK
ATKINS
Supported by Arup, TFP Farrells, DLS Kenneth Ng
CADD REF. X_0412.dgn

CONTRACT C802
TUNNELS & ASSOCIATED STRUCTURES (SOUTH)
XRL ALIGNMENT
(PLAN & ELEVATION)

SCALE N.T.S. DRAWING NO. X_0412 REV. –

Twelve separate work contracts have been identified for the construction of the XRL tunnels and associated structures, three of which will use Drill and Blast construction method as the dominant construction method. The work areas and the associated contracts using Drill and Blast are shown in *Table 2.1* below.

Table 2.1 *XRL Contracts and Works Areas*

Contract No.	Storage Magazine	2 Day Explosive Storage Requirement per contract	Works Area	Blast Faces	Delivery Point
Southern Area					
821	So Kwun Wat	600 kg	Kwai Chung	- North drive - South drive - Adit	2d- Kwai Chung
			Mei Lai Road	- North drive - South drive - Adit	2e- Mei Lai Road
822	So Kwun Wat	600 kg	Shek Yam	- North drive - South drive - Adit	2b- Shek Yam
			Shing Mun	- Adit	2c- Shing Mun
Northern Area					
822	Tai Lam	400 kg	Pat Heung	- North drive - South drive - Adit	1b- Pat Heung
824	Tai Lam	400 kg	Tai Kong Po	- North drive	1c- Tai Kong Po
			Ngau Tam Mei	- South drive	1d- Ngau Tam Mei

To enable a timely delivery of explosives to site and in order to meet the proposed construction work programme and allow for a buffer in the event of delays to replenishment of the magazines, two explosive storage magazines are required, one for the southern area with a total explosive storage capacity of 1200 kg and one for the northern area with at total capacity of 800 kg. Each magazine consists of at least 2 or more individual magazine stores; each store will not be shared between contractors. Detonators will be stored in a separate chamber within each store. The purpose of the Magazines is to maintain progress rates for construction activities in case of delivery interruptions by

Mines Division. Mines Division will deliver explosives and initiation devices (detonators) to the Magazine on a daily basis.

The appointed contractors of MTRC will transport explosives in licensed trucks (licensed by Mines Division) to be operated by the contractors, from their allocated Magazine store to a particular construction site for the daily or twice-daily blasts depending on requirements for construction. Generally, the quantity of explosives that can be transported in any 3rd party contractor's truck is limited by the Mines Division to maximum 200kg.

The explosives to be stored and transported from the Magazines to the construction sites will include detonators, detonating cord and cartridged emulsion.

The majority of the XRL Drill and Blast tunnels will be a single bore, twin track tunnel, with an average full face excavation area of approximately 125m^2 (ie a dedicated tunnel for each direction). Each blast would require, on average, 125 production holes and 45 perimeter holes. If a pull length of 5m per blast is assumed, then each blast would need approximately:

- 20kg of detonating cord with a Pentaerythritol Tetranitrate (PETN) load density of 40g/m;
- 22kg of cartridged emulsion (assuming the use of 125g cartridged emulsion);
- 950kg bulk emulsion (sensitised on site) or ANFO (produced at site); and
- 170 detonators (Non Electric detonators (1g/ detonator) eg. Nonels).

The blasting programmed is based on the following advance rates:

- 120m / month cycle: based on 6 blast cycles a week (1 per 24 hrs) with a 5m pull rate per day;
- 168m / month cycle: based on 8.5 blast cycles a week (3 per 48 hrs) with a 5m pull rate per day;
- 60m / month cycle: similar to the 120m cycle, but with alternating heading / bench excavation which reduces the advance rate by half. Also, it allows for shorter pull length in poor ground.

2.2 EXPLOSIVE TYPES FOR XRL

2.2.1 PROPOSED EXPLOSIVES

Two types of explosives will be used for the construction of XRL by Drill and Blast methods. These are:

- Initiating explosives: cartridged emulsion explosives, detonating cord and detonators; and

- Blasting explosives: site-sensitised bulk emulsion explosives or site mixed ANFO.

Both the cartridged and bulk emulsions contain 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. ANFO has similar composition but has no water or aluminium content.

Cartridged emulsion will be delivered from the Explosive Magazine to the various construction sites by the appointed contractors using Mines Division licensed trucks.

Bulk emulsion precursor will be transported to the blast sites within the Adits/Tunnels by the appointed third party supplier. It only becomes classified as an explosive after being sensitized at the blast location or working face, by the addition of a gassing agent as it is pumped into the blastholes at the excavation face.

ANFO, if used, will be also prepared at the construction site.

Detonators and detonating cord will be used to initiate the blast at the working face. Detonators approved for use in Hong Kong are of the Non-Electric Type, ie. initiated by shock tube.

2.2.2 *Explosives Properties and Regulations*

Explosives that are relevant to the XRL 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	Example
Blasting explosives	Explosive used as main blasting explosive	General blasting, Shattering rock/structures	Bulk emulsion, ANFO
Initiating explosives	To initiate the main blasting explosives	Initiation of secondary explosive	Detonators, Cartridged emulsion Detonating cord

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, ie 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 *Bulk Emulsion Precursor*

Bulk Emulsion has a similar composition to Cartridged Emulsion, except that it does not contain aluminium and is non-sensitized. The bulk emulsion precursor has a density of 1.38-1.40 gms/cc. Prior to sensitizing, it is not considered as an explosive and is classified as UN 5.1 oxidising agent and Dangerous Goods Ordinance (Cap. 295) Category 7, ie Strong Supporters of Combustion. This material is stored in a Category 7 store, which falls under the jurisdiction of the Fire Services Department (FSD), and not Mines Division.

Bulk emulsion precursor is stable under normal conditions and there is no major fire hazard before sensitization. Hazards associated with bulk emulsion precursor are mainly due to its oxidizing properties causing irritation to eyes and skin. Explosion is considered possible only under prolonged fire, supersonic shock or very high energy projectile impact.

Storage and transport of bulk emulsion precursor is not included within the scope of this study.

2.2.5 *Bulk ANFO*

Depending on blasting requirements, ANFO may be used in this project. ANFO will be produced on site by using a mixing truck. ANFO consists of an oxidizing substance mixed with 6% by weight of diesel fuel oil. ANFO is classified as UN HD 1.1D.

2.2.6 BLASTING EXPLOSIVE: BULK EMULSION

Bulk emulsion or ANFO, depending on project requirements, will be used as the main or 'bulk' blasting explosive to excavate rock by tunnel blasting. Both will be manufactured on site and require the use of initiating explosives.

Bulk emulsion precursor is sensitised at the blast site by the addition of a gassing solution containing sodium nitrite. This is applied at the excavation face underground and is added to the charging hose downstream from delivery pump.

ANFO is manufactured on site by mixing an oxidizing substance with oil.

A delivery pump is used for the loading of the blasting explosives into the blastholes. There are two different types of pump driving mechanisms, which are:-

- Pneumatic; and
- Hydraulic.

A hydraulic driven pump has a delivery accuracy of ± 100 g, compared to a pneumatic driven pump with an accuracy of ≥ 200 g.

For emulsion, a gassing solution is injected into the precursor to reduce the density to 0.8 to 1.1g/cc at the discharge end of the loading hose. This sensitises the emulsion by producing nitrogen gas bubbles that aid the propagation of the detonation wave. Hence, the bulk emulsion does not become an explosive until it is pumped into the blastholes at the working blast face. The sensitised emulsion can then be detonated with the assistance of a small booster (generally, a stick of cartridged emulsion) and a detonator. The bulk emulsion, once it is gassed is classified as UN 1.5D explosive or a Dangerous Goods (DG) Category 1 explosive under the Hong Kong classification system.

Blasting explosives which are pumped into blastholes completely fill the blasthole and thus are 'fully coupled' to the rock. This results in improved explosive performance.

2.2.7 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; however, these are no longer used therefore, 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 in a manner such that they may be handled

and used with minimal risk. They are packaged in a manner that, 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 6.5mm 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 0.9g. 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.

2.3 STATUTORY/LICENCING REQUIREMENTS AND BEST PRACTICE

The Commissioner of Mines Division 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 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 type 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 work site for the carrying out of blasting. The Division is responsible for delivering explosives to blasting sites and carrying out audit inspections at times that match with the works 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) explosives depot. Users will then place orders from Mines Division for delivery to their 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 this List. All the explosives to be transported in the XRL 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 at the blasting location. The blast design will be produced by the blasting engineer using computer aided tools, checked and approved by the project Registered Engineer (RE), and then endorsed by Mines Division 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 and detonators for the blast will be collected by the Registered Shotfirer and delivered to the blasting site by the licensed 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 consultant (ie. Resident Site Engineer, (RSS)), a representative from the Contractor, and sometimes on a spot-check basis, a representative from Mines Department.

Licensing Requirements for Transportation of Explosives from the Magazines 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 5kg 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 licensed 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) 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;

(b) 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;

(c) An emergency procedure appropriate to the explosives being carried shall be approved by Mines Division; and

(d) The driver and attendant shall have documentary evidence that they have acquired the basic knowledge of handling explosives and the properties of explosives being carried; and are conversant with the emergency procedures.

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; and

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

Condition of Cargo Compartment:

(a) The cargo compartment of the vehicle, including the floor, shall be constructed with sheet metal at least 3mm 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.

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

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 shall be located in front of the cargo compartment of the vehicle.

(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) At least two serviceable water or carbon dioxide fire extinguishers with a minimum capacity of 2 kilograms each shall be mounted on the vehicle in an easily accessible position.

(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) Explosives or detonators shall not be carried on the same vehicle.

Display 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 250mm x 250mm) 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"

of red colour displayed on both sides and rear face of the goods compartment.

A typical contractor's explosive vehicle within a typical Hong Kong Mode A Explosive Store is shown in *Figure 2.2*. It is to be noted that truck shown on the figure was used on the MTR Penny's Bay Link project in 2003, and at this time the vehicle was not required to be painted white.

Figure 2.2 ***Typical Contractor's Explosive Truck and Magazine***

2.3.2 STORAGE AND USE OF EXPLOSIVES

Explosive Magazine

All Magazines will comply 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 Explosives Store Licence". Each magazine will be a single storey detached bunded structure with dimensions as specified on Mines and Quarries Division Drawing MQ1630 "Typical Details of Explosives Magazine – Plan A". All magazine buildings will each be fenced and secured in accordance with the Commissioner of Mines' requirements and surfaced road access suitable for 11 tonne trucks will be 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 Manufacture and Storage of Explosives Regulations 2005 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 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 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 four 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.

Explosives Produced at Site

Bulk emulsion explosives and bulk ANFO are commonly manufactured at blast sites and used immediately for rock blasting. Under Regulation 31A of the Dangerous Goods (General) Regulations, *Cap. 295B*, a licence is required to manufacture a nitrate mixture outside a factory as Category 1 dangerous goods. The Commissioner of Mines is the Authority for issuing the licence.

The Manufacturing Unit (MU) shall follow the following requirements:

The owner of an MU should make an application to the Commissioner of Mines in writing for approval of the MU for manufacture of bulk explosives at blast sites. An approval of the MU will be issued, subject to satisfactory compliance with the following documentation requirements:

(a) A manual on operation of the equipment fitted to the MU and on procedures for manufacturing explosives;

(b) Procedures for safe handling and use of the manufactured explosives;

(c) Procedures for disposal of any waste product;

(d) A risk assessment on overheating, building up of high pressure at product pump, etc., and the associated control measures on how to prevent the hazards during the manufacturing process of explosives;

(e) Emergency response plan to deal with hazards of the raw materials being transported, fires on carrying vehicle, etc and an emergency contact list; and

(f) Technical and safety information set out in Annex A of the document (CEDD 4).

For surface or underground transport by vehicles, the Transport Unit (TU) carrying a Manufacturing Unit (MU) must comply with the following requirements:

(a) It shall have a diesel-powered engine.

(b) The TU carrying an MU shall be roadworthy with a valid vehicle licence issued by the Commissioner for Transport.

(c) The TU shall be equipped with an emergency stop at an easily accessible position.

(d) All cables to rear lights shall be fitted with fire resisting conduits.

(e) The TU shall be equipped with two 9 kg dry chemical powder fire extinguishers.

(f) The TU shall be equipped with personal protective equipment, which shall be worn by all operators appropriate to the products being handled, in accordance with the MSDS.

(g) No explosives, detonators or other dangerous goods shall be carried on the TU.

(h) Where mechanical track haulage is used for underground transport, the electric locomotive shall pull the trailer carrying the MU as close as possible to the blast face. The locomotive shall be equipped with:

  (i) Effective headlights and rear lights, and

  (ii) Adequate earthing provisions.

Storage of Cat. 7 Dangerous Goods

Ammonium nitrate (AN) is used for manufacturing bulk emulsion explosives and bulk ANFO at blast sites. Under Regulation 3 of the Dangerous Goods (Application and Exemption) Regulations, *Cap. 295A*, AN is classified as Category 7 – Strong Supporters of Combustion. A licence for the storage of Cat. 7 Dangerous Goods (DG) is required. The Fire Services Department is the authority for issuing the licence.

The following are the general requirements from the Fire Services Department (FSD) in processing the application

(a) The Dangerous Goods store is to be provided in accordance with plans approved by the Director of Fire Services.

(b) High and low level ventilators covered internally with brass wire gauze and externally with non-corrodible metal gratings to be provided to the store.

(c) "NO SMOKING" notices and the names of the Dangerous Goods in 120 mm English and Chinese characters to be painted on the door of the store.

(d) A 'Cat. 7 D.G.' plate, which may be purchased from Fire Protection Command Headquarters, to be provided and fixed at a conspicuous position above the main entrance to the premises.

(e) One 9-litre water type fire extinguisher and two buckets of sand to be provided and allocated outside the Dangerous Goods store near the doorway.

(f) No storage of any articles or goods to be effected in the vicinity of the store tank.

(g) No shades over any open yard to be permitted.

(h) The interior of the Dangerous Goods store and around the premises is to be cleared of rubbish and maintained in a clean and tidy condition.

(i) The ultimate licensee/user must confirm in writing to the Department that he is in fact in receipt of the approved plans and set of F.S. requirement.

(j) The actual layout of the installation is to be in accordance with the plans approved by Director of Fire Services.

(k) If mechanical ventilation is provided, details/plans to be submitted to the Ventilation Division of the FSD for approval prior to the commencement of work.

(l) Any proposed alteration to the Fire Service Installation on the premises to be carried out by a registered Fire Service Installation Contractor (appropriate to the class) and amended Fire Service Installation plan are required to be approved by the FSD, prior to the commencement of work. The installation is to be tested to the satisfaction of the FSD.

(m) Lighting rod and earthing connections shall be provided to the store.

Detailed requirement for the storage of Dangerous Goods will be provided upon the owners of storage units make an application to Fire Service Department in writing. An approval licence will then be issued, subjected to the satisfactory compliance with the requirements.

For outside emulsion matrix Cat. 7 storage, FSD would typically require compliance with the following requirements:

(a) The compound shall be fenced.

(b) A six metre clearance should be maintained between the tank(s) and the fence in all directions.

(c) Adequate lightning protection shall be provided.

(d) The bund shall be able to contain at least 110% spill of the largest tank inside the bund.

(e) Sand/water buckets and appropriate fire extinguishers should be made available.

(f) Safety signage should be provided.

(g) There should not be any other combustible material within the compound.

2.4 *DESIGN AND LOCATION OF THE EXPLOSIVE MAGAZINE*

As the magazine sites in both the northern and southern areas will need to service two works contracts each (Northern area: Contracts 822 and 824 and Southern area: Contracts 821 and 822), two separate magazines will be required, one for each contractor. Potential magazine site locations in both the north and the south have been investigated. Of these, a site in So Kwun Wat and a site in Tai Lam have been identified suitable for locating explosives magazines. The Tai Lam site will serve worksites (Contracts 824 and 822) in the Northern New Territories and the So Kwun Wat site will serve the worksites within the urban Kowloon areas (Contracts 822 and 821). The locations of the magazines and contract packaging are shown in *Figure 2.1.* All sites comply with the separation requirements of Mines Division.

Each 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 magazines by Mines Division. The storage quantity for each magazine has been determined with sufficient margin by the design consultant based on estimated project explosives consumption.

So Kwun Wat site

The site is located in area of low population density. There is a low population density development just outside the safety distance zone. In order to comply with the separation distance requirements (MSER, 2005), a configuration has been adopted that comprises 4 magazine structures storing 300kg of explosives each. A preliminary magazine design plan for this site is provided in *Figure 2.3* and the magazine location is shown in *Figure 4.2*.

Tai Lam Site

A single site configuration has been considered that comprises two magazine compounds, each with a single structure storing 400kg 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 (MSER, 2005). A preliminary magazine design plan for this site is provided in *Figure 2.4*. The layout is to be finalized in the detailed design phase. The location of the magazine is shown in *Figure 4.1*.

Figure 2.3 So Kwun Wat Magazine Site Layout

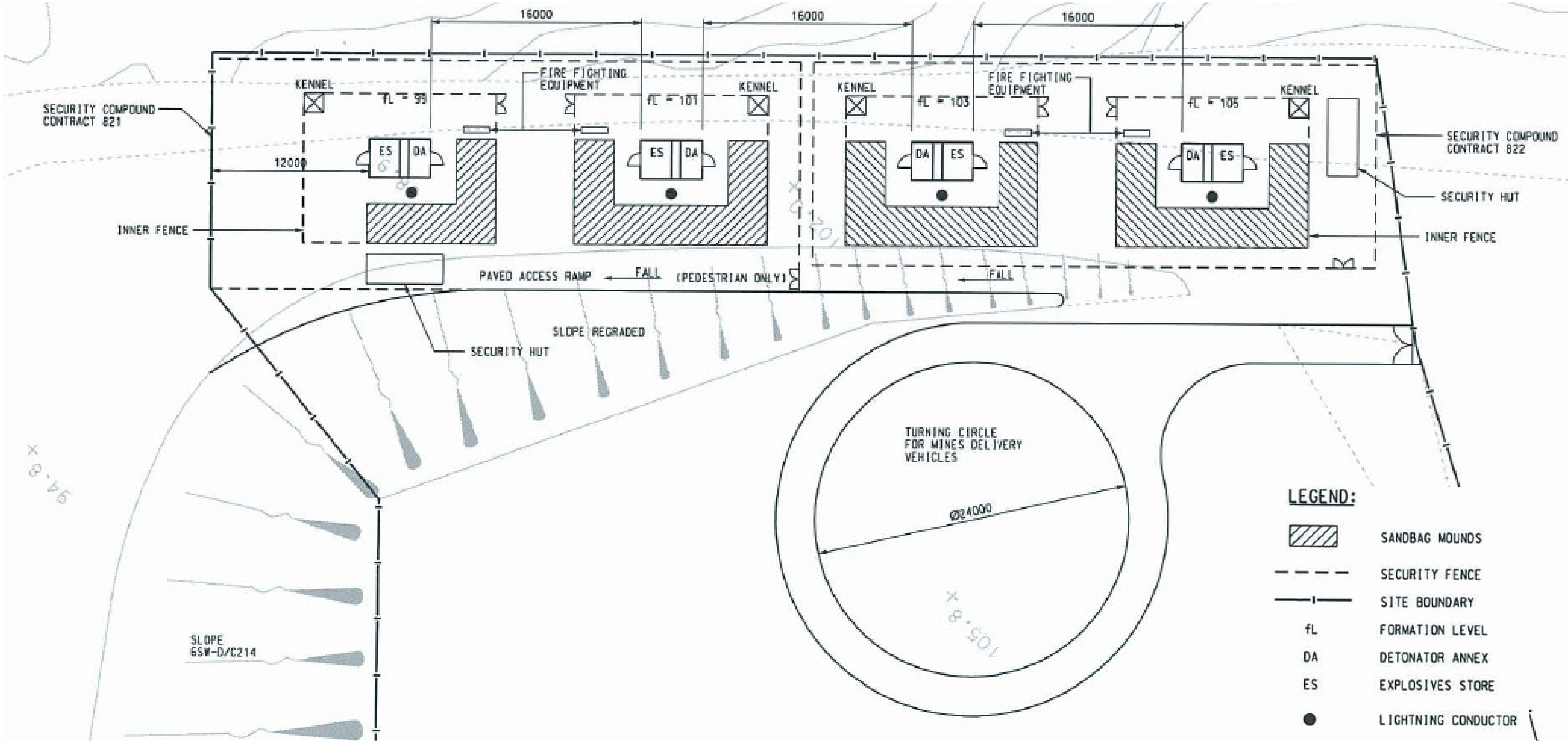
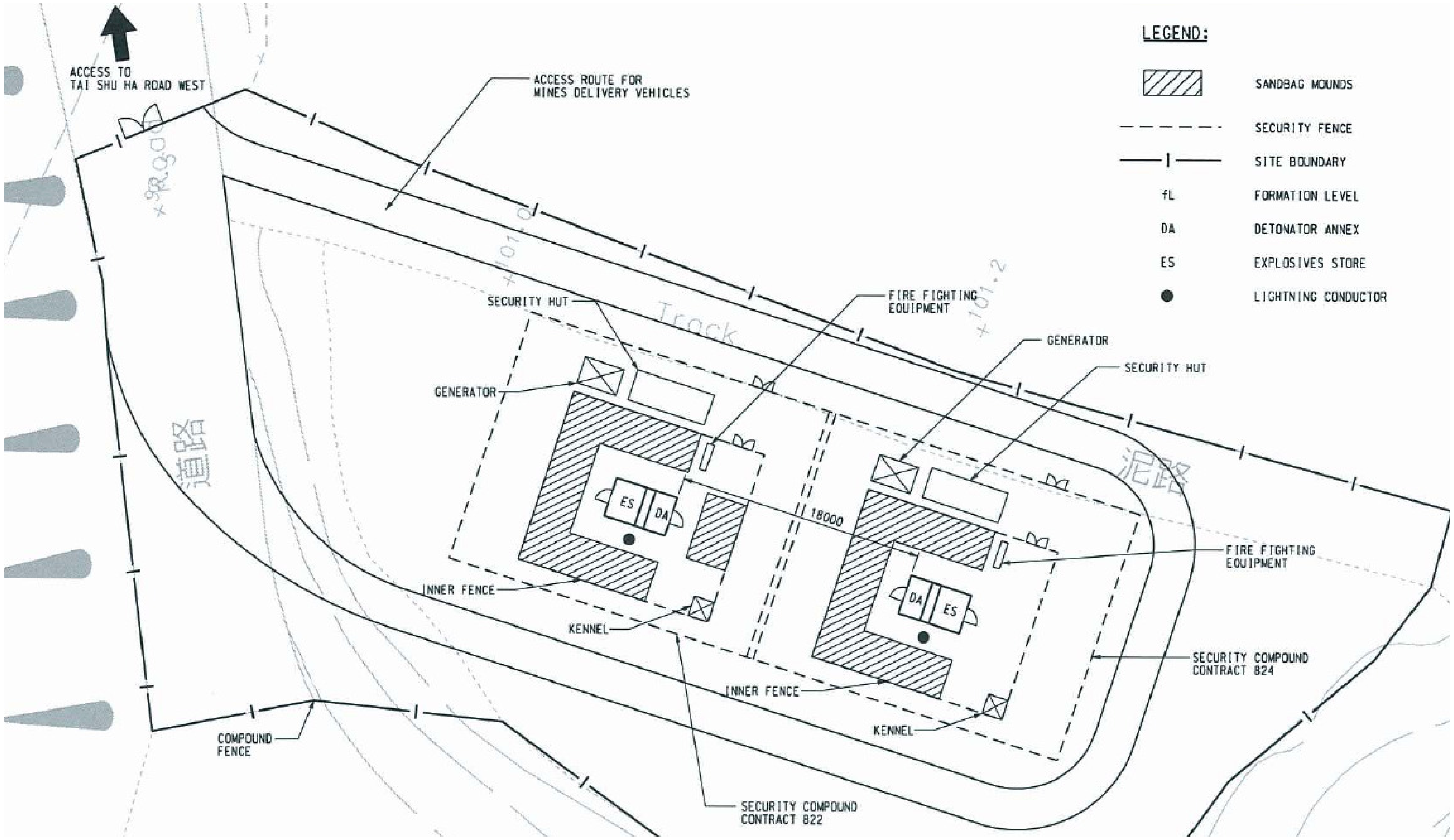


Figure 2.4 Tai Lam Magazine Site Layout



2.5 CONSTRUCTION CYCLE AND PROGRAMME OF THE XRL TUNNELS AND ADITS

2.5.1 CONSTRUCTION CYCLE

After commissioning of the Magazines 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 magazine store(s). Each contractor will have one or more dedicated explosive stores.

3. Transfer from the explosives store(s) to the main construction access shafts of the excavation utilizing public roads via routes as indicated in *Figure 2.6*, *Table 2.10*, and *Table 2.11*.

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.

6. Storage in the magazine store(s). Each contractor will have one or more dedicated explosive stores.

2.5.2 DRILL AND BLAST INITIATING EXPLOSIVE REQUIREMENTS

Based on the envisaged XRL construction programme, the Drill and Blast activities together with the required amount of initiating explosives is summarised as shown in *Table 2.3*. The actual amount of initiating explosives is based on the tunnel profiles described in *Table 2.4* and the types of explosives listed in *Table 2.5*.

Table 2.3 XRL Drill and Blast Initiating Explosive Requirements (Summary)

Works Area	Delivery Point	Blast Face	Approximate No of Blasts	Initiating Explosive Load (kg/blast)
Mei Lai Road (821-S)	2e			
		Adit	130	27
		South	198	31
		North	496	18
Kwai Chung (821-S)	2d			
		Adit	177	38-51
		South	346	39
		North	293	39

Works Area	Delivery Point	Blast Face	Approximate No of Blasts	Initiating Explosive Load (kg/blast)
Shek Yam (822-S)	2b			
		Adit	144	23
		South	115	39
		North	750	39-51
Shing Mun (822-S)	2c			
		Adit	30	27
Pat Heung (822-N)	1b			
		Adit	86	38-51
		South	779	39-51
		North	160	23
Tai Kong Po (824-N)	1c			
		North	216	23
			218	42
			141	39
Ngau Tam Mei (824-N)	1d			
		South	262	42
			131	39

Table 2.4 XRL Drill and Blast – Typical Tunnel Profiles

Profile	Description	Section Area (m²)	No of production holes	No of perimeter holes	Primer (kg)	Detonating Cord (kg per meter drilled)	Detonators (kg)
Adit	Ventilation Adit	179	215	45	33	0.08	0.26
AditKC	Kwai Chung Adit	180	215	45	33	0.08	0.26
AditPH	Pat Heung Adit	180	215	45	33	0.08	0.26
AditSM	Shing Mun Adit	116	125	45	21	0.08	0.17
CAdit	Construction Adit	62	68	28	12	0.08	0.10
CAditTbm	Construction Adit for TBM Removal	145	130	45	22	0.08	0.18
ST	Single Tube Single Track	58	68	28	12	0.08	0.10
STa	Single Tube Single Track TBM Reception	145	130	45	22	0.08	0.18
TT	Single Tube Twin Track 7.2m Centres	125	125	45	21	0.08	0.17

Profile	Description	Section Area (m²)	No of production holes	No of perimeter holes	Primer (kg)	Detonating Cord (kg per meter drilled)	Detonators (kg)
TTa	Single Tube Twin Track 7.2m Centres with TVS 2No. 30m2	200	222	45	33	0.08	0.27
TTaa	Single Tube Twin Track 7.2m Centres with TVS 2No. 30m2 (Vertical wall)	204	222	45	33	0.08	0.27
TTc	Single Tube Twin Track 12m Centres	182	215	45	33	0.08	0.26
TTd	Single Tube Twin Track 12.8m Centres	196	222	45	33	0.08	0.27

Table 2.5 XRL Drill and Blast – Initiating Explosive Types

Explosive	Quantity per Production/Perimeter Hole
Cartridged emulsion	0.125 kg (125 g per cartridged emulsion)
Detonating Cord	0.080 kg/m based on density of 0.040 kg/m (40 g/m)
Detonator	0.001 kg (9 g each)

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 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 explosive delivery truck when the blasting programmes for the blast faces of the work area overlap (eg when the blasting programme for a southern drive based on 24h or 12h cycle overlaps with the blasting programme of the northern drive based on a 24h or 12h cycle for the same work area, a single explosive delivery will most likely be made). It follows that the initiating explosives for Kwai Chung southern and northern drives can be combined on a same explosive delivery with a total initiating explosive quantity of 78 kg. 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 or less 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 and/or bulk ANFO, which will be manufactured on-site. The on-site manufacture of ANFO and 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 explosive delivery from the relevant magazine 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 specific site conditions (eg. geology). To consider the uncertainty in the envisaged construction programme, a Base Case, which accounts for expected programme variations, and a Worst Case, which presents the worst programme scenario, have been considered for the assessment.

Base Case for the Hazard to Life Assessment

Based on the envisaged construction programme and sequence of works, the annual travel distance by explosive vehicles, carrying cartridged emulsion and detonating cord, will reach a peak in the period between September 2011 and August 2012, as shown in *Table 2.6*. This period is referred as the peak explosive delivery period which is taken to represent the Base Case scenario for the Hazard to Life Assessment. Within this period, the annual number of deliveries is 2671 while the explosive trucks travel distance is around 42,000 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 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 explosive load has been estimated on the basis that, for a particular delivery point, when the blast time for various excavation faces coincides in the construction programme within the peak delivery period, explosives will be transported on the same truck. This applies, for instance, when the blast programme of the northern drives and southern drives for a particular delivery point overlaps.

In the Base Case, it was considered that blasting could be carried out at predetermined time during the day as given in the envisaged construction programme. A distribution of delivery time has thus been considered based on the envisaged construction programme.

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

The travel distance from magazine sites 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.

Table 2.6 Travel Distance from Magazine Site to Each Delivery Point

Delivery Points	Pat Heung	Tai Kong Po	Ngau Tam Mei	Shek Yam	Shing Mun	Kwai Chung	Mei Lai Road	Total
Travel distance (km) from Magazine Site to Delivery Point	13.5	8.9	11.2	17.2	18.7	17.6	20.3	107.4

Table 2.7 Explosive Deliveries for Every 12-Month Period During Construction and Each Work Area

12-Month Delivery Period	Total Explosive Delivery Trips within the 12-Month Period							Total No. of trip	Total Distance Travelled (km)
	Pat Heung	Tai Kong Po	Ngau Tam Mei	Shek Yam	Shing Mun	Kwai Chung	Mei Lai Road		
Jan-2011 – Dec 2011	231	48	0	415	30	389	322	1435	24628
Feb-2011- Jan 2012	257	100	0	441	30	418	374	1620	27455
Mar-2011- Feb 2012	282	150	0	441	30	444	424	1771	29710
Apr-2011- Mar -2012	285	204	26	428	30	471	478	1922	31870
May-2011- Apr -2012	307	235	51	414	30	495	510	2042	33554
Jun-2011- May 2012	375	262	78	402	30	523	538	2208	35870
Jul-2011- Jun 2012	456	288	104	427	30	549	564	2418	38901
Aug-2011- Jul 2012	518	314	130	406	30	576	590	2564	40902
Sep-2011 – Aug 2012 (1)	**531**	**341**	**157**	**392**	**27**	**606**	**617**	**2671**	**42400**
Oct-2011 – Sep-2012	543	366	182	378	1	579	626	2675	42045
Nov-2011 - Oct -2012	558	393	209	367	0	533	608	2668	41407
Dec-2011 - Nov -2012	571	419	235	368	0	481	556	2630	40152
Jan-2012 - Dec -2012	582	397	261	379	0	427	502	2548	38538
Feb-2012 - Jan -2013	597	372	288	394	0	375	450	2476	37108
Mar-2012 - Feb -2013	608	346	312	405	0	325	400	2396	35588
Apr-2012 - Mar -2013	620	318	312	417	0	271	346	2284	33660
May-2012 - Apr -2013	611	313	313	431	0	221	296	2185	31851
Jun-2012 - May -2013	558	313	313	445	0	167	242	2038	29330
Jul-2012 - Jun -2013	483	287	289	438	0	115	190	1802	25726

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)
Pat Heung	61
Tai Kong Po	42
Ngau Tam Mei	42
Shek Yam	51
Shing Mun	27
Kwai Chung	78
Mei Lai Road	31

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.

In this project, for a particular delivery point, it is possible that the explosive load required for each delivery will be higher than what is indicated in the envisaged programme due to particular site conditions and blasting requirements; however, the explosive load to be transported will be, as a worst case, the maximum explosive load for the site (sum of the loads for each blast face within the same work site). The delivery load, in the Worst Case Scenario, has been selected as the sum of the loads for each blast face within the same work site.

In this Worst Case Scenario, explosives could be delivered at peak day times.

The explosive loads which will be transported in this Worst Case are given in *Table 2.9* for each delivery route.

Table 2.9 Worst Case Explosive Loads to be Transported for Each Work Area

Works Area	Explosive Load Transported (kg/trip)
Pat Heung	125
Tai Kong Po	42
Ngau Tam Mei	42
Shek Yam	112
Shing Mun	27
Kwai Chung	129
Mei Lai Road	76

2.6 *TRANSPORT OF BLASTING EXPLOSIVES AND INITIATION SYSTEMS*

2.6.1 *OVERVIEW*

Blasting explosives (Bulk emulsion or ANFO) 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 site magazines and transported to the construction sites by the contractor. Mines Division requires that blast hole loading is commenced immediately, as far as practical, upon receiving the explosives (it may take 2 to 4 hours to transport the explosives from the surface to the blast face, charging the face, evacuating the area and execute the blast).

Where no dedicated explosive magazine exists, explosives will be delivered by Mines Division on a daily basis, arriving at the designated site at around 12 noon to 1:00 pm. This means that blasts can only be fired mid-late afternoon, and limits the project to one blast face per day.

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 faces per day.

Mines Division 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 licensing limit. However, this is not the case for this project as the transport load per trip is less than 200kg.

Detonators shall be transported in a separate licensed 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*

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

Explosives will be transferred from the relevant store by the relevant contractor. Two licensed explosive trucks will be required for each delivery - one will only transport detonators while the other will transport a cargo of cartridged emulsion and detonating cord. The explosives transport strategy is shown in *Figure 2.5*.

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

2.6.3 *TRANSPORT TO SITE*

Explosives and detonators will be transported separately but in convoy from the magazine to the designated access shafts / blasting sites by the contractors' licensed 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 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 Cat. 1 explosives on the roads has been minimised by using bulk emulsion and/or bulk ANFO wherever possible, which will be manufactured on-site. The manufacture of ANFO and bulk emulsion will require the transportation of Cat. 7 oxidizing substances, which fall outside the scope of this study.

2.6.4 *SAFETY FEATURES OF TRANSPORT VEHICLES*

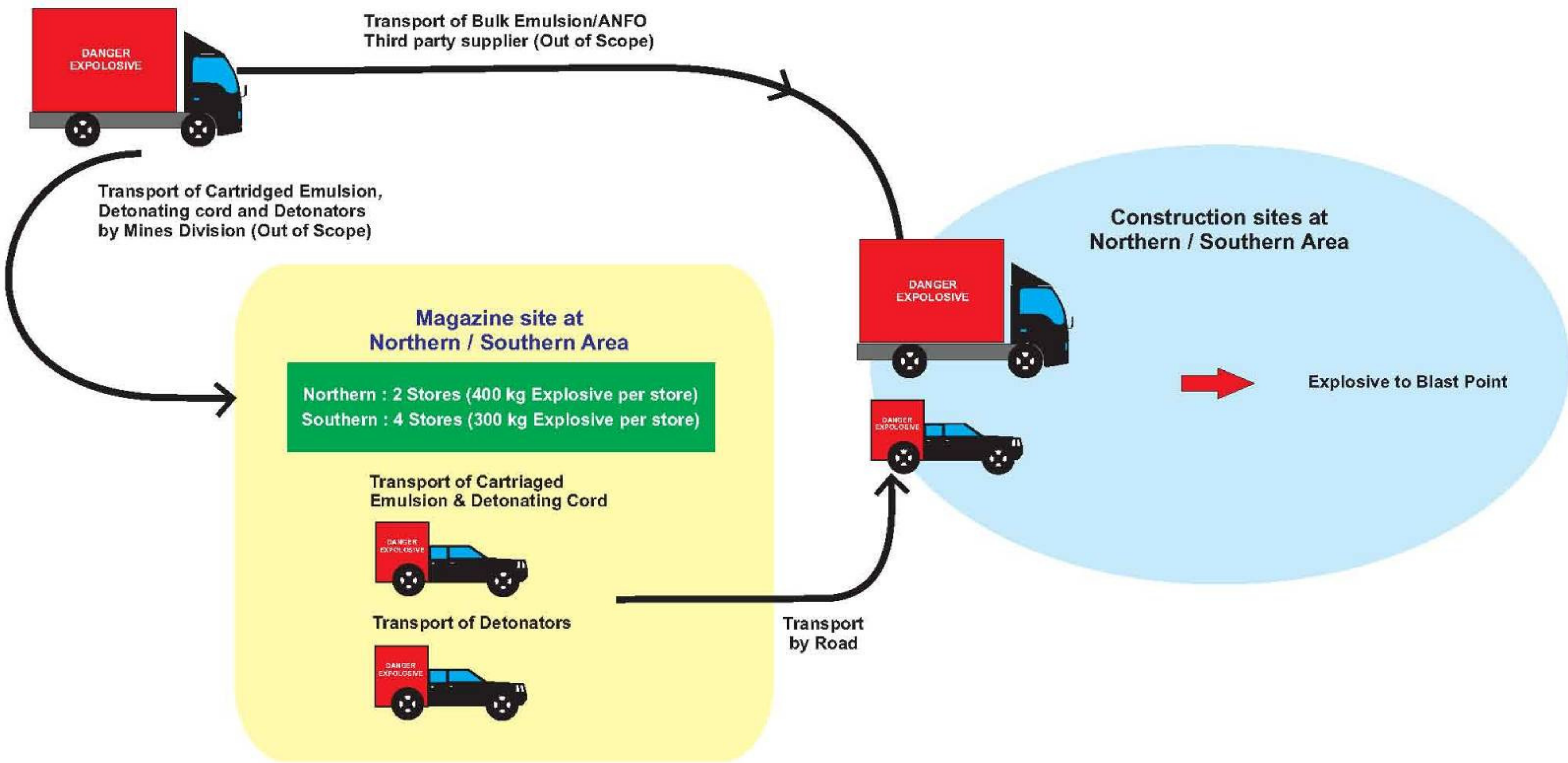
The contactors' pick up trucks (LGV pick up truck) for delivery of explosives from the Magazines to the blast faces will be licensed by Mines Division and will meet all regulatory requirements for that transport.

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

- Diesel powered;
- Manual fuel isolation switch;
- Forward mounted exhaust with spark arrestor;
- Electric wiring or electrical devices will not be installed inside the cargo compartment;
- All electrical wiring and fittings will be shrouded in fire resisting conduits;
- The fuel tank will be protected from accidental damage, and designed to prevent accumulation of spilt fuel on any part of the vehicle;

- Two serviceable water or carbon dioxide fire extinguishers with a minimum capacity of 2 kilograms each will be mounted on the vehicle in an easily accessible position;
- Fire resistant material shall be fitted between the wheel arches and the goods compartment;

Figure 2.5 Transport Strategy for the Explosives



- Lockable wood lined steel or aluminium receptacles mounted on the vehicle tray; and
- Fold down / up explosives warning signs and rotating flashing light.

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.

2.6.5 *DETAILS OF INITIATING EXPLOSIVE DELIVERY ROUTES*

The Initiating Explosives will be delivered from the two magazines to the various work areas using the public roads as shown in *Figure 2.6*.

To ensure that the transport risk has been minimised, alternative routes have been considered. In particular, the option of transporting explosives along Castle Peak Road instead of Tuen Mun Highway. For other route segments, the shortest route has been selected.

The explosive delivery routes from the Tai Lam magazine to the work sites (Pat Heung, Tai Kong Po & Ngau Tam Mei) will mainly utilise Yuen Long Highway and Kam Tin Road passing through areas which are mostly uninhabited. The delivery routes from the So Kwun Wat magazine to the work sites (Shek Yam, Shing Mun, Kwai Chung & Mei Lai Road) will involve transportation on the main roads such as Tuen Mum Road, Castle Peak Road passing through densely populated areas, in particular Tsuen Wan, Kwai Chung and Lai Chi Kok.

Although explosives deliveries to 7 works sites are planned, a maximum of 6 will be in operation simultaneously during the 8 month period from March to October 2012. On average, following the current work programme, during the 3 year construction phase, deliveries to 4 or 5 works sites are expected at any one time.

Since the explosive transport from the magazines to the delivery points will involve more than 20 kilometres of road transport across a number of main roads as well as small roads, 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 2.10* and *Table 2.11*.

Figure 2.6 XRL Alignment, Magazine Locations and Explosives Transport Routes

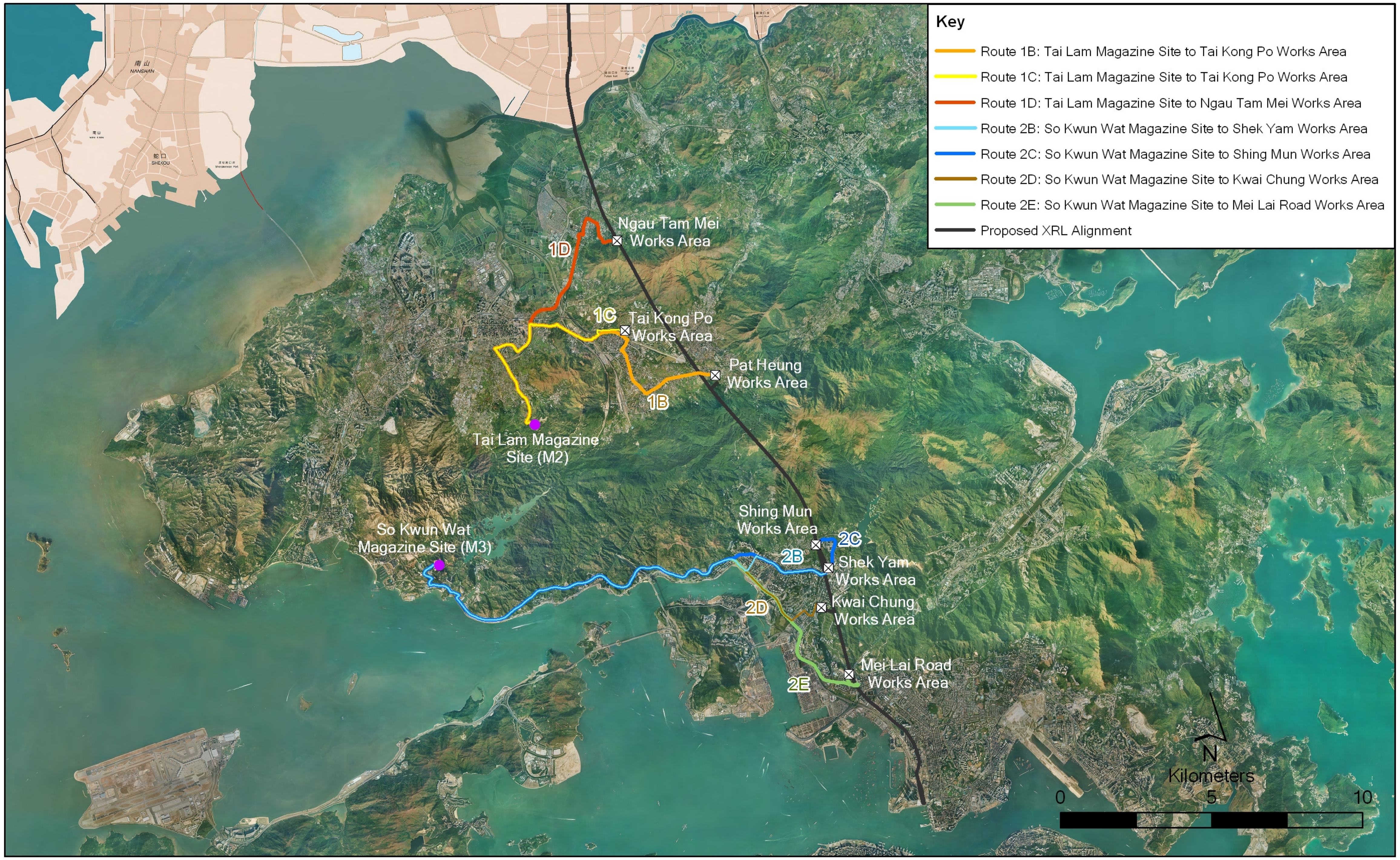


Table 2.10 Delivery Routes from Tai Lam Magazine

Section ID	Description
Route 1b (Tai Lam Magazine M2 - Pat Heung)	
Road 1b1	Access road toward Tai Shu Ha Rd West
Road 1b2	Tai Shu Ha Road West 1
Road 1b3	Tai Shu Ha Road West 2
Road 1b4	Shap Pat Heung Road (Tai Shu Ha Rd - Shap Pat Heung Interchange)
Road 1b5	Yuen Long Highway (Shap Pat Heung Interchange - Pok Oi Interchange)
Road 1b6	Castle Peak Road - Yuen Long (Pok Oi Interchange - Kam Tin Rd)
Road 1b7	Kam Tin Road (Castle Peak Rd - Yuen Long - Kam Tin Bypass)
Road 1b8	Kam Tin Bypass Road
Road 1b8a	Kam Tin Bypass Road (2nd section)
Road 1b9	Tung Wui Road
Road 1b10	Kam Sheung Road
Road 1b11	proposal haul road towards PHV off Kam Sheung Rd
Route 1c (Tai Lam Magazine M2 - Tai Kong Po)	
Road 1c1	Access road toward Tai Shu Ha Rd West
Road 1c2	Tai Shu Ha Road West 1
Road 1c3	Tai Shu Ha Road West 2
Road 1c4	Shap Pat Heung Road (Tai Shu Ha Rd - Shap Pat Heung Interchange)
Road 1c5	Yuen Long Highway (Shap Pat Heung Interchange - Pok Oi Interchange)
Road 1c6	Castle Peak Road - Yuen Long (Pok Oi Interchange - Kam Tin Rd)
Road 1c7	Kam Tin Road (Castle Peak Rd - Yuen Long - Kam Tin Bypass)
Road 1c8	Kam Tin Bypass Road
Road 1c9	Kam Hing Rd
Road 1c10	Chi Ho Rd
Road 1c11	proposed haul road towards TPV off Chi Ho Rd
Route 1d (Tai Lam Magazine M2 - Ngau Tam Mei)	
Road 1d1	Access road toward Tai Shu Ha Rd West
Road 1d2	Tai Shu Ha Road West 1
Road 1d3	Tai Shu Ha Road West 2
Road 1d4	Shap Pat Heung Road (Tai Shu Ha Rd - Shap Pat Heung Interchange)
Road 1d5	Yuen Long Highway (Shap Pat Heung Interchange - Pok Oi Interchange)
Road 1d6a	Yuen Long Highway
Road 1d6b	Yuen Long Highway (to Tsing Long Highway)
Road 1d7	Tsing Long Highway
Road 1d8	San Tin Highway (San Tin Interchange)
Road 1d9	San Tam Rd (San Tin Interchange - Chun Shin Rd)
Road 1d10	Chuk Yau Rd

Table 2.11 Delivery Routes from So Kwun Wat Magazine

Section ID	Description
Route 2b (So Kwun Wat Magazine M3 - Shek Yam)	
Road 2b1	Siu Lam Magazine site track
Road 2b2	Kwun Fat Street
Road 2b3	Castle Peak Road - Tai Lam
Road 2b4	Tuen Mun Road - Siu Lam Interchange slip road
Road 2b5	Tuen Mun Road (Siu Lam - Sham Tseng)
Road 2b6	Tuen Mun Road (Sham Tseng - Ting Kau Bridge)
Road 2b7	Tuen Mun Road (Ting Kau Bridge - Castle Peak Rd - Tsuen Wan)
Road 2b7a	Tuen Mun Road (2nd section of 7)
Road 2b8	Tsuen Wan Road (Tuen Mun Rd - Hoi Hing Rd Interchange)
Road 2b9	Tai Chung Road (Tsuen Wan Rd - Castle Peak Rd Tsuen Wan)
Road 2b10	Castle Peak Road - Tsuen Wan (Tai Chung to Tai Ho Rd)
Road 2b11	Castle Peak Road - Tsuen Wan (Tai Ho to Chung On St)
Road 2b12	Castle Peak Road - Tsuen Wan (Chung On St to Texaco Rd)
Road 2b13	Castle Peak Road - Kwai Chung (Texaco Rd)
Road 2b14	Castle Peak Road - Kwai Chung (Ting Kwok St to Kwai Chung Rd RA)

Section ID	Description
Road 2b15	Cheung Wing Road (Kwai Chung Rd RA - Yau Ma Hom Rd Shek Yam workarea)
Route 2c (So Kwun Wat Magazine M3 - Shing Mun)	
Road 2c1	Siu Lam Magazine site track
Road 2c2	Kwun Fat Street
Road 2c3	Castle Peak Road - Tai Lam
Road 2c4	Tuen Mun Road - Siu Lam Interchange slip road
Road 2c5	Tuen Mun Road (Siu Lam - Sham Tseng)
Road 2c6	Tuen Mun Road (Sham Tseng - Ting Kau Bridge)
Road 2c7	Tuen Mun Road (Ting Kau Bridge - Castle Peak Rd - Tsuen Wan)
Road 2c7a	Tuen Mun Road (2nd section of 7)
Road 2c8	Castle Peak Road - Tsuen Wan (Tuen Mun Rd - Castle Peak Rd Tsuen Wan)
Road 2c9	Castle Peak Road - Tsuen Wan (Sha Tsui Rd - Tsuen King Circuit)
Road 2c10	Castle Peak Road - Tsuen Wan (Tsuen King Circuit - Tai Chung Rd)
Road 2c11	Castle Peak Road - Tsuen Wan (Tai Chung to Tai Ho Rd)
Road 2c12	Castle Peak Road - Tsuen Wan (Tai Ho to Chung On St)
Road 2c13	Castle Peak Road - Tsuen Wan (Chung On St to Texaco Rd)
Road 2c14	Castle Peak Road - Kwai Chung (Texaco Rd)
Road 2c15	Castle Peak Road - Kwai Chung (Ting Kwok St to Kwai Chung Rd RA)
Road 2c16	Cheung Wing Road (Kwai Chung Rd - Wo Yi Hop Rd)
Road 2c16a	Cheung Wing Road (2nd section)
Road 2c17	Wo Yi Hop Road (Cheung Wing Rd - Lei Shu Rd)
Road 2c17a	Wo Yi Hop Road (Lei Shu Rd - Ngong Hom Rd)
Road 2c18	Wo Yi Hop Road (Ngong Hom Rd - Wo Yi Hop Interchange)
Road 2c19	Wo Yi Hop Interchange (Wo Yi Hop Rd - Sam Tung Uk Rd)
Road 2c20	Cheung Shan Estate Road West (Cheung Shan Est Rd E - Wo Yi Hop Rd)
Route 2d (So Kwun Wat Magazine M3 - Kwai Chung)	
Road 2d1	Siu Lam Magazine site track
Road 2d2	Kwun Fat Street
Road 2d3	Castle Peak Road - Tai Lam
Road 2d4	Tuen Mun Road - Siu Lam Interchange slip road
Road 2d5	Tuen Mun Road (Siu Lam - Sham Tseng)
Road 2d6	Tuen Mun Road (Sham Tseng - Ting Kau Bridge)
Road 2d7	Tuen Mun Road (Ting Kau Bridge - Castle Peak Rd - Tsuen Wan)
Road 2d7a	Tuen Mun Road (2nd section of 7)
Road 2d8	Tsuen Wan Road (Tuen Mun Rd - Hoi Hing Rd Interchange)
Road 2d9	Tsuen Wan Road (Hoi Hing Rd Interchange - Texaco Rd RA)
Road 2d10	Tsuen Wan Road (Texaco Rd - Kwai Tsing Rd)
Road 2d11a	Hing Fong Road (Kwai Tsing Interchange to Kwai Fuk Rd)
Road 2d11	Hing Fong Road (Kwai Fuk Rd - Kwai Foo Rd)
Road 2d12	Kwai Foo Road (Hing Fong Rd - Kwai Chung Rd)
Road 2d13	Kwai Chung Road (Kwai Foo Rd - Kwai On Rd)
Road 2d13a	Kwai On Rd (Kwai Chung Rd - Tai Lin Pai Rd)
Road 2d14	Tai Lin Pai Road (Kwai On Rd to Wing Yip St)
Road 2d15	Wing Yip Street
Route 2e (So Kwun Wat Magazine M3 - Mei Lai Road)	
Road 2e1	Siu Lam Magazine site track
Road 2e2	Kwun Fat Street
Road 2e3	Castle Peak Road - Tai Lam
Road 2e4	Tuen Mun Road - Siu Lam Interchange slip road
Road 2e5	Tuen Mun Road (Siu Lam - Sham Tseng)
Road 2e6	Tuen Mun Road (Sham Tseng - Ting Kau Bridge)
Road 2e7	Tuen Mun Road (Ting Kau Bridge - Castle Peak Rd - Tsuen Wan)
Road 2e7a	Tuen Mun Road (2nd section of 7)
Road 2e8	Tsuen Wan Road (Tuen Mun Rd - Hoi Hing Rd Interchange)
Road 2e9	Tsuen Wan Road (Hoi Hing Rd Interchange - Texaco Rd RA)
Road 2e10	Tsuen Wan Road (Texaco Rd - Kwai Tsing Rd)
Road 2e11	Tsuen Wan Road (Kwai Tsing Rd - Tsuen Wan Rd section over container port rd)
Road 2e12	Tsuen Wan Road (Tsuen Wan Rd - Kwai Tsing Rd)
Road 2e13	Kwai Chung Road (up to Lai Chi Kok Bridge)
Road 2e14	Kwai Chung Road (Lai Chi Kok Bridge - Cheung Sha Wan Rd)
Road 2e15	Cheung Sha Wan Rd (Cheung Sha Wan Rd - butterfly valley Rd)

Section ID	Description
Road 2e16	Castle Peak Road (Lai Chi Kok Interchange to Butterfly Valley Interchange)

2.7. *DESIGN DOCUMENTATION USED AS THE BASIS FOR THE HAZARD TO LIFE ASSESSMENT*

The following preliminary design documentation from XRL forms the basis for this assessment:

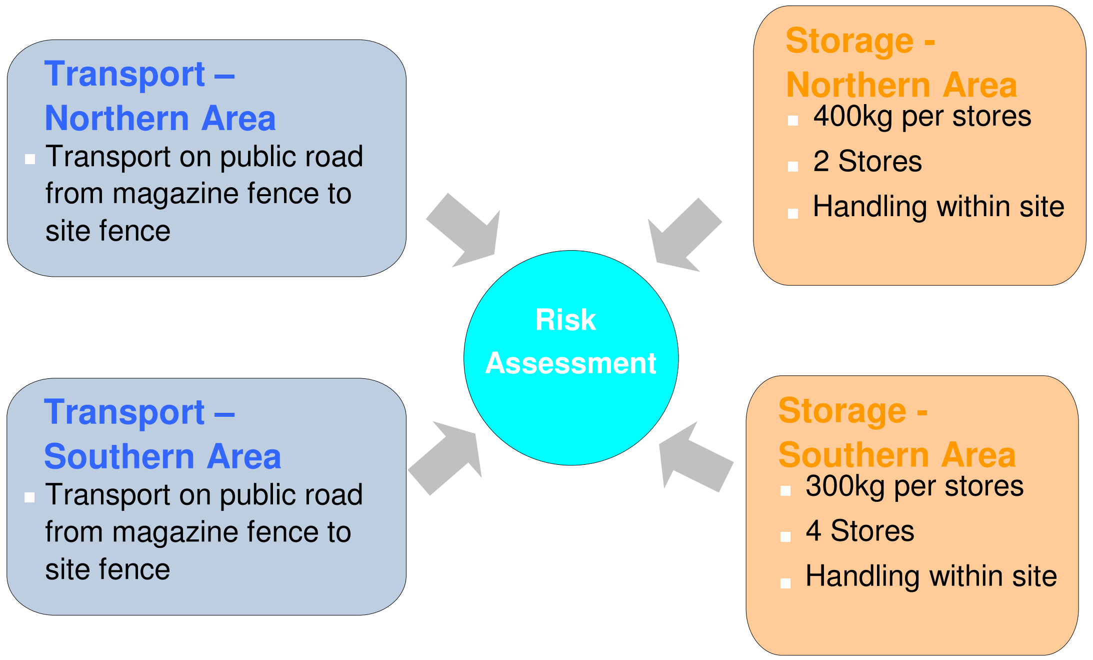
- D3.10C Final Civil Engineering Scheme Report;
- D3.10E Final Site Impact Assessment Report;
- D3.10F Final Natural Terrain Hazard Study Report;
- D3.10I Final Blast Assessment Report;
- D3.16 Final Environmental Description Report;
- D3.19A Existing Building Impact Report;
- D3.19D Final Explosives and Blasting Logistics; and
- Blasting schedule: Blasting Schedule Third Draft.xls (dated 5-12-2008) provided on 9-12-2008.

3 *HAZARD TO LIFE ASSESSMENT METHODOLOGY*

3.1. *OVERVIEW OF THE METHODOLOGY*

The overall methodology for the Hazard to Life Assessment addresses the risk associated with the storage and transport of explosives for the XRL construction (see *Figure 3.1*).

Figure 3.1 Components of the Risk Assessment



The potential effects 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 proposed Magazines, the transport from the magazines, as well as population and vulnerable receptors, such as slopes, retaining walls etc., in the vicinity of the tunnel construction 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 XRL projects 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 previews Hong Kong studies, UK HSE, US DoD, Dutch TNO (TNO Purple Book), latest accident statistics from the Transport Department and Fire Service 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 adopted in previous Hong Kong EIAs.

- The frequency model was updated, in accordance with the methodology adopted in the ERM (2008) study and the DNV (1997) study which was based on the ACDS (1995) and Moreton (1993) studies, to reflect the current Transport Department statistics, Fire Service Department statistics, specific design features applicable for the XRL project and current knowledge of explosives.

- The consequence and frequency data were subsequently combined using ERM's in-house proprietary software Riskplot ™ to produce the required risk estimates. The transport part of the risk assessment has been updated compared to the ERM (2008) study. An in-house Explosive Transport GIS Risk Assessment tool (E-TRA) 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 Riskplot ™.

- 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 XRL construction. 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:

- West Island Line (WIL) study (ERM, 2008);

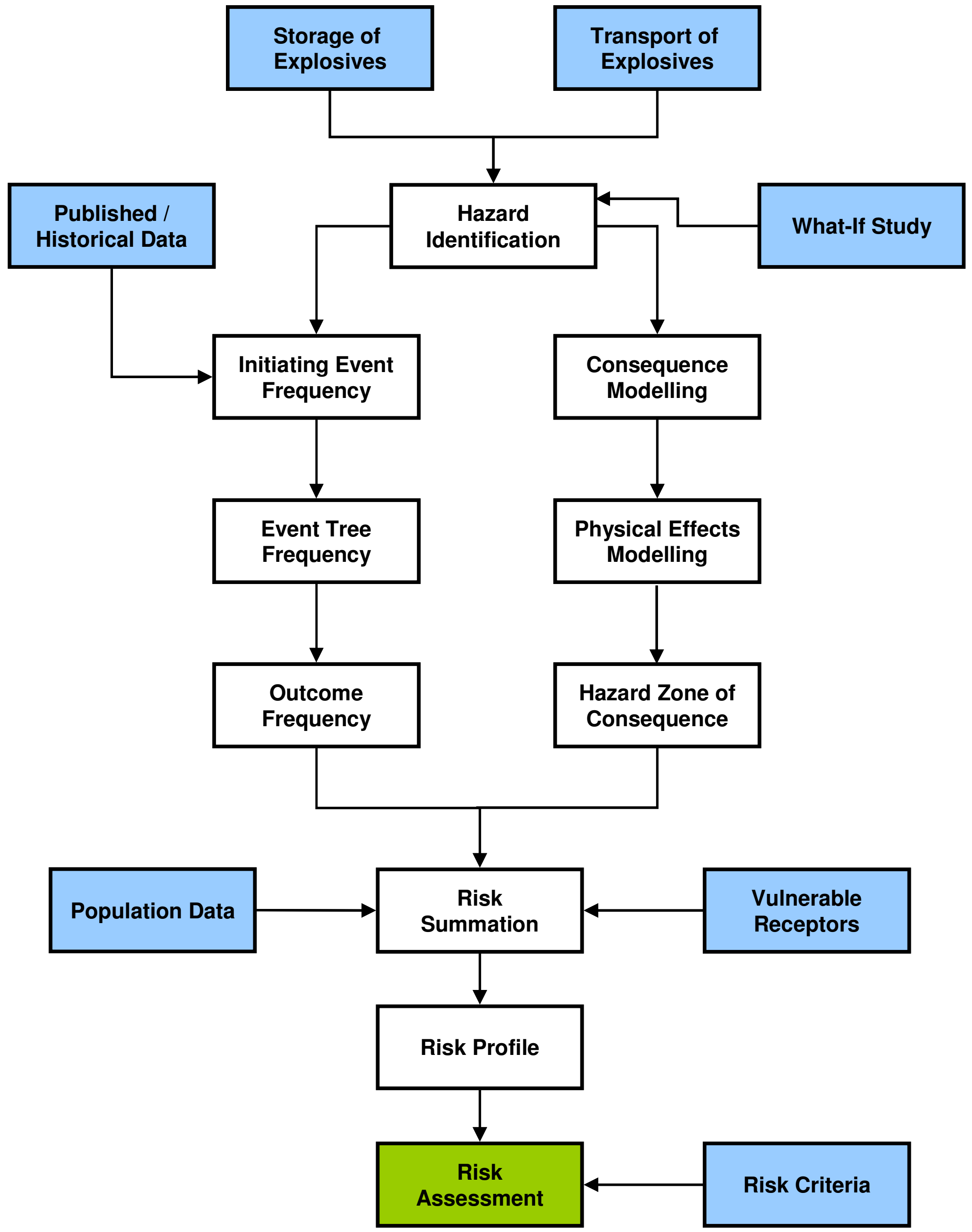
- Hazard to Life Assessment section of the Ocean Park (Maunsell, 2006);

- The territory wide study for the transport of explosives (DNV, 1997); which was the basis for the ERM (2008) study and ACDS (1995) study which was the basis for the DNV (1997) study. The basis for the frequency assessment data and methodology for the DNV (1997), as well as the ACDS (1995) study, has been reported separately in Moreton (1993).

- Hazard to Life Assessment section of the Penny's Bay Rail Link EIA, (ERM, 2001).

ERM (2008) study for the West Island Line is the latest QRA on the transport of explosives in Hong Kong and has formed the primary reference for the XRL Hazard to Life Methodology.

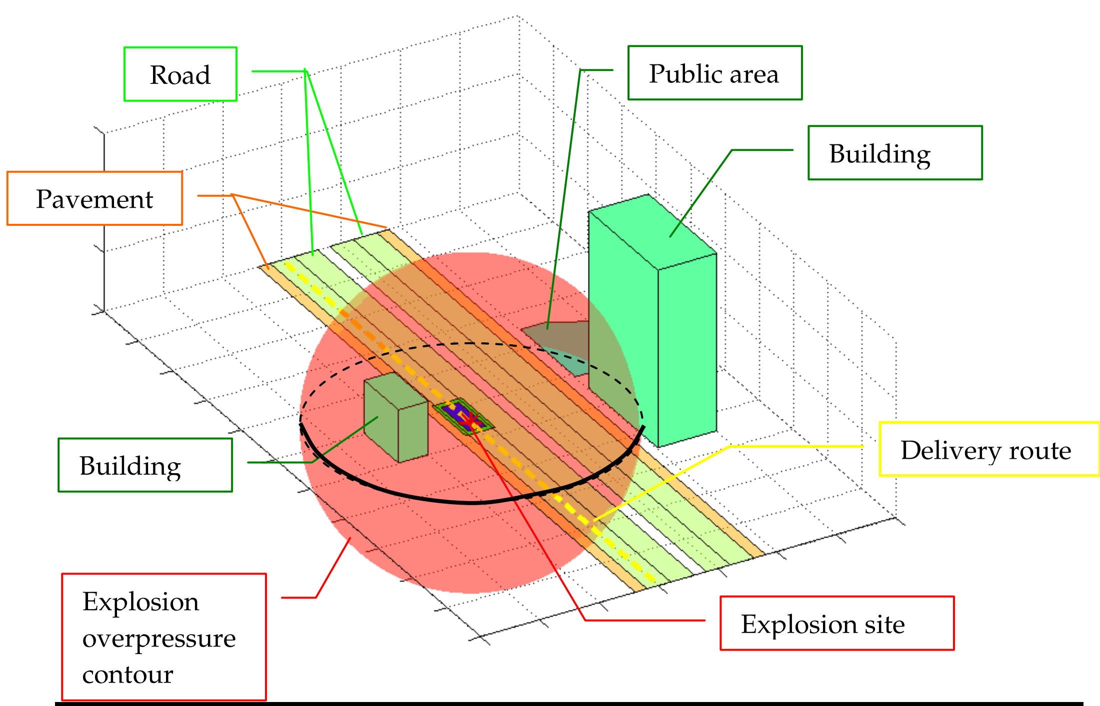
Figure 3.2 *Schematic Diagram of QRA Process*



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 for Mines Division explosive truck study (DNV, 1997), but is fully 3-dimensional and GIS based. It also accounts for the potential increased risk when the explosive truck travels on elevated roads. The route from the magazine to each work site is divided into sections for analysis, according to road conditions. 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 procedure, the 2-dimensional case at ground level is firstly considered (*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. The geometric means have been applied to the model. Although the geometric means has no physical meaning, the levels calculated with the geometric means using the fatality probabilities listed above closely match with the true average explosive effect distances.

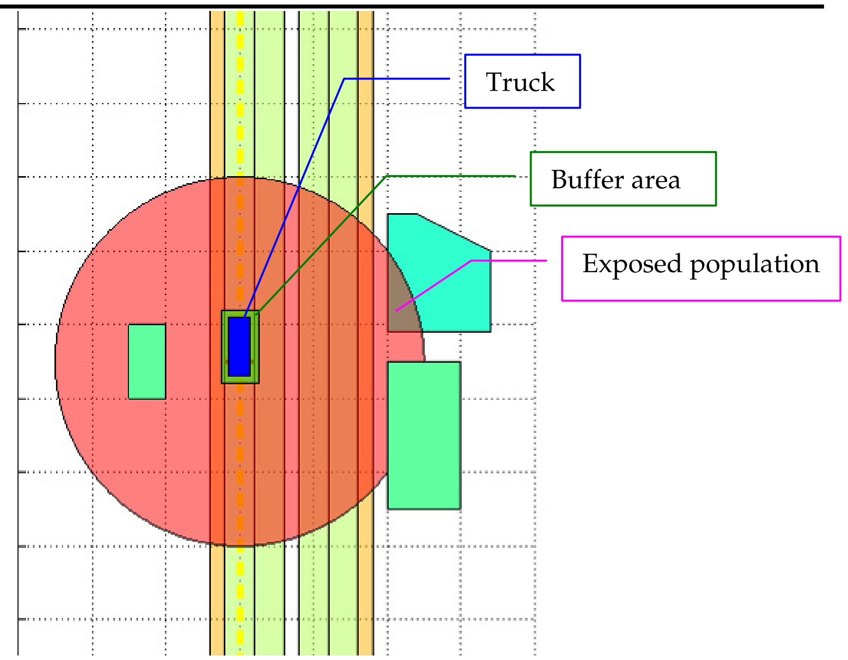
To define the population polygons, each section of a route is characterised in terms of the number of traffic lanes on nearside and far side, widths of traffic lanes, width of the centre divides and widths of nearside and far side pavements. Polygons describing buildings and public areas on each side 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 2011-Base District Traffic Model (BDTM) and Annual Average Daily Traffic data (AADT), both 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. The transport routes are typically of the order of 20 km in length and hence with an explosion modelled every 10 m, about 2,000 potential explosion locations are considered in the modelling.

Other assumptions made in the model include:

- The explosive 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 explosive 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 work site A, followed by direct routing to work site B etc. are not considered in the model;
- The explosive trucks are expected to be a light truck eg. 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 5m×10m in which the population is taken to be zero.

Figure 3.4 Explosion Overpressure Footprint at Ground Level



Extension to 3-Dimensional Modelling

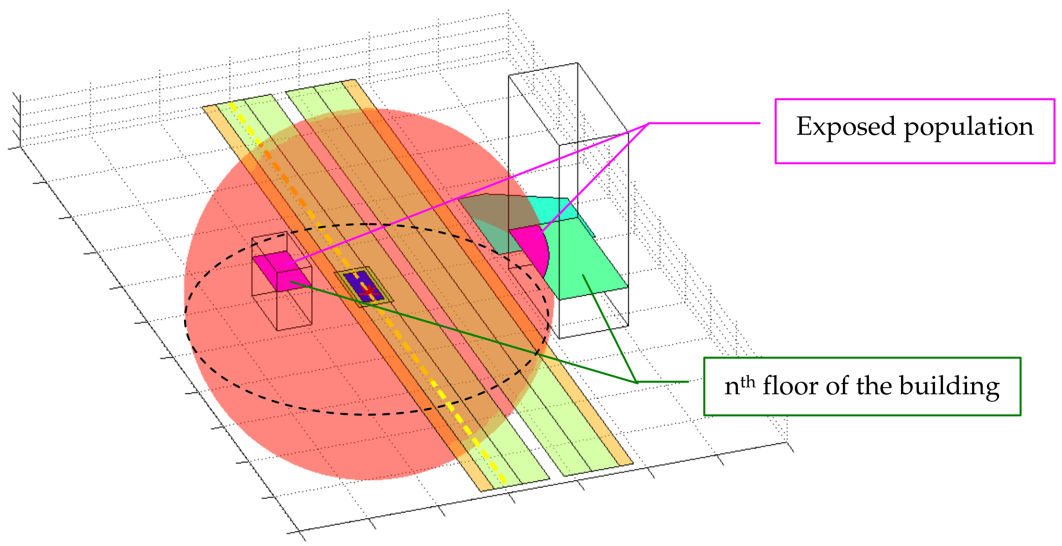
Buildings are modelled in 3-dimensions. This is achieved in essentially the same manner as the 2-D calculations, but the overlap areas between explosion overpressure contours and building polygons is calculated floor by floor (*Figure 3.5*). Since the explosion effects are spherical, the extent of the 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 have been assumed to face 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 60m, there will be very few instances of impacts reaching the second line of buildings. 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 10m). 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 FN curves.

$$PLL = \sum_i f_i N_i$$

FN curves plot the frequency *F*, of *N* or more fatalities against *N*. The frequency *F* is therefore an accumulative 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 THE EXPLOSIVE MAGAZINES

Two Magazines are required in order to enable efficient delivery of explosives to work areas (see *Figure 2.6*):

- The first Magazine will be located in the northern New Territories at Tai Lam and will supply explosives to work areas at Ngau Tam Mei, Tai Kong Po and Pat Heung; and
- The second Magazine will be located at So Kwun Wat near Siu Lam and will supply explosives to work sites in urban Kowloon at Shing Mun, Shek Yam, Kwai Chung and Mei Lei Road.

These Magazine sites have been selected based on consideration of separation distances from public areas and buildings and on practicality grounds for their proximity to works areas and transport routes.

Population within the vicinity of these sites is based on surveys conducted by ERM in December 2008. Additional information was gathered from GIS tools and aerial maps. From these, potential sensitive receivers in the vicinity of each site were identified and their population estimated.

The consequence analysis (*Section 7*) demonstrated that the maximum effect radius from a blast at a Magazine which could produce 1% fatality is about 65m. All population within 65m radius from each site was therefore estimated.

4.1.1 TAI LAM SITE

The Tai Lam site is located on a disused quarry near Yuen Long. This is a relatively remote location surrounded by woodland and is currently unoccupied (*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 300m from the magazine. The distance of the entrance of the club to the magazine is about 200m. 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 200m from the magazine, is outside the area of interest, ie the separation distance for the magazine.

Figure 4.1 Aerial Photo of the Tai Lam Disused Quarry Site

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*, and the results are summarised in *Table 4.1*.

4.1.2 SO KWUN WAT SITE

The So Kwun Wat site (*Figure 4.2*) is located at the top of a small hill. The site is a levelled area, currently in use as a contractor's temporary depot for a Water Service Department (WSD) project. It is remote from buildings and inhabited areas and is surrounded by vegetation (woodland) and rocks. The only substantial structure in the vicinity is a WSD covered service reservoir located about 92 m to the north. The site survey observed 4 to 5 workers within the WSD site; however, since these are beyond the maximum effects radius, this population was not included in the model. The service reservoir is also at a lower level (about 10m lower) than the proposed magazine site, and there is no direct line-of-sight between the two installations. The WSD service reservoir is mainly a concrete structure which would be subject to similar blast damaging criteria as buildings.

The public section of the access road is more than 180m from the magazine and was therefore ignored in the modelling.

There is no known (current or future) permanent, temporary or transient population within the hazard zones of the So Kwun Wat magazine site.

Figure 4.2 Aerial Photo of the So Kwun Wat Magazine Site

Table 4.1 Population Considered Near Tai Lam Magazine Site

Name	Weekday AM Peak	Weekday Daytime	Weekday PM Peak	Weekday Night	Saturday AM Peak	Saturday Daytime	Saturday PM Peak	Saturday Night	Sunday AM Peak	Sunday Daytime	Sunday PM Peak	Sunday Night
Tai Shu Ha Road west 1 pavement (persons/m^2)	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Tai Shu Ha Road west 1 vehicle (persons/m^2)	0.002343	0.002343	0.002343	0.002343	0.002343	0.002343	0.002343	0.002343	0.002343	0.002343	0.002343	0.002343

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 4.2* have been used consistently with the ERM (2008) study.

Table 4.2 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 particular 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	
Passenger Car Unit (PCU)	3 persons per PCU	This is only applicable to the BDTM model

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

Population on the roads was estimated from a combination of:

- Base District Traffic Model (BDTM) 2011;
- Annual Traffic Census 2007 (ATC, 2007); and
- Road Traffic Accident Statistics 2007 (TD, 2007a).

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

- Centamap (2008); and
- Geographic Information System (GIS) database (2007/2008 data).

Accounting for the maximum licensing limit of 200 kg for the transport of explosives, all buildings within a 100m 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 initiation of 200kg of explosives, for example, does not extend as far as 100m and all transport loads considered in this project are less than 200kg.

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 frequency section), an accidental explosion due to vehicle collision or transport of unsafe explosives will be spontaneous and can only impact a free flowing traffic. Explosive initiation following a vehicle fire (following a traffic accident or otherwise) could impact a queuing traffic (half jammed) conservatively assumed to occur on each lane on either side of the road in day or night conditions. 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 December 2008.

The following sections also present the approach taken, for the base case scenario, where the deliveries could be scheduled at predetermined time during the blast cycles. For the Worst Case, it was considered that deliveries could take place at peak day time.

4.2.1 ROUTE SECTIONALISATION

The explosive delivery routes from the Tai Lam magazine to the work sites (Pat Heung, Tai Kong Po & Ngau Tam Mei) and the delivery routes from the So Kwun Wat magazine to the work sites (Shek Yam, Shing Mun, Kwai Chung & Mei Lai Road) have been broken down into sub-sections for the assessment as described in *Section 2.6.5*.

4.2.2 *ROAD POPULATION*

Also represented in the risk model is the population associated with traffic on the roads. The traffic density information used in this study is based on the latest 2007 Annual Traffic Census and the 2011-Base District Traffic Model (BDTM). A growth of 1% per year to the year of completion of the blasting work (2013) 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 (ie subject to glass debris impact). The traffic density information used in this study was based on the latest 2007 Annual Traffic Census, supplemented by data from the 2011-Base District Traffic Model (BDTM) developed by the Transport Department. A growth of 1% per year was assumed to extrapolate current data to the end year of construction, 2013.

The BDTM data mainly represent peak traffic conditions and has therefore been used for modelling uncongested peak traffic conditions (free flowing traffic). AADT data gives daily average traffic conditions and, for some stations, data are available at different times of the day. AADT data therefore appropriately represent normal traffic flows at non-peak hours.

Flowing Traffic Population

The traffic density information used in this study was based on the latest 2007 Annual Traffic Census (ATC, 2007), supplemented by data from the Base District Traffic Model (BDTM) developed by the Transport Department. A growth of 1% per year was assumed to extrapolate current data to the year of construction, 2013.

Road population density was calculated using the following relations:

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 meter, based on actual data
V is the vehicle speed in km/hr

Based on average vehicle occupancy reported in the Traffic Census for the relevant transportation route, the average vehicle occupancy is around 5 persons per vehicle.

V has been selected as 60 km/h for highways and 50 km/h for non-highway route section consistently with previous Hong Kong studies.

BDTM Model

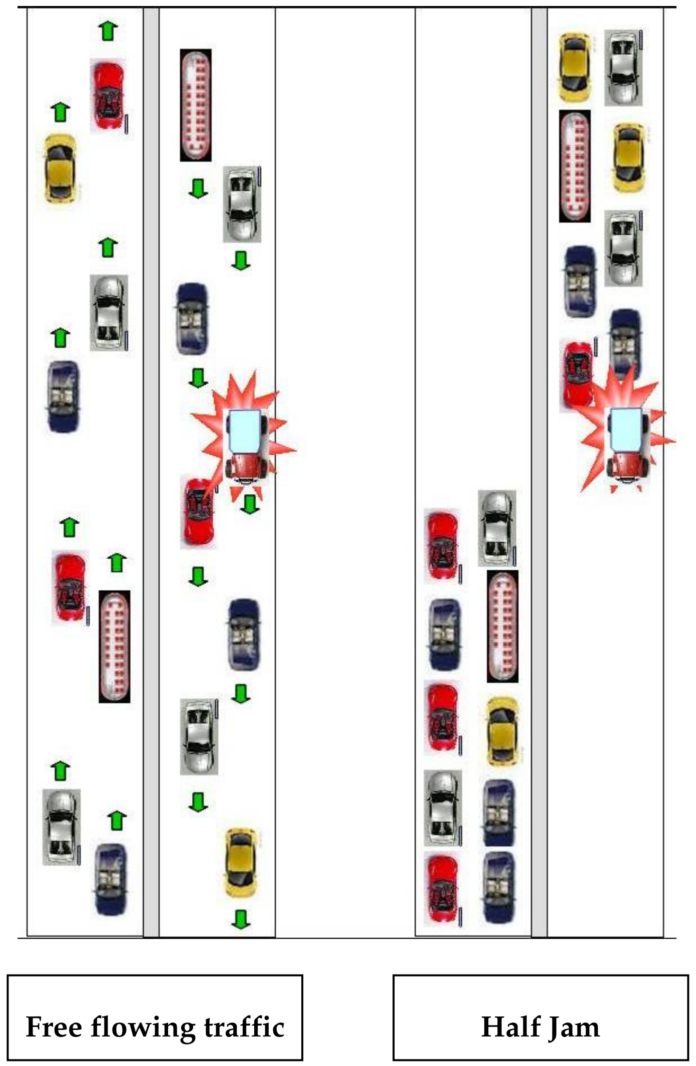
Population Density (persons/m^2) = PCU / V / W /1000

where:
PCU is passenger car unit per hour
W is the road width in meter, based on actual data
V is the vehicle speed in km/hr

The number of vehicle occupants within a PCU has been taken to be 3 consistently with previous studies (ERM, 2008).

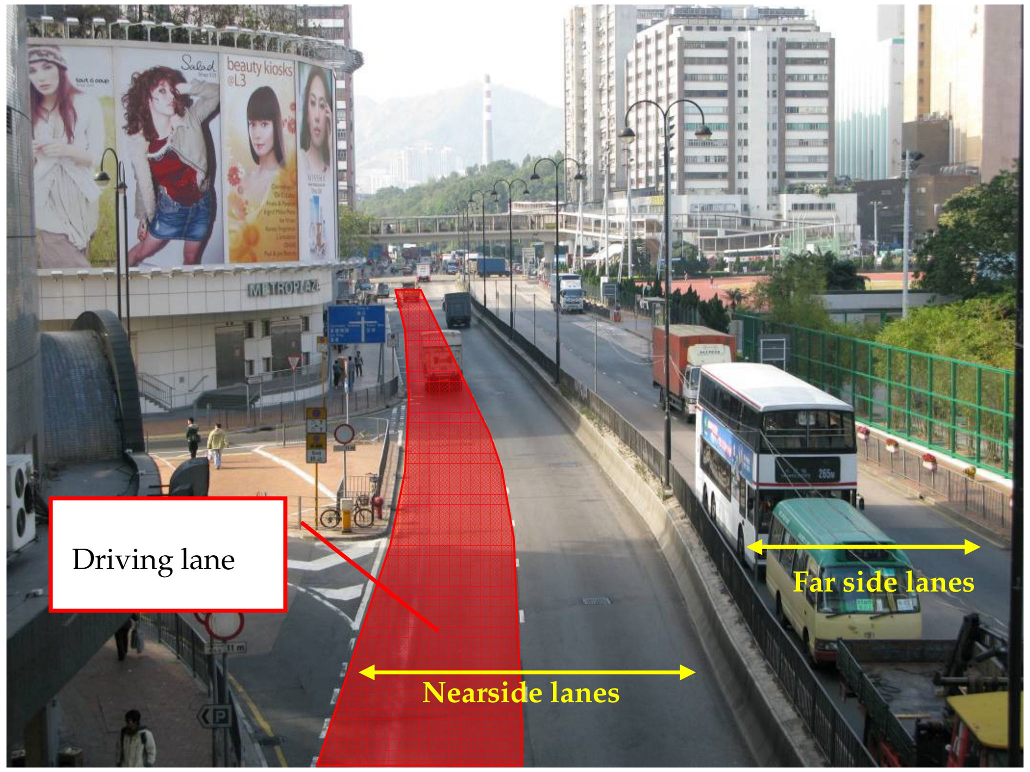
The above formulae based on AADT and BDTM provide population information for average and peak flowing traffic conditions respectively. There is a possibility of a traffic jam when explosive initiation occurs. For example, if the explosives truck catches fire either due to an accident or due to other causes, the incident could disrupt traffic flow and lead to a traffic jam. It follows that, several traffic conditions were considered in the road population estimates (see *Figure 4.3*).

Figure 4.3 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 explosive truck (the far side lanes) (*Figure 4.4*).

Figure 4.4 *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 2007. Four core stations were selected as representative of the transport routes from the magazine sites (*Table 4.3*). As a conservative measure, the peak occupancy numbers from these 4 core stations were used in the assessment (*Table 4.9*).

Table 4.3 *Core Stations along the Proposed Transport Routes*

Core Station	Description	Applicable Transport Route
Stn 5012	Tuen Mun Road (from Sham Tseng to Tsing Long Highway – Ting Kau Bridge)	So Kwun Wat
Stn 5029	Tsing Long Highway – Tai Lam Tunnel (from Au Tau Interchange to Tuen Mun Road)	Tai Lam
Stn 6208	Kam Sheung Road (from Kam Tin Road to Kam Tin Road)	Tai Lam / Lam Kam
Stn 5030	Kwai Chung Road (from PMH Interchange Slip Road to Kwai Chung Road N-B to Tsuen Wan Road)	So Kwun Wat

Table 4.4 *Vehicle Occupancy for Different Types of Vehicle*

Vehicle Type	AADT Core Station				Average
	5012	5029	6208	5030	
Motorcycle	1.2	1.6	1	1.2	1.25
Private car	1.5	1.9	1.8	1.6	1.7
Taxi	2	2.9	2.4	2	2.33
Public light bus	13.9	0	12.5	15.6	10.5
Goods vehicle	1.45	1.55	1.65	1.55	1.55
Bus	73.6	68.2	35.8	65.2	60.7

The vehicle mix was estimated from the vehicle kilometres travelled (TD, 2007a) (VKT) by each type of vehicle in 2007 (*Table 4.5*). 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 4 core stations listed in *Table 4.5* and found to match closely. Combining the vehicle mix with vehicle occupancies from *Table 4.9* gives an average population density within vehicles of 0.5 persons per metre of road. For sections of the transport routes with multiple traffic lanes, a population density of 0.5 persons/m per lane was used. Road populations were further converted to a density per square metre using the lane width.

Table 4.5 *Road Population Density*

Vehicle Type	VKT in 2007 (million)	Fraction of VKT	Occupants	Length of road per vehicle (m)	Population (persons/m)
Motorcycle	319	0.0269	1.25	5	0.007
Private car	4442	0.3749	1.7	5	0.127
Taxi	2102	0.1774	2.325	5	0.083
Public light bus	387	0.0327	10.5	10	0.034
Goods vehicle	3719	0.3139	1.55	20	0.024
Bus	878	0.0741	60.7	20	0.225
Total	11847	1			0.500

4.2.3 *PEDESTRIAN POPULATION*

Pedestrian flow on the pavement was assessed along the explosives delivery routes by site survey carried out in December 2008. 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:

- Key roads along the delivery routes were selected for the survey (*Table 4.6*);
- Each route section was categorized according to land use type (i.e. type of surrounding buildings); high rise residential, rural etc. (see *Table 4.7*);
- A survey of pavement population was conducted for the selected road sections 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 road width (m)
  Q is the pedestrian speed (km/hr)

- The survey produced a range of populations for each land use type. The upper limit of this range was selected for use in the assessment. This upper limit was further increased by 10% as a conservative measure and applied to all time periods. The results are shown in *Table 4.7*;
- This conservative upper limit on pavement population density was then applied, based on site visit, to all road sections along the route with the same type of surrounding buildings; 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 4.6 ***Key Roads Covered in Site Survey***

Roads
<u>*Delivery from Tai Lam Magazine Site M2 (Route 1)*</u>
Tai Shu Ha Road West
Kam Tin Bypass Road
Tung Wui Road
Kam Sheung Road
Kam Hing Road
Chi Ho Road
Yuen Long Highway
Tsing Long Highway
San Tin Highway
Chun Shin Road
<u>*Delivery from So Kwun Wat Magazine Site M3 (Route 2)*</u>
Kwun Fat Street
Tuen Mun Road
Tsuen Wan Road
Cheung Wing Road
Castle Peak Road – Tsuen Wan
Wo Yi Hop Road
Cheung Shan Estate Road West
Hing Fong Road
Kwai Foo Road
Kwai Chung Road
Kwai On Road
Tai Lin Pai Road
Wing Yip Street
Cheung Sha Wan Road
Castle Peak Road

Table 4.7 ***Pavement Population Density***

Surrounding Land Use Type	**Pavement Population Density (person/m²)**
Rural	0.001
Low Rise Residential (Rural)	0.025
High Rise Residential	0.12
High Rise Industrial	0.060
Hospital	0.030
School	0.020
Recreational	0.11
High Rise Residential & Commercial	0.26

Note 1: Growth factor of 1% per year is taken into account in above data

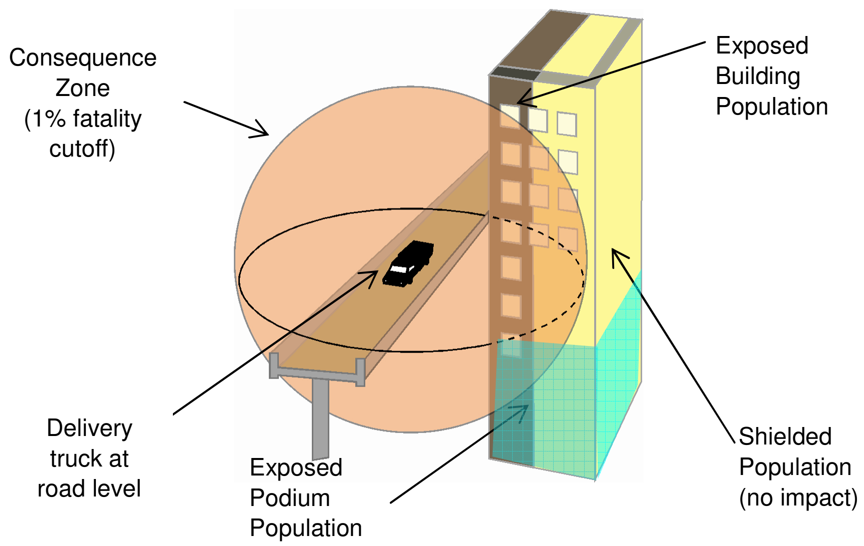
4.2.4 *LAND AND BUILDING POPULATION*

Buildings within a 200m corridor (100m 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 3000 buildings along the route, the task of assessing population building-by-building is substantial but is necessary to accurately model the F-N pairs with a high N values. Building populations are then extrapolated to Year 2013.

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 facing the road 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 4.5 ***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 and distribute predicted future residential population data among identified residential buildings based on a uniform population growth factor of 1% per year. This was assumed for the study area up to 2013.
- 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 (LD, 2008). Additionally, the GIS building height information for most of the buildings (but usually not podiums or other similar structures) were available from the same source. 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-categorize buildings by their 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, the number of floors was estimated from the aerial photos.

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 developer website. For all the remaining buildings, including the village houses and estate high-rises, number of units per floor, was estimated from the floor area, assuming 1 unit per about 78 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

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 4.8.* However, since more detailed information on the building heights and areas is available in this study for most buildings considered, based on that information the typical values have been, where possible, derived accurately from the number of units and the occupied surface areas. In

particular, the maximum density of people in most non-residential building types has been assumed as one person per 9 m^2, based on the Code of Practice for the Provision of Means of Escape in Case of Fire. For other buildings, where details were not available, the following assumptions in line with the ERM (2006) studies were used.

Table 4.8 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
	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

Category	Building Height /Size(1)	Assumption			Total
	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 carpark			
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

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 characterization 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 ERM (2008) study.

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 summarized in *Table 4.9*.

Table 4.9 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 4.10*. These are based on extensive surveys conducted in the ERM (2006) study. For vehicle and pavement populations, distribution across time periods were based on data provided in AADT / BDTM and site surveys.

Table 4.10 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%
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 both the So Kwun Wat and Tai Lam magazine sites as shown in *Table 4.11*. These have been considered in the Hazard to Life Assessment.

Table 4.11 Slopes Identified

Slopes	Site	Distance from explosive store (m)	Population
6SW-D/C214	So Kwun Wat site	20	No road or population nearby
6SW-D/C215	So Kwun Wat site	60	Adjacent to the service reservoir
6SW-D/C219	So Kwun Wat site	55	Adjacent to the magazine access road
6SW-D/C221	So Kwun Wat site	20	No road or population nearby
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	Autoignition 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

* 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' (eg sparks, friction, impact, electrostatic discharge etc);
- Shock stimulus: Subject to shock or high velocity impact: (eg bullet impact, detonation of other explosives, etc.); or
- Thermal stimulus: Subject to mass heating leading to exothermic reaction (eg 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 HAZARD 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 explosive. The sensitivity of AN based explosives to deflagration or detonation is increased at elevated temperatures.

There are two broad categories of emulsions:

- Packaged emulsion (sensitized); 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 sensitized state. Bulk emulsions are sensitized 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 (sensitized) 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 it becomes contaminated with other materials eg. 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, its 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 eg 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 be eventually 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 min. 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 bullet impact test, it requires at least 10 times the energy level of that required to detonate a nitroglycerine 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, is typically much less than that required to initiate most commercial explosives (eg 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 *HAZARD 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 are 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 PETN. Detonators also contain a primary explosives substance, e.g. lead azide, that is very sensitive to initiation.

In the case of detonating cord, PETN has similar sensitivities (somewhat less sensitive) than nitroglycerine (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 (ie 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 bullet impact test, it requires at least 10 times the energy level of that required to detonate a NG based explosive (ERP, 2009).

5.3 *ACCIDENTAL INITIATION ASSOCIATED WITH STORAGE AT MAGAZINE*

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

- Inadequately controlled maintenance work (eg hot work);
- Poor housekeeping (eg 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);
- 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 MAGAZINES*

Both cartridged emulsion 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 such will require a significant crash impact and/or a fire to cause a concern to the explosive load. As reported in the ACDS (1995) study, 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 min) 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 min for the explosive to reach critical conditions. This time may be considerably reduced for mix loads of cartridged emulsions and detonating cord; however, no accurate time could be predicted from detonating cord transport accident data (ERP, 2009).

In this project, the relative amount of detonating cord and cartridged emulsion is different to previous EIAs. The behaviour of explosives as transported in this project was reviewed with assistance from experts in the explosive 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 has considered in more 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 (AN)). 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 next section.

Regarding, 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 fuse 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 about in about half of the 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 (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. Analysis 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 (eg NG based explosives, ANFO, Plastic (C4), etc.) as relevant for the Frequency Assessment part of this Hazard to Life Assessment.

5.5.1 *EXPLOSIVE 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 XRL 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. The international experience of incidents involving the transport of explosives on road has therefore been reviewed in details.

A review of international incident databases indicate that the EIDAS database contain 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 watergel 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 watergel (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 annual consumption of explosives per year). Of this total, approximately 3,000 tonnes (0.3%) is non-bulk explosive (boosters or cartridged emulsion) (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 had a good safety record. In a recent study released by 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 has not been any known transport related explosions involving purely packaged emulsion, hence, accidents data have been examined for other types of explosives having similar properties like bulk emulsion or ANFO although they may be subject to different explosion mechanisms;

- There has been numerous accidents involving crash impact and even with more sensitive explosives such as nitroglycerine based explosives, there is 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 resulted in truck overturn or significant scenarios and no explosion occurred purely due to the shock impact (Oct 2008 (US), Aug 2008 (US), Jul 2008 (US), May 2008 (Spain), etc.).

- There have been only six reported transport related accidents involving emulsion (Jun 2004 in Russia and Mar 2007 in Chile) and bulk ANFO (which would behave like emulsion in a fire condition) (Apr 1959 in USA,

Aug 1998 in Canada, Dec 1998 in Australia and Sept 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 ie mixing explosives with other materials eg. 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 MAGAZINES

A magazine site typically contains more than one explosive stores. So Kwun Wat, for example, will have 4 stores while Tai Lam will have 2 stores. 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 analysis therefore considers the worst case scenario to be the detonation of the full contents of one store. Further justification for this is provided in *Section 6*. 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.

The above scenarios are common to all the proposed magazine sites.

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 explosive trucks are allowed to load explosives at the same time, it was simplistically and conservatively assumed than 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 and 4 fold increase in truck load explosion frequency for a Magazine with 4 stores.

The explosive loads considered are listed in *Table 5.4*. The detonator explosive load has been considered in the total explosive load.

Table 5.3 *Explosives Storage Quantities*

Storage 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)
So Kwun Wat	1200	5,600	1368	4	342
Tai Lam	800	3,800	911	2	456

Notes:

1 Assumed 40% detonating cord & 60% cartridged emulsion based on a typical pull length of 5m which would require 18kg of detonating cord and 29kg of cartridged emulsion

2 Detonating cord are made of PETN

3 Each detonator contains about 0.9g of PETN

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

5.6.2 TRANSPORT OF EXPLOSIVES

Hazardous scenarios considered for the transport of explosives are:

- Accidents involving explosives delivered and transferred from magazine to each delivery point from the gate of each magazine to the gate of the construction 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 HD 1.4B or HD 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 200g per trip to be transported in XRL, 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 XRL project will be carried out over a 3 year 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 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 So Kwun Wat site	342	-	Total of 4 stores
02	Detonation of full load of explosives in one store in Tai Lam site	456	-	Total of 2 stores
03	Detonation of full load of explosives in one contractor truck on the access road within the So Kwun Wat magazine site boundary	91	1642	
04	Detonation of full load of explosives in one contractor truck on the access road within the Tai Lam magazine site boundary	71	1029	
	Transport of Explosives			
05	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2b Shek Yam	57	392	
06	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2c Shing Mun	28	27	

Tag	Scenario	Explosives load (TNT eqv. kg)	No. of Trips per year	Remarks
07	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2d Kwai Chung	91	606	
08	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2e Mei Lai Road	34	617	
09	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam site to delivery point 1b Pat Heung	71	531	
10	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam site to delivery point 1c Tai Kong Po	45	341	
11	Detonation of full load of explosives in one contractor truck on public roads – from Tam Lam site to delivery point 1d Ngau Tam Mei	45	157	

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 So Kwun Wat site	342	-	Total of 4 stores
02	Detonation of full load of explosives in one store in Tai Lam site	456	-	Total of 2 stores
03	Detonation of full load of explosives in one contractor truck on the access road within the So Kwun Wat magazine site boundary	148	1970	
04	Detonation of full load of explosives in one contractor truck on the access road within the Tai Lam magazine site boundary	141	1235	
	Transport of Explosives			
05	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2b Shek Yam	129	470	
06	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2c Shing Mun	28	32	
07	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2d Kwai Chung	148	727	
08	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2e Mei Lai Road	81	740	
09	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam site to delivery point 1b Pat Heung	141	637	
10	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam site to delivery point 1c Tai Kong Po	46	409	
11	Detonation of full load of explosives in one contractor truck on public roads – from Tam Lam site to delivery point 1d Ngau Tam Mei	46	188	

6 FREQUENCY ASSESSMENT

6.1 STORAGE OF EXPLOSIVES

6.1.1 EXPLOSION IN CONTRACTOR'S COLLECTION TRUCK WITHIN THE MAGAZINE SITE

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 the *Section 6.2* and is consistent with the approach considered in the ERM (2008) study. The base frequency for accidental explosion during transport has been taken at 7.69×10^{-10}/km, and the same frequency has been assumed while the contractor's truck is onsite at the magazine. For cases where, several explosive 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	Route length (km)	Total number of deliveries (/year)
So Kwun Wat	0.127	1707
Tai Lam	0.196	1352

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 Magazines*

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 per magazine site has been taken for generic causes of explosion during storage in the magazine site based on the UK historical records (Merrefield, 1998) as detailed in the ERM (2008) study. 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 explosive types to be used in the XRL 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 explosive magazine is protected from external fire due to location of explosives inside a concrete or brick wall building and will be protected with 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 proposed magazines are provided with a comprehensive security system as elaborated in the previous section (*Section 2.3.2*) and thus the possibility of vandalism may be reduced.

The installation of fire fighting measures within each 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 x 10^{-4} per 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 magazines compared to international practice; hence risks due to manual transfer are taken to be covered in the generic failure causes.

Lightning Strike

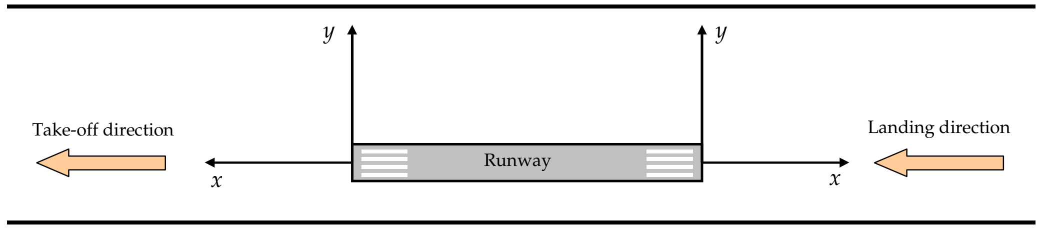
The magazines will be protected with lighting conductors to safely earth direct lightning strikes. The potential for a lighting strike to hit the facility and cause a detonation of explosive is therefore deemed to be unlikely although

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 1986-2005 show a downward trend with recent years showing a rate of about 2×10^{-7} per flight. However, only 13.5% of accidents are associated with the approach to landing, 15.8% are associated with take-off and 4.2% are related to the climb phase of the flight (NTSB, 2001). The accident frequency for the approach to landings hence becomes 2.7×10^{-8} per flight and for take-off/climb 4.0×10^{-8} per flight. The Civil Aviation Department (CAS) reports an annual number of flights at Chek Lap Kok is about 300,000.

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 (150,000 per year) and half are landings (150,000 per year). Assuming each runway is used with equal probability, the frequency of crashes at the magazine sites 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 480 m^2 for So Kwun Wat since it has 4 stores, and 240 m^2 for Tai Lam which has only 2 stores.

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

Table 6.3 Airplane Crash Frequencies

Magazine	Distance from Runway Threshold (km)				Crash Frequency (/km²/yr)*					Magazine Store Area (m²)	Impact Frequency (/yr)
	07L/25R		07R/25L		07L Take-off	25R Landing	07R Take-off	25L Landing	Total		
	x	*y*	*x*	*y*							
So Kwun Wat	7.5	3.0	7.5	4.5	3.8×10^{-8}	2.6×10^{-8}	8.4×10^{-9}	1.7×10^{-8}	9.0×10^{-8}	480	4.3×10^{-11}
Tai Lam	12.5	7.5	12.5	9.0	1.1×10^{-11}	8.6×10^{-10}	2.3×10^{-12}	6.4×10^{-10}	1.5×10^{-9}	240	3.6×10^{-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 sites

Hill/Vegetation Fires

Hill/vegetation fires are relatively common in Hong Kong, and could potentially occur near a magazine site. Recent statistics for these fires in Hong Kong country parks have been reviewed. Although the magazines are not actually located in country parks, the surrounding terrain and vegetation are similar to those typically found in country parks. According to Agriculture, Fisheries and Conservation Department (AFCD) statistics, the average number of hill fires is 52 per year during the five years 2003-7 (range: 41 to 66). The area affected by fire each year is available from AFCD annual reports for 2004-2006 (*Table 6.4*). These are compared to the total area of country parks in Hong Kong of 43394 Ha.

Averaging the data for the 3-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)	% of Total Country Park Affected
2004	371	0.85
2005	144	0.33
2006 (most recent available)	872	2.01

With respect to the explosive magazine design, the land within the compound will be cleared of vegetation to remove combustible materials (see *Section 2.3.2g*). The Magazines, 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 magazines are 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) (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 ERM (2008) study, it is not considered possible that an explosion within one magazine store will directly initiate an explosion within an adjacent store (ie 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 229mm/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 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 XRL project considering the amount of explosives to be stored in each storeroom at each Magazine site.

Applying the above equation and the ground coupling correlation of the ERM (2008) study, the maximum ground vibration generated from detonating of 456kg TNT equivalent explosive is calculated at 153 mm/s for a separation of 16m, 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 Magazines

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 SO KWAN WAT AND TAI LAM SITES*

The proposed So Kwun Wat and Tai Lam magazine sites will be located about 2km and 5km respectively from the regular departure and arrival flight paths at Hong Kong International Airport (*Figure 6.2* and *Figure 6.3*). Missed approaches to runway 07L would also involve aircraft climbing away from Chep Lap Kok on a flight path that passes close to So Kwun Wat. (*Figure 6.4*)

Figure 6.2 Arrival Flight Paths of Hong Kong International Airport

Figure 6.3 Departure Flight Paths of Hong Kong International Airport

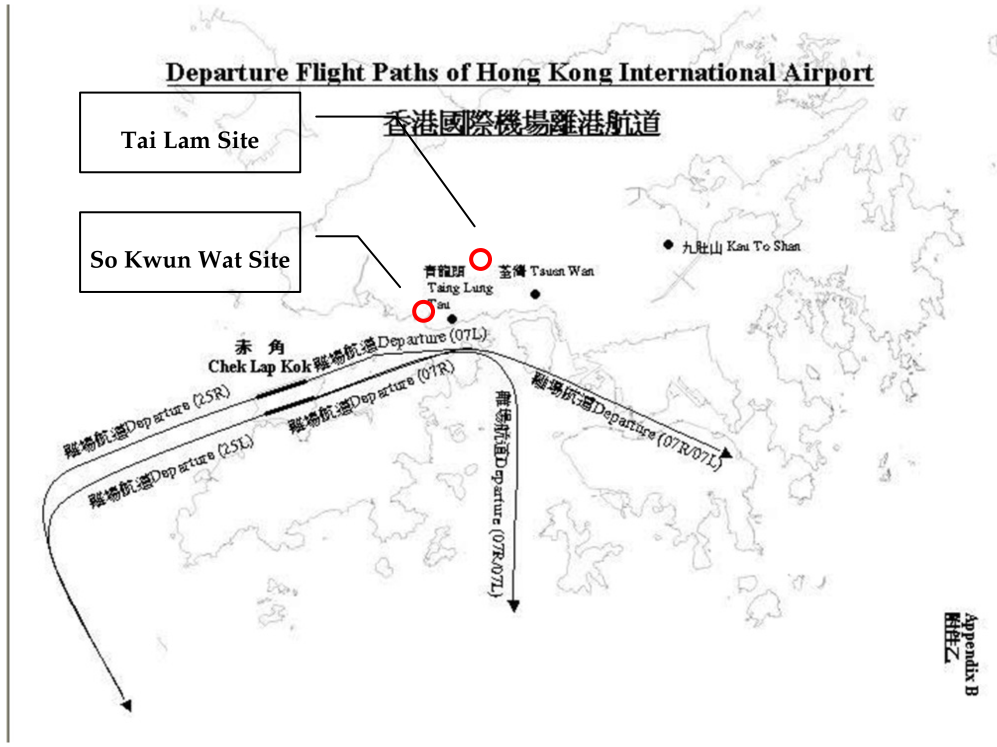
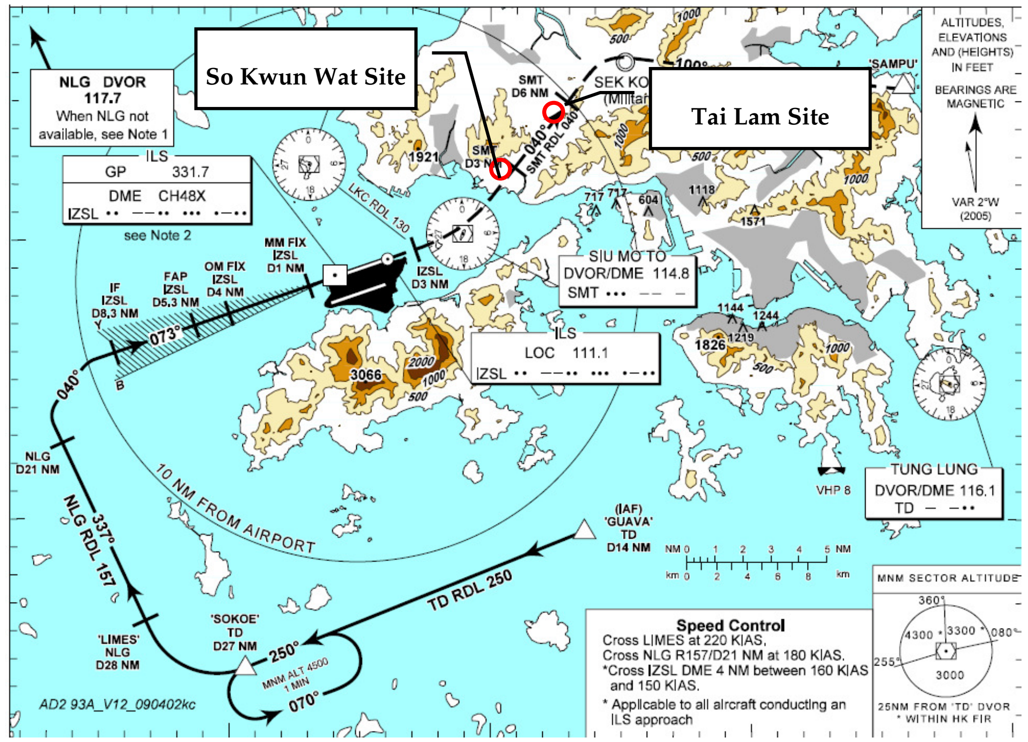


Figure 6.4 Missed Approach Flight Path



Impact on Regular Arrival and Departure Flight Paths

Both the regular arrival and departure flight paths are more than 2km from both proposed magazines. This distance is far beyond the maximum impact zone of fragments generated in the event of an explosion. Any incident at either 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 So Kwun Wat and Tai Lam sites (*Figure 6.4*). The altitudes of planes are expected to be about 200m and 600m above the So Kwun Wat site and the Tai Lam sites respectively. 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 So Kwun Wat site and Tai Lam sites. During the 12 month period from April 2008 to March 2009, based on information provided by the CAD, there were a total of 387 missed approaches recorded at the airport and about 70% of landings take place on runway 07L. This gives about 270 missed approaches per year for runway 07L that may pass over the magazine sites. 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 270 x 14 / (365 x 24 x 3600) = $1.2x10^{-4}$. Although the missed approach flight path is close to the proposed magazine sites, 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} x $1.2x10^{-4}$ x 0.25 = $3.0x10^{-9}$ 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 $3.0x10^{-10}$ per year.

This calculation is applicable for So Kwun Wat, but the probability for Tai Lam will be even lower given its greater distance from the airport. It is concluded that the risk of magazine explosions impacting on aircraft is negligible, ie. $<10^{-9}$ 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 Magazines to the construction sites. The causes of potential accidental explosion during transportation have been identified in the WIL QRA study (ERM, 2008), which was based on the DNV (1997) study and to a great extent on the ACDS (1995) study and its associated frequency assessment reported by 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 (1995) study. 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.

The probability of spontaneous explosion due to the potential transport of 'unsafe explosives' is considered low considering the types of explosives transported in Hong Kong and the existing regulations in place. This frequency component has been reviewed in the ERM (2008) study.

This Hazard to Life Assessment study has been performed based on the latest information available on the explosive properties, vehicle incident frequencies provided by the Transport Department and Fire Service Department, and the specific explosive transport vehicle design and operation to be used as part of the XRL project. The historical background for the derivation of each frequency component is given below and comparison is made with the approach adopted in this study to ensure consistency with previous studies.

6.2.1 EXPLOSIVE INITIATION FREQUENCY DURING TRANSPORT AS USED IN PREVIOUS HONG KONG STUDIES

In previous Hong Kong studies, it was considered that explosives initiation during road transport can be caused by spontaneous fire (non-crash fire), fire after a vehicle crash (crash fire) and impact initiation in crash.

The basic event frequencies derived in previous Hong Kong studies for road accidents were based on those derived in the ACDS study (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 (1997) studies 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 ERM (2008), Maunsell (2006) and ERM (2001) studies adopted the frequencies derived for the M/HGV Mines Division trucks based on in the DNV (1997) study and applied this for the transport of explosives in pick-up truck type Light Good Vehicles (LGV) operated by contractors from the relevant magazines to the construction sites.

Accounting for the safer nature of the explosives to be transported nowadays in Hong Kong, the ERM (2008) study proposed a refined approach for the assessment of the explosion frequency associated with the transport of 'unsafe

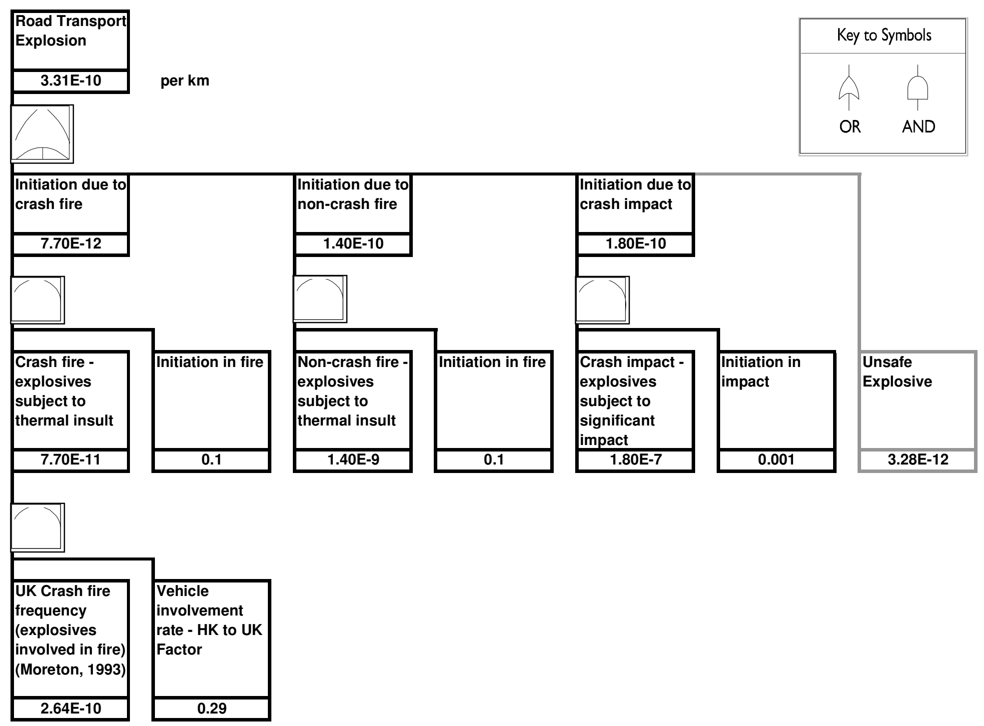
explosives'. Although such events are considered extremely unlikely for the types of explosives used in Hong Kong, it has not been possible to completely rule out its occurrence. As such, the assumption that the assessed frequency of explosion will be doubled as used in the ACDS study (1995) has been dismissed for the particular types of explosives transported in Hong Kong and replaced, instead, by an overall frequency increase by 1% (ie a factor of 1.01 was applied to the overall frequency). The details of the approach are presented in the ERM (2008) study report.

The components of the explosive initiation fault tree adopted in the ERM (2008) study as well as their individual probabilities are shown in *Table 6.5* and the fault tree model for the road transport explosion shown in *Figure 6.5*. The frequency of explosives initiation during road transport was therefore estimated at 3.31 x10^{-10}/km considering an additional 1% increase for "unsafe explosives" (ie a factor of 1.01), as justified in the WIL QRA (ERM, 2008).

Table 6.5 ***Explosives Initiation Fault Tree Inputs After ERM (2008)***

Event	Event type	Value
Vehicle crash	Frequency	1.8 x10^{-7} /km
Crash fire	Frequency	7.7 x10^{-11} /km
Non-crash fire	Frequency	1.4 x10^{-9} /km
Explosives initiation in fire	Probability	0. 1
Explosives initiation in impact	Probability	0.001

Figure 6.5 ***Explosives Initiation Fault tree – Road Transport Events After ERM (2008)***



Note: Derivation of the *Vehicle involvement rate – HK to UK factor* of 0.29 is discussed below in the crash fire section

Background of Probability of Explosive Initiation in Hong Kong Studies

The source document which assesses the risks associated with the transport of explosives in previous Hong Kong Transport QRA Studies is the DNV (1997) study which was itself based, using modification factors, on the Moreton (1993) study. The historical background for each frequency component is summarised below:

Non-crash fire:

This cause category included any explosion instance where the explosive load has been subject to thermal stimulus which resulted from a fire engulfing the explosive load.

The frequency under this category was based on a review of UK road fire incidents associated with Heavy Goods Vehicles (HGV) during the 1987-88 period, adjusted for the conditions of explosive transports in UK (Moreton, 1993). In this accident data review, only the fire incidents escalating to the truck cargo (ie leading to explosive burning) were counted as applicable to explosive vehicles. The review indicated that, in the UK, roughly 60% (1,360 in 1987 and 1,380 in 1988) of the total vehicle fire incidents (total reported fire incidents were 2,401 in 1987 and 2,203 in 1988) propagated beyond initial ignition point. About 14% (377 out of 2740) propagated to the load. Although a significant number of incidents which propagated beyond their initial point were discounted in the analysis, it is not clear whether such incident could have induced sufficient heat transfer to the explosive load. Referring to the Hazard Identification section, this type of thermal stimulus has been identified as a potential explosion scenario. In addition, incidents which could not have occurred on explosive vehicles and incidents not occurring on public roads were screened out of the analysis.

The main causes of non-crash fire incidents identified were partitioned into the following ignition source categories:

- Cab or engine fire (including electrical faults, fuel fires, engine overheating, etc. but excluding fire due to vehicle crash);
- Smokers' materials (including careless use of cigarette, matches, lighters, etc.)., however it is noted that smoking is strictly prohibited in site magazines and trucks;
- Arson; and
- Tyre fire (including jammed brake events, friction between the two wheels on double wheels of a rear axle, if any).

In the absence of relevant data for Hong Kong, it was simply assumed in the DNV (1997) study that the transport conditions of explosive trucks in Hong Kong were similar to UK explosive trucks in 1987-88 and would be subject to the same fire probabilities.

The main safety features accounted in the Moreton (1993) and DNV (1997) studies were the provision of the fire screen between the cab and the load compartment for which a failure probability of 0.1 was used and two small 9-litre water-gas fire extinguishers for which a failure probability of 0.5 was assumed. Credit was also given to account for the Approved Code of Practice (ACOP) accompanying the 1989 Carriage of Explosives Regulations applicable in the UK at the time of the ACDS (1995) study by assigning a probability for breach of regulations of 0.01 to arson frequency on an attended vehicle and 0.01 to the fire probability due to Smokers' materials.

Given the vehicle design and operation differences for the Light Goods Vehicles (LGV) explosive trucks to be used for the XRL project up to 2013, this frequency component has been reassessed. Although, the Moreton (1993) failure frequency data included intervention of the fire brigades, the DNV (1997) excluded such intervention.

The DNV (1997) study also provided a review of the FSD fire calls for Dangerous Goods in Hong Kong during the period 1991-1994. All fire reports related to other types of dangerous goods, mainly Cat. 5 (flammable liquids) and are not directly relevant to Cat. 1 (explosives) vehicles. It is worth noting the response time provided by the FSD which ranged from 2.3 min to 13.3 min in a sample of 15 fire calls related to dangerous goods. The response time varied mainly according to the distance travelled by the FSD. An analysis was attempted to identify the relative contribution to each cause distinguishing crash-fires from non-crash fires and the various causes of non-crash fires; however, the data sample available did not permit the derivation of Hong Kong specific probabilities.

Following the review of FSD dangerous goods data, the DNV (1997) study adopted the UK fire statistics applicable for commercial explosive road transport, as reported by Moreton (1993), without any adjustment factors; albeit the assumptions made in Moreton (1993) were reviewed. The UK fire statistics as adopted by Moreton (1993) as well as the adjustment factors applied in DNV (1997) are summarized in *Table 6.6*.

Table 6.6 Explosives Initiation Fault Tree Inputs After Moreton (1993) and Adjustment Factors Accounted in DNV (1997) Study

Cause of Fire	UK HGV kilometres travelled (1987-88 average) (km)	No of UK HGV incidents in 10% sample in year 1987-88 escalating to the cargo load	Applicable Scaling Factor	Frequency of UK HGV fires escalating to the cargo load (1987-88) (km^{-1})	%	Adjustment factor (UK) for explosive vehicles	Moreton (1993) rationale for adjustment factor	Additional adjustment factors accounted in DNV (1997) study	Fire Fighting Factor	DNV (1997) rationale for adjustment factor	Net Frequency (km^{-1})	%
Cab or engine fire	2.65E+10	15	10	5.65E-09	40%	0.1	Fire resisting screen provided to act as a fire shield between the engine, exhaust, generator, switches, cab, etc. and the load-carrying part of the vehicle	1	1	Extinguishment more likely in Hong Kong than average	5.65E-10	17%

Cause of Fire	UK HGV kilometres travelled (1987-88 average) (km)	No of UK HGV incidents in 10% sample in year 1987-88 escalating to the cargo load	Applicable Scaling Factor	Frequency of UK HGV fires escalating to the cargo load (1987-88) (km^{-1})	%	Adjustment factor (UK) for explosive vehicles	Moreton (1993) rationale for adjustment factor	Additional adjustment factors accounted in DNV (1997) study	Fire Fighting Factor	DNV (1997) rationale for adjustment factor	Net Frequency (km^{-1})	%
Crash fire	2.65E+10	7	1 **	2.64E-10	2%	1	Sample represents all HGV UK events (no adjustment factors or scale up factor required)	0.3 *	1	Crash fires dominated by fuel fire events. UK frequency factored by ratio of HGV accident involvement rate HK (0.18 pmvkm) to UK (0.62 pmvkm) (ie applying a factor of 0.3)	7.92E-11	2%
Smoker materials	2.65E+10	4	10	1.51E-09	11%	0.01	Smoking not allowed but possible	1	1	Smoking not allowed but possible	1.51E-11*	0%
Arson	2.65E+10	4	10	1.51E-09	11%	0.01	Vehicles attended at all times	1	1	Vehicles attended at all time	1.51E-11	0%

Cause of Fire	UK HGV kilometres travelled (1987-88 average) (km)	No of UK HGV incidents in 10% sample in year 1987-88 escalating to the cargo load	Applicable Scaling Factor	Frequency of UK HGV fires escalating to the cargo load (1987-88) (km^{-1})	%	Adjustment factor (UK) for explosive vehicles	Moreton (1993) rationale for adjustment factor	Additional adjustment factors accounted in DNV (1997) study	Fire Fighting Factor	DNV (1997) rationale for adjustment factor	Net Frequency (km^{-1})	%
Tyre fire	2.65E+10	14	10	5.28E-09	37%	1	The original study accounted for fire brigade attempt to attend to the fire with a success probability of 0.5. No credit has been given in the DNV (1997) study	0.5	1	Tyre fires less frequent in Hong Kong probably due to lower speed	2.64E-09	80%
Summary												
Crash Fire				2.64E-10	2%						7.92E-11	2%
Non-crash fire				1.39E-08	98%						3.23E-09	98%
Total				1.42E-08	100%						3.31E-09	100%

* See following section

** The sample analysed included all UK incident data

pmvkm denotes 'per million vehicle kilometres'

Crash fire:

This cause category is similar to the non-crash fire category but only concerns fires resulting from vehicle collisions.

The frequency under this category in the DNV (1997) study was based on UK road fire incidents associated with HGVs during the 1987-88 period as reported by Moreton (1993) where the crash fire explosive cargo damaging rate was assessed to be 2.64 x 10^{-10} per km. In the DNV (1997) study, this was subsequently factored by 0.3 being the ratio of Mine Division explosive vehicle involvement rate in 1993 in Hong Kong (0.18 per million vehicle kilometers (pmvkm)) to the UK reportable HGV (over 3.5 te) vehicle accident involvement rates in 1992 (0.62 pmvkm). The UK involvement rate in 1992 was used on the basis of a downward accident trend from 1988 to 1992.

In subsequent Hong Kong studies, in the absence of further relevant data, it was implicitly assumed that Hong Kong Mines Division M/HGV trucks in 1993 and Contractors LGV explosive trucks would be subject to similar conditions.

Crash impact:

This cause category included all instance of vehicle collisions with sufficient mechanical energy to significantly affect the explosive and which could have the potential to cause an accidental explosion.

The frequency under this category was based on Hong Kong M/HGV vehicle involvement rate from the Transport Department for year 1993 (DNV, 1997) being 0.59 per million vehicle kilometers (pmvkm). It included all the M/HGV accident involvements which led to fatal, serious injury or minor injury assuming that any injury related incident could cause an impact on the explosive load.

This figure, as used in the DNV (1997) study, could be considered conservative compared to the original assessment (ACDS, 1995 and Moreton, 1993) which considered that, on average, only fatal and serious injury accidents have the potential to be severe enough to have also caused damage to any cargo carried on the vehicle. It was recognized in these studies that cargo damage events may not always lead to injury but conversely injury events do not always result in cargo damage. In absence of cargo damaging rate correlation, the approach of only considering fatal and serious injury as representative for cargo damage rate is consistent with a number of studies assessing the risks associated with the transport of dangerous goods (Davies, 1992) and historical accident data.

It is recognized that for vehicle of a higher design and operation standards such as those associated with the transport of explosives or other hazardous materials, the accident rate would be less than normal goods vehicles. Davies (1992) reported that probability adjustment factor of 0.8 should be appropriate for dangerous goods while, based on a review gathered for UK Ministry of

Defense munitions vehicles, an adjustment factor of 0.1 to 0.33 should be adopted for munitions vehicle. The DNV (1997) study adopted an adjustment factor of 0.3 (upper range of Davies (1992) data for munitions vehicles) which was consistent with the excellent safety records of Mines Division trucks (zero accident in 2 million kilometers travelled at the time of the assessment).

The overall accident involvement rate applicable for Mines Division vehicles was assessed at 1.8 x 10^{-7} per km (0.59 pmvkm x 0.3). This figure was then applied to all the other studies in Hong Kong regardless of the vehicle type, and design and operation standards. Hence, in absence of specific data available, it was implicitly assumed that Hong Kong Mines Division M/HGV trucks in 1993 and Contractors LGV explosive trucks would be subject to similar conditions.

Spontaneous Explosion ('Unsafe Explosive')

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

Where commercial explosives are concerned, the term 'unsafe explosives' has been used historically to describe products such as Dynamite and Gelignite (generic names for NG based explosives) which for one reason or another have become degraded. These products contain NG (glyceryl trinitrate) which is a powerful explosive composition, highly sensitive to shock, friction and heat.

Commercial explosives containing NG [$C_3H_5(NO_3)_3$] were first manufactured in the 1860's and due to the absence of safer technology, were not replaced by lower sensitivity commercial explosives until the early 1980's.

When dynamite dries out, it may exude NG and also, the various salts in the explosive mixture may crystallize out, producing sharp crystals that may be sensitive enough to initiate the free NG. In this form, the explosive is extremely sensitive to heat, impact, shock and static electricity.

Starting from 1950s, various types of blasting explosives were developed to replace the highly sensitive NG based explosives. ANFO and Tovex ® (watergel explosives) were manufactured and commercialized, which was followed by the discovery of emulsion explosives. Bulk emulsion that meets the requirements of UN 3375 does not contain sensitizers while packaged emulsion is typically sensitized with sodium nitrite and contains a sensitizing substance such as powdered aluminum. All theses formulations were inherently reducing risk and improving safety in manufacture, transportation, storage and use.

The emulsion family of explosives that are transported, stored and used in Hong Kong today are by far the safest commercial explosives manufactured globally to date and do not degrade or form extremely sensitive by-products. When degradation does occur (usually due to temperature cycling above/below 34^{o} C), emulsions become less sensitive and eventually are not capable of detonating.

Accounting for the safer nature of the explosives to be transported nowadays in Hong Kong, the ERM (2008) study proposed an overall frequency increase by 1% to account for 'unsafe explosives' instead of doubling in frequency used in earlier studies. This approach is considered appropriate for the types of explosives transported in the XRL project and this has been re-confirmed following a review with globally renowned experts for the XRL project (MTR, 2009).

6.2.2 DERIVATION OF TRANSPORT EXPLOSION FREQUENCY FOR XRL

Severe Impact Accident Involvement for Explosive Trucks

Hong Kong Experience with the Transport of Explosives

In the past 40 years, there have been a significant number of projects requiring the transport of explosives. The previous DNV explosive transport study (DNV, 1997) quoted a total travel distance by Mines Division trucks carrying explosives from 1971 to 1995 (25 years) of 2,273,182 km.

Additional travel distance data were collected from Mines Division for the period of 1996 to 2008. Route mileage was actually recorded for a period of 7 years and 7 months from 2001 to 2008 with a total 762,377 km.

The above data were extrapolated by Mines Division based on average yearly mileage carrying explosives of 50,289 km to cover the 13 year period from 1996 to 2008 giving a total of 653,757 km for Mines Division explosive trucks carrying explosives.

Therefore, it is estimated that during a period of 38 years, Mines Division trucks have carried explosives for a total of 2,926,939 km (rounded to 2,900,000 km to cover for uncertainties in the estimate).

During the 38 year period, for all trucks carrying explosives on the road, there have been no major accidents and no incident of fire or explosion.

Using a Poisson distribution assuming zero incident, the major truck accident probability at 50% confidence level, for a Mines Division truck carrying explosives, can be estimated at: 0.7/2,900,000 = 2.4×10^{-7} per kilometre (0.24 per million vehicle kilometre).

It can be estimated that, accounting for return journeys, the overall travelled distance in that period for Mines Division trucks is around 5,800,000 km. As reported by DNV (1997), there is only one known vehicle accident, which involved a rear-end collision of a private car into an empty Mines truck on a return journey. Likewise, using a Poisson distribution assuming one incident, the major truck accident probability at 50% confidence level, for a Mines Division truck carrying explosives, can be estimated at: 1/5,800,000 = 1.72×10^{-7} per kilometre (0.17 per million vehicle kilometre). This is about 50% lower

than the estimated figure at the time of the DNV (1997) study but is consistent with the assessed vehicle involvement rate (0.18 pmvkm) based on a review of M/HGV data and UK munitions vehicles, reported in the DNV (1997) study.

To evaluate whether these figures are statistically significant, it is necessary to review the overall Hong Kong accident data for LGVs as applicable to the Contractors' explosive vehicles and M/HGV vehicles as well as accident statistics available for Dangerous Goods (DG) vehicles. This is discussed in the following sub-sections.

It should be noted that, based on the minimum safety requirements imposed by Mines Division, the design of the Contractors' explosive trucks is different from the design of Mines Division truck, which formed the assessment basis for the previous Hong Kong studies. The design differences are described in *Section 2*. Particularly, the Contractors' explosive truck is an LGV type pick-up type truck and does not require adopting all the safety features required on Mines Division trucks given the lower quantities of explosives to be transported.

UK Experience with the Transport of Explosives

The rate at which explosives may be expected to sustain impact forces of sufficient severity to cause damage but not necessarily initiation has been derived in the ACDS Report (1995) based on UK historical data.

The ACDS Report (1995) indicates, based on accident records over a 15 year period from 1975 to 1989 and data supplied by the principal transporters of commercial explosives in UK, a severe impact probability of 8×10^{-8} per km (0.08 involvements pmvkm). This figure was based on 5 events involving commercial explosives and a total movement estimated at 6×10^{7} km by the principal transporters.

In the absence of further data from the principal transporters of commercial explosives in the UK, it is difficult to update this figure, however, an attempt is made below to extrapolate this figure. The 6×10^{7} km travelled from 1975 to 1989 suggests an annual distance travelled of 4×10^{6}. In the period of 1990 to 2008, there has been a further three reported incidents involving transportation of commercial explosives. This, combined with the 5 incidents between 1975 and 1989, gives a total of 8 incidents involving explosive vehicles over a period of 34 years. The average involvement rate is then $8/34/4 \times 10^{6} = 5.8 \times 10^{-8}$ per km. This figure is considered as a rough estimate; however it reinforces the confidence level in the assessed figure of 8×10^{-8} per km (0.08 involvements pmvkm) in the ACDS Report (1995).

For the same period, the fatal and serious injury involvement rate for HGVs in the UK was estimated at 4×10^{-8} per km (0.04 involvements pmvkm) which shows a good correlation with the serious involvement rate of 0.08 pmvkm.

This explosive truck involvement rate for the UK is about a factor of two lower than the explosive vehicle involvement rate (0.17 pmvkm) based on Mines Division data for all incidents. Accounting only for serious accident, the serious accident involvement rate for Mines Division trucks would be roughly one order of magnitude lower than the serious and fatal accident involvement rate for M/HGVs of 0.22 pmvkm (referring to *Table 6.8*).

US Experience with the Transport of Explosives

Santis (1999) analysed the explosive transportation incident and accident data collected by the US Department of Transportation (DoT) Data from 1993 to 1998. He reviewed incident and accident data recorded by the Research and Special Programs Administration (RSPA), the Institute of Makers of Explosives (IME) and Federal Highway Administration (FHWA)'s Office of Motor Carriers (OMC).

RSPA Data

RSPA data includes a mix of incidents and accidents associated with air, rail and road transport. RSPA's requires reporting any incidents if one or more of the following occur during transportation of a hazardous material:

- There has been an unintentional release of hazardous materials from a package (including tanks);
- A person is killed as a direct result of the hazardous materials;
- A person receives injuries requiring his or her hospitalization as a direct result of the hazardous materials;
- Estimated carrier or other property damage exceeds US$50,000 as a direct result of the hazardous materials;
- An evacuation of the general public occurs lasting one or more hour as a direct result of the hazardous materials;
- One or more major transportation arteries or facilities are closed or shut down for one hour or more as a direct result of the hazardous materials; or
- The operational flight pattern or routine of an aircraft is altered as a direct result of the hazardous materials.

The RSPA database contained 86 incidents involving Class 1 materials in transit from 1993 to 1998, with 32 occurring on public highway and 10 out of these 32 incidents related to blasting explosives. RSPA defines serious incidents as those which involve a fatality, major injury, closure of a major transportation artery or facility, evacuation of six or more persons, or a vehicle accident or derailment. Of these 86 incidents, 45 (50%) were determined to be serious incidents in the RSPA database and seven incidents (8%) involved a fire event. There were no fatalities, one major injury, and three minor injuries caused by the hazardous materials in all the incidents. The major injury occurred on a plane involving smoke signals. Although an explosion reportedly occurred in six incidents, they involved small explosive devices and caused practically no property damage. It is not clear from the reports

whether these involved commercial explosives. Seven incidents involved a fire.

OMC Data

For its public data collection needs, the OMC administers data collection in cooperation with the States under the Motor Carrier Safety Assistance Program. The OMC Crash data file should contain all incidents and accidents reported by the States involving a commercial motor vehicle operating on a highway in interstate or intrastate commerce which results in:

- A fatality;
- Bodily injury to a person who, as a result of the injury, immediately receives medical treatment away from the scene of the accident; or
- One or more motor vehicles incurring disabling damage as a result of the accident, requiring the motor vehicle(s) to be transported away from the scene by a tow truck or other motor vehicle.

The OMC Crash database contained 81 incidents that likely involved Class 1 materials, but not necessarily commercial explosives. There were 7 fatalities and 61 injuries in these accidents although the explosives caused none. After analysing the causes and consequences of the incidents, Santis (Santis, 1999) concluded that none of these led to explosion. Santis noted numerous discrepancies in the database and concluded that any use of the OMC Crash data to evaluate accidents involving Class 1 materials should be viewed with extreme caution.

Out of these incidents, the class of explosives for 20 events were related to the transport of Class 1.1 explosives but could not be determined for a total of 18 reported incidents (22.2%). Assuming, within these 18 reported incidents, an equivalent ratio of incidents involving class 1.1 explosives, the rough estimation of the Class 1.1 explosive vehicle involvement rate would be 25. Within the data analysed, fire events represented over 4% of the incidents reported.

The OMC data also contains environmental conditions at the time of the accident. The road surface was wet in 38% of the accidents involving Class 1 materials; the weather conditions were adverse eg. snow, ice etc. in 36% of the accidents involving Class 1 materials; and it was nitghtime for 38% of the accidents involving Class 1 materials. In all, over half (54%) of the accidents involving Class 1 materials occurred during less than ideal driving conditions.

IME Data

The IME maintains records of accidents involving Class 1 materials. These records come from IME member reports and the news media. A review of IME accident records for the period of 1993 to 1998 shows 29 accidents involving commercial Class 1 materials that seemed to meet FHWA or RSPA criteria that do not appear in the OMC or RSPA databases. Only one of the IME accidents reported did not meet the FHWA reporting criteria indicating that States underreport accidents while industry generally complies with RSPA incident reporting requirements.

Santis further performed a comparison of the IME, OMC and RSPA databases and indicated that none of the incidents or accidents involving Class 1 materials was recorded in more than one database.

Adding the number of Class 1 commercial incidents or accidents from these three sources leads to a total of 74 events in the 6-year period from 1993 to 1998 that met Federal reporting requirements (10 from the NFPA database, 25 from the OMC database and 29 from the IME records). This number is likely to be conservative as events accounted in the OMC and IME databases may not relate to commercial explosives.

Given that a typical shipment in the US may cover more than 100 km on average, it can be estimated that during this period a total number 3×10^{8} shipment kilometres has been carried out. Based on the review of reported transport incidents as reported by IME, RSPA and OMC, a rough estimate of $74 / 3 \times 10^{8}$ commercial vehicle involvements can be estimated, giving 2.46×10^{-7} per km or 0.24 pmvkm. All of the three datasets contain entries even if the event cause could not possibly result in an explosion. In addition, the total number of incidents not related to Class 1.1 commercial vehicles could not be entirely excluded from this analysis. The explosive vehicle involvement rate is therefore considered to be an overestimate although used as a benchmark in this study.

Historical LGV and MGV/HGV Accidents in Hong Kong

A review of the Hong Kong accident data for LGVs was carried out based on the data published by the Transport Department in 2007.

To be able to provide a valid comparison, it is important to note how accidents and accident involvements are defined in Hong Kong. A road traffic accident is reported to the police if it results in fatalities or injuries but not if they cause property damage only. This is similar to the practice overseas.

Accident data varies significantly depending on the type of vehicles. In general, based on the review of accident data from the Transport Department, accidents involving LGV or MGV/HGV vehicles have a lower probability of occurrence per kilometre than average but a higher fatality rate.

The overall number of accident involvements per kilometre is given in *Table 6.7* for LGVs, M/HGVs and all motor vehicles. The data generally shows a constant overall accident involvement rate in the past 5 years. The 2007 statistics indicate an overall accident involvement rate of 1.23 involvements per million vehicle kilometre (pmvkm) for LGVs and 0.82 involvement pmvkm for M/HGVs. Using a five year average, the LGV and MGV/HGV involvement pmvkm are respectively **1.27** and **0.85** involvements pmvkm. For comparison purpose, the vehicle involvement rate for HGV vehicle in 1996

(figure used as the basis for the DNV (1997) study) was **0.59** pmvkm for M/HGVs. The apparent increase is mainly explained by the change of MGV definition in 2000 by the Transport Department. Those figures are also generally higher than those estimated based on the history of operating Mines Division trucks.

Table 6.7 *Hong Kong Vehicle Accident Involvements*

Vehicle involvements	2003	2004	2005	2006	2007	5 y avg
Light goods vehicle						
No. involved in accident	2728	2822	3008	2919	2952	2885.8
% of total involvements	*13.8%*	*13.9%*	*14.4%*	*14.2%*	*13.7%*	*14.0%*
No. licensed (mid-year)	68275	67995	68266	69054	69363	68590.6
Annual mvkm	2194	2205	2247	2316	2396	2271.6
Invol rate : per 1,000 veh	40	41.5	44.1	42.3	42.6	42.1
Invol rate : pmvkm	1.24	1.28	1.34	1.26	1.23	1.27
% of total vehicle km	*24.4%*	*25.4%*	*26.9%*	*25.3%*	*24.7%*	*25.3%*
distance travelled in million vehicle km	*2,200.00*	*2,204.69*	*2,244.78*	*2,316.67*	*2,400.00*	*2,272.28*
Medium & Heavy goods vehicles						
No. involved in accident	1108	1197	1180	1155	1081	1144.2
% of total involvements	*5.6%*	*5.9%*	*5.7%*	*5.6%*	*5.0%*	*5.6%*
No. licensed (mid-year)	41761	42106	42549	42261	41659	42067.2
Annual mvkm	1398	1344	1333	1347	1323	1349
Invol rate : per 1,000 veh	26.5	28.4	27.7	27.3	25.9	27.16
Invol rate : pmvkm	0.79	0.89	0.89	0.86	0.82	0.85
% of total vehicle km	*9.9%*	*10.8%*	*10.5%*	*10.0%*	*9.0%*	*10.0%*
distance travelled in million vehicle km	*1,402.53*	*1,344.94*	*1,325.84*	*1,343.02*	*1,318.29*	*1,346.12*
Total						
No. involved in accident	19743	20355	20850	20540	21517	20601
No. licensed (mid-year)	522912	528172	537124	546409	555861	538095.6
Annual mvkm	11190	11109	11193	11521	11973	11397.2
Invol rate : per 1,000 veh	37.8	38.5	38.8	37.6	38.7	38.28
Invol rate : pmvkm	1.76	1.83	1.86	1.78	1.8	1.806

Severe Impact Accident Involvements for LGV and MGV/HGV in Hong Kong

The risk of cargo damage for a given vehicle involvement is highly dependent on the impact velocity for the vehicle, the crash conditions (front collision, side collision, etc.) and the type of crash (vehicle to vehicle, vehicle to object, etc.).

A numbers of studies were performed in the UK (Davies, 1992) to assess the ratio of fatal incidents to non fatal accidents (Davies and Lees). The range was roughly estimated at 2%-5% for roads with speed limits lower than 40 mph and 10%-15% for other roads. This is consistent with the Transport Department data reported for fatal and serious injury considering an average speed. Although it may be possible to distinguish accidents in terms of impact speed in Hong Kong, the quality of accident statistics data available is such that a number of assumptions would be required which will lead to results with insufficient confidence levels. For instance, the impact velocities and level of vehicle damage are not reported in Hong Kong. This is similar to the practice overseas.

The traditional approach to conducting a QRA on dangerous goods vehicles is to assume that only fatal and serious accidents could result in cargo damage assuming a correlation between severe accidents and, fatal & serious injury accidents. Such an approach has been adopted in a number of previous studies: Davies (1992) and ACDS (1995). This approach is a refinement to the approach adopted in previous Hong Kong studies which used all injuries and fatal accidents; however, it is consistent with accident data associated with vehicles carrying explosives. The DNV (1997) study did not make the distinction; however, the study was dealing with different vehicle types.

A review of fatal and serious accidents as shown in *Table 6.8*, indicates a probability for a serious impact on a LGV or M/HGV vehicles to be roughly at a factor of 0.2 and 0.25 (80% and 75% lower) lower respectively. Accounting for only fatal and serious accidents, the LGV and M/HGV significant accident involvement rate is estimated at around 0.24 pmvkm and 0.20 pmvkm respectively (5 year average values).

To recognise some uncertainties in the assumed correlation between serious impact rates and fatal & serious accident rates, 10% of the slight injury involvements have also been conservatively included in this Hazard to Life assessment as having the potential to cause a significant mechanical (impact) energy on the explosive cargo.

Table 6.8 Hong Kong Vehicle Accident Involvements

Serious and Fatal Vehicle involvements	2003	2004	2005	2006	2007	5 y avg
Invol rate : per million veh-km						
LGV	1.24	1.28	1.34	1.26	1.23	1.27
M/HGV	0.79	0.89	0.89	0.86	0.82	0.85
Total Involvements						
LGV	2728	2822	3008	2919	2952	2885.8
M/HGV	1108	1197	1180	1155	1081	1144.2
Fatal Involvements						
LGV	40	35	44	46	38	41
M/HGV	50	31	27	25	21	31
Serious injury involvements						
LGV	553	511	512	457	430	493
M/HGV	255	291	257	212	188	241
Slight injury involvements						
LGV	2754	2988	3231	3090	2484	2909
M/HGV	1136	1380	1412	1364	872	1233
Fatal Vehicle Involvement Ratio *						
LGV	1.5%	1.2%	1.5%	1.6%	1.3%	1.4%
M/HGV	4.5%	2.6%	2.3%	2.2%	1.9%	2.7%
Serious injury Involvement Ratio *						
LGV	20.3%	18.1%	17.0%	15.7%	14.6%	17.1%
M/HGV	23.0%	24.3%	21.8%	18.4%	17.4%	21.0%
High impact accident involvement rate per million vehicle km **						
LGV	0.018	0.016	0.020	0.020	0.016	0.018
M/HGV	0.036	0.023	0.020	0.019	0.016	0.023
Medium impact accident involvement rate per million vehicle km **						
LGV	0.251	0.232	0.228	0.197	0.179	0.218
M/HGV	0.182	0.216	0.194	0.158	0.143	0.178

* For years 2003 to 2006 the serious and fatal involvement rates are calculated based on the ratio of casualties to total number of involvements for a given vehicle type. This will give a slight overestimate since some accidents will have more than one casualties and the database include pedestrian hit casualties.

Explosive Truck Involvement Compared to Vehicles Not Carrying Hazardous Materials

It can be expected that due to increased awareness of the risk and improved training of the explosive truck drivers and its passengers, a number of accidents which could occur on standard LGV or M/HGV are unlikely to occur for an explosive truck. As per the Requirements for Approval of an Explosives Delivery Vehicle (Guidance Note) in Hong Kong, referring to *Section 2*, the driver and attendant shall have documentary evidence that they have acquired the basic knowledge of handling explosives and the properties of explosives being carried, and are conversant with the emergency procedures. A training programme will be developed on that basis (refer to the Recommendation Section in this Appendix).

The causes of Hong Kong vehicles accidents, as reported by the Transport Department, were examined to attempt an evaluation of the number of accidents which could be avoided by introducing driver training programme. In general, accidents due to causes such as overspeeding, breach of rules & regulation, careless and negligent behaviours could be avoided by proper training provided to the driver. These causal factors are referred as 'Trainable Factors'. Other accidents due to causes such as bad weather, third party involvements, incapacitation, etc. and due to technical defects are generally unavoidable (although a lower speed driving behaviour may reduce their occurrence). Based on a review of 23,321 vehicle involvements (all vehicles included) from the 2007 Transport Department statistics, the split between avoidable accidents and non-avoidable accidents is estimated as shown in *Table 6.9* (the assessed split is conservative as all the unknown causes were assumed to be unavoidable). This assessment confirms the original factor of 0.8 suggested by Davies (1992) as applicable for Dangerous Goods (DG) vehicles. However, as it would be the case on an explosive vehicle, credit could also be given to the vehicle passengers if appropriately trained. Third party perception of risk, while being aware of the hazardous materials being transported (eg provision of safety signs, etc.), may also contribute to some reduction in the accident involvement rate. The assessment performed in *Table 6.9* assumed an intervention success/ error recovery of 50% for the driver alone. A proper training programme given to the driver and the passengers can achieve a higher error recovery rate and reduce the overall accident involvement rate significantly lower.

Table 6.9 Driver Contribution to Overall Accident Involvement Rate

Explosive truck accident to non-explosive truck involvement ratio	**2007**
Percentage of accidents avoidable by training or passenger interventions	
* Accidents due to driver - factors avoidable by training (all involvements)	8074 Considered avoidable
* Accidents due to driver - factors not avoidable by training or passenger interventions (all involvements)	7121 Considered unavoidable
* Accidents not due to driver factors	8126 Considered unavoidable
* Percentage of accidents avoidable by training	34.6%
* For a given avoidable accident - chance of driver or passenger intervention success due to increased training and risk perception	50%
Adjustment factor due to driver	0.83
Adjustment factor due to third party perception of risks	1
Overall Adjustment factor for Dangerous Goods vehicles	0.83

Although a similar driving improvement factor was quoted in the DNV (1997) study for DG vehicles, an improvement factor of 0.3 (70%) risk reduction) was used for Explosive Vehicles quoting an adjustment factor of 0.1 to 0.33 range. This referred to an UK MoD munitions vehicle analysis performed in Davies (1992) and assumed a similar standards of training applicable for drivers and attendants of Mines Division trucks. A similar standard of training as

applicable to MoD munitions vehicles or Mines Division truck was also assumed in this Hazard to Life Assessment to justify a factor of 0.3.

Historical Expressway and Non-expressway Accidents in Hong Kong

It is generally anticipated that, although the speed is higher on expressways or major roads and therefore the potential collision energy would be higher, the overall vehicle involvement rate would be lower than on non-expressways.

This distinction is important for this study since most of the proposed explosive transport route will include Tuen Mun Highway. Additionally, the average (all route combined) accident involvement rate could yield an underestimate of the accident involvement rate on non-expressway roads.

The Transport Department publishes accident data for expressways and average for all roads. From this data the accident statistics could be derived for both expressway and non-expressway traffic. Adjustment factors are accordingly derived based on fatal and serious accidents as shown in *Table 6.10* below. It can be seen that, generally, the accident involvement rate are lower on highways and major roads than non-expressways. Also the average vehicle involvement rate for non-expressways is generally 20-30% higher than average. As expected, the difference between highway and all roads involvement rates is less for fatal accidents due to relatively higher impact speeds on highways.

Table 6.10 Expressways and Non-expressway Involvement Rates (all vehicle types)

Rate of significant vehicle accidents per road type (all vehicles)	**Tuen Mun Highway**	**All expressways**	**Non-expressways**	**All roads**
Accident rate pmvkm	0.33	0.31	1.65	1.28
Annual veh-km (in millions)	603.0	3309.7	8655.2	11964.8
Total Accidents	199	1026	14289	15315
Fatal Accidents	4	14	139	153
Serious Accidents	41	194	2182	2376
Fatal Accident Rate pmvkm	0.007	0.004	0.016	0.013
Serious Injury Accident Rate pmvkm	0.068	0.059	0.252	0.199
Fatal Accident Rate Ratio (compared to all roads as base case)	0.52	0.33	1.26	1.00
Serious Accident Rate (compared to all roads as base case)	0.34	0.30	1.27	1.00

This assessment is consistent with the findings of the DNV (1997) study and Davies (1992) reporting a lower vehicle accident frequency on major roads and highways.

Regional Accidents in Hong Kong

The majority of the explosive transport will be carried out in rural areas although some delivery points will require transportation through highly populated areas. It may be relevant to analyse accident statistics at regional level.

A breakdown in the accident involvement rate is available for different districts of Hong Kong (Kowloon, Hong Kong Island and New Territories). Differences of up to 40% are observed between these districts.

It should be however noted that differences in accident statistics should not be used as representative for a road section in a particular region. The differences may be explained due to different ratios in expressway to non-expressway route lengths and different ratios of roads with central partitions in respective regions. Such differences may not apply for the particular route sections used by the explosive vehicles and, therefore, region based involvement rates are not considered further in this analysis.

Junction and non-junction accidents in Hong Kong

The DNV (1997) study reported that junction accidents in Hong Kong were not dominant and no distinction between junction and non-junction accidents has been made in Hong Kong QRA studies.

Referring to *Table 6.11*, a review of the Transport Department statistics (TD 2007b) confirms the above; junction related accidents are approximately 30% of the total number of accidents. For consistency, no distinction is made in this report.

Table 6.11 Junction and Non-junction Vehicle Involvements (all vehicle types)

Road traffic accidents at junction by junction type, junction control and severity 2007

Junction type / Junction control	Severity			
	Fatal	Serious	Slight	Total
Roundabout				
signalised	0	1	10	11
non-signalised	1	19	116	136
Sub-total	*1*	*20*	*126*	*147*
T-junction				
signalised	13	171	1 141	1 325
non-signalised	11	140	986	1 137
Sub-total	*24*	*311*	*2 127*	*2 462*
Staggered				
signalised	0	5	22	27
non-signalised	0	6	43	49
Sub-total	*0*	*11*	*65*	*76*
Y-junction				
signalised	1	9	46	56
non-signalised	2	13	94	109
Sub-total	*3*	*22*	*140*	*165*
Slip road				
signalised	0	3	10	13
non-signalised	0	6	33	39
Sub-total	*0*	*9*	*43*	*52*
Cross roads				
signalised	18	90	567	675
non-signalised	1	32	242	275
Sub-total	*19*	*122*	*809*	*950*
Multiple				
signalised	1	7	36	44
non-signalised	0	2	14	16
Sub-total	*1*	*9*	*50*	*60*
Private access				
signalised	0	2	1	3
non-signalised	0	0	4	4
Sub-total	*0*	*2*	*5*	*7*
Other				
signalised	0	11	36	47
non-signalised	1	12	79	92
Sub-total	*1*	*23*	*115*	*139*
Total				
All junctions	49	529	3 480	4 058
All roads	153	2 376	12 786	15 315

Vehicle collision types in Hong Kong

It is generally expected that the type of collisions will affect the chance of cargo damage. Front-end collision and vehicle to hard structure collisions will generally produce the highest mechanical (impact) energy while vehicle overturning and vehicle hitting persons or small objects will produce much lower mechanical (impact) energy to affect the explosive load. Although such factors are relevant for this study, it is difficult to assess the proportion of vehicle accidents leading to significant mechanical (impact) energy based on data available from the Transport Department statistics. For consistency with previous studies, it is proposed to correlate high impact accidents with fatal and injury accidents as discussed in previous sections.

Initiation due to crash impact given an explosive truck accident involvement

The DNV (1997) study referred to the ACDS (1995) study for the assessment of initiation given a vehicle crash impact.

The ACDS study (1995) adopted a common initiation probability on impact for all types of blasting explosives considered. This included sensitive secondary explosives such as nitroglycerine based explosives and less sensitive explosives such as PETN and emulsions.

As described in the ACDS (1995) study report, a generic explosion probability has been derived from a series of drop hammer trials undertaken with packaged cartridges containing NG based explosives as part of the former ICI Garnock Wharf study (Garnock, 1989). The tests were designed to mimic the impact of dropping cased explosives from a height above 12m (corresponding to the mishandling scenarios in ports) into a hard, unyielding surface. The trials typically resulted in damage to the explosives to the extent they sustained indentation but no initiation was observed in 1150 trials.

One could argue that the impact force may be higher in some circumstances in a vehicle crash. The ACDS (1995) study reports that all the accidents counted as significant impact accidents in the derivation of significant explosive truck involvement frequency did not result in impact forces greater than the test trials. Based on these observations, the test trials could be considered representative for the behaviour of cartridged explosives in a traffic accident. The DNV (1997) study also considered that, on average, this probability should to be applicable for normal transport conditions.

The ACDS (1995) study conservatively rounded up this probability figure to 0.001 and applied it to all types of secondary explosives. This probability was used in conjunction with fatal and serious vehicle involvement rate.

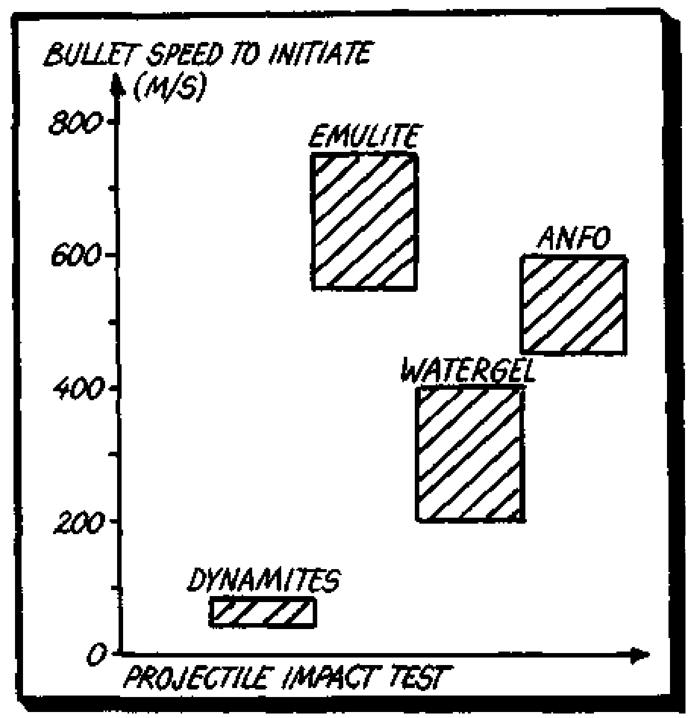
The DNV (1997) study directly applied this probability for watergel/emulsion type explosives (less sensitive than nitroglycerine based explosives) used in Hong Kong in 1996 on the basis this figure was conservative. This assumption was further reviewed as part of this study in the following paragraphs.

A bullet impact (normal bullet speed: 500 m/s) can be considered as an extreme event compared to transport accidents. Based on the bullet impact test results from Holmberg's paper (*Figure 6.6*) and PETN sensitivity test data published by Santis (1990), it can be observed that for both materials, at least, a bullet impact speed of around 500 m/s would be required to observe an initiation (not necessarily an explosion). This is to be compared with NG based explosives which would require a bullet impact speed ranging from 50 to 100 m/s. This implies that, at least, both emulsion based explosives and PETN based explosives will require 10 times more energy than NG based explosives which would translate into reduction factor of 0.1 to the initiation

on impact probability assessed for NG based explosives in the ACDS (1995) report and subsequent Hong Kong studies.

The overall initiation on impact probability assessed in this study has therefore been taken as 0.0001. Based on test data available to date, this number may still be considered as high based on the views of a number of explosive specialists.

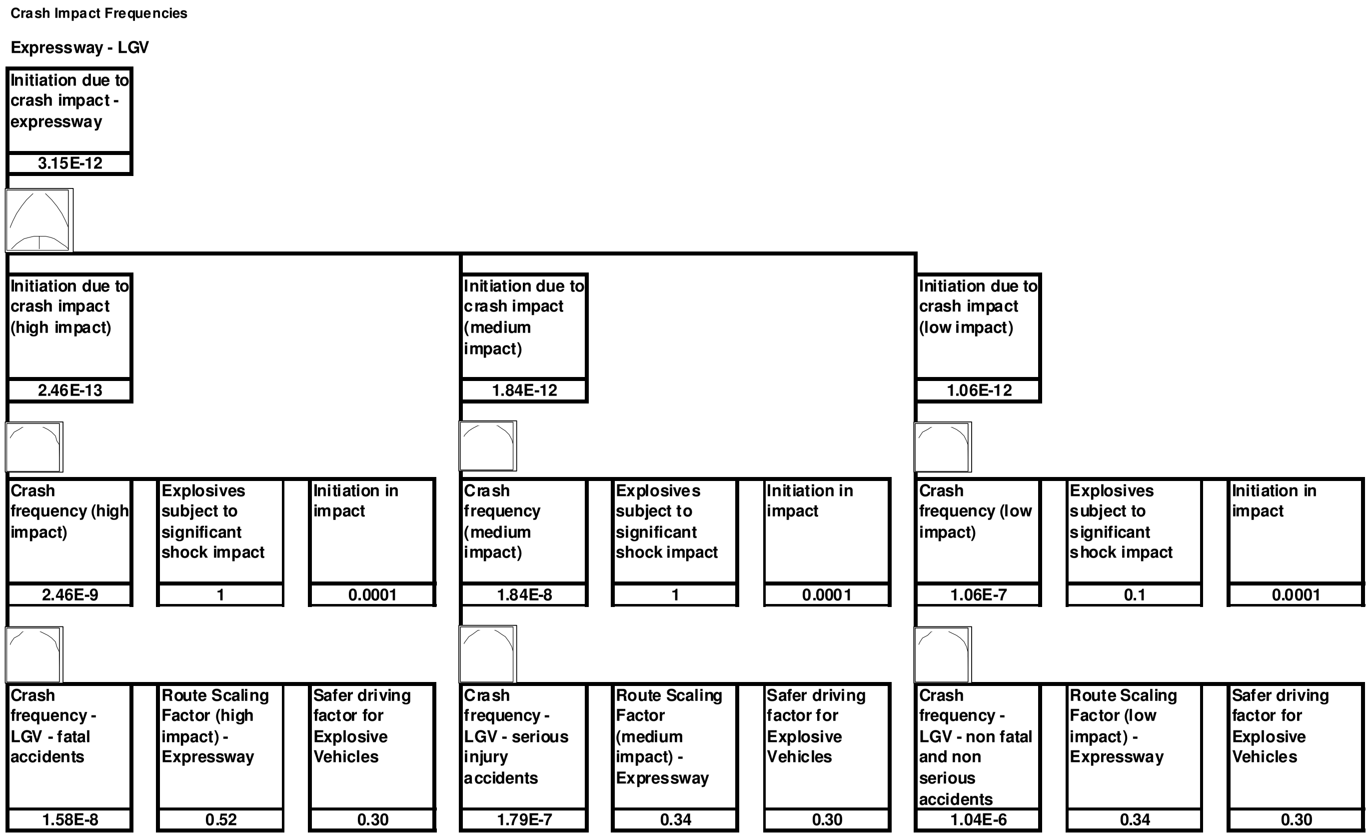
Figure 6.6 ***Explosive Relative Sensitivity to Impact***



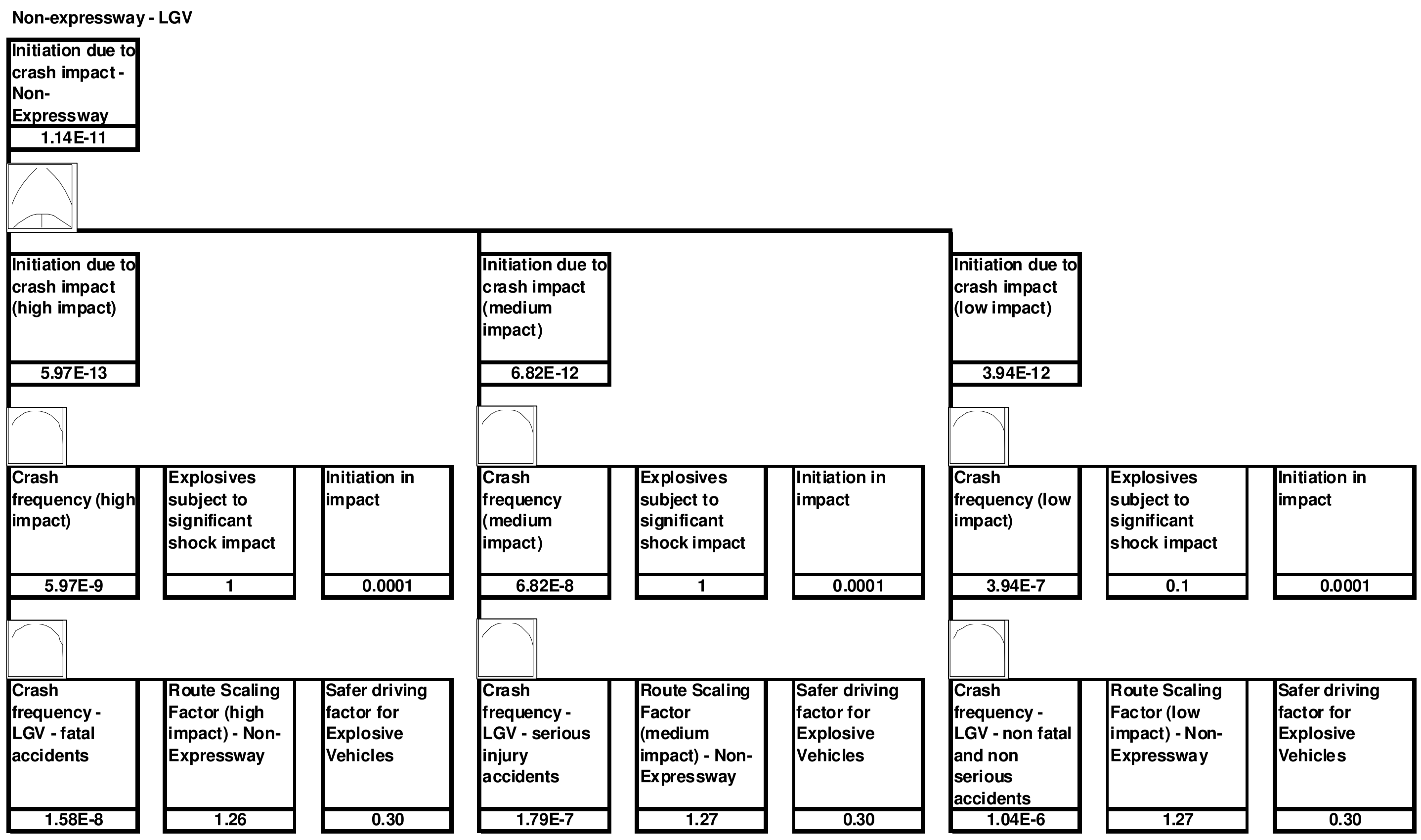
Derivation of severe impact frequency which has the potential to damage the explosives

A fault tree has been developed based on the probabilities derived above. Separate fault trees have been developed for expressway and non-expressway vehicle involvement scenarios. The Fault Trees presenting the frequency of explosive load initiation due to impact are presented in *Figure 6.7*. The derived severe impact rates for the explosive trucks are also shown in *Figure 6.7*.

Figure 6.7 Fault Tree – Explosive Load Initiation Due to Impact (per year)



Note: The total crash frequency for explosive vehicles is 1.27e-7 per year for expressway (ie. summation of crash frequencies of low, medium and high impact), and this figure was fed into the later explosion frequency fault tree (*Figure 6.10*, expressway – LGV)



Note: The total crash frequency for explosive vehicles is 4.68e-7 per year for non-expressway (ie. summation of crash frequencies of low, medium and high impact), and this figure was fed into the later explosion frequency fault tree (*Figure 6.10*, non-expressway – LGV)

Crash and non-crash vehicle fire involvement rates

Hong Kong Experience with Explosive Trucks

As discussed in the above sections, the number of kilometers run by Mines Division trucks has been estimated at 2,900,000 km without any fire occurrence on the truck. This will give an upper estimate of: 0.7/2,900,000 = 2.4 x 10^{-7} vehicle fire per kilometre (0.24 per million vehicle kilometre).

Vehicle Fire Experience in Hong Kong

The Fires Service Department (FSD) maintains records of all the fire calls and reports the number of fires occurring on motor vehicles on a yearly basis.

The total number of fire calls on motor vehicles for years 2004-2008 (5 year average) can be summarised as shown in *Table 6.12*:

Table 6.12 ***Vehicle fire calls per cause (all vehicle types) – 2004 to 2008 average***

Type of Fire Cause, Average 2004-2008	Commercial (Incl. D.G.)	Dangerous Goods Only	Private and Government	Explosive Vehicle Applicability
Sparks from welding & oxygen acetylene cutting	1.0	0.0	0.0	No
Children playing with matches	0.0	0.0	0.0	Yes to some extent
Over-heating of engines, motor & machinery	47.2	0.2	33.8	Yes to some extent
Careless disposal of joss stick, joss paper & candles, etc	0.2	0.0	0.2	Yes to some extent
Food stuff (stove overcooking)	0.0	0.0	0.0	No
Careless handling or disposal of cigarette ends, matches & candles, etc	16.6	0.0	13.8	Yes to some extent
General electrical fault	48.0	0.0	47.8	Yes to some extent
Naked flame	1.0	0.0	0.4	No
Undetermined	30.0	0.2	63.6	Possible
Deliberate act	5.0	0.0	10.8	Yes to some extent
Miscellaneous	23.2	0.5	36.0	Possible
Unknown	9.0	0.0	22.4	Possible
Total	181.2	1	228.8	

It can be seen that, unlike in the UK, tyre fires in Hong Kong do not appear to be a main risk contributor. There is however a large number of incidents (62 incidents) for which the cause has not been identified.

The average yearly fire incidents in Hong Kong, considering only fire types applicable to explosive trucks, are shown in *Table 6.13* against the generic cause categories identified in *Table 6.6*.

Table 6.13 ***Vehicle fire calls per cause (all vehicle types as applicable to explosive trucks) – 2004 to 2008 average***

Contributing causes potentially applicable to explosive vehicles	Commercial (Incl. D.G.)	Dangerous Goods Only	Private and Government
Cab or engine fire	95.2	0.2	81.6
Crash fire	not known	not known	not known
Smoker materials	16.8	0.0	14.0
Arson	5.0	0.0	10.8
Tyre fire	not known	not known	not known
Unknown, miscellaneous and undetermined	62.2	0.7	122.0
Total	**179.2**	**1.0**	**228.4**

The total annual vehicle travelled distance in 2007 was 11,973 million vehicle kilometres (mvkm) and 7,212 mvkm specifically for all goods vehicles combined. This gives an average goods vehicle fire rate of 2.48x10^{-8} per km or 0.0248 pmvkm. This may be reduced by around 10% to 0.0219 pmvkm to exclude arson and smoker materials provided strict controls are applied. This could be reduced even further should a breakdown of the causes for unknown, miscellaneous and undetermined fire incidents were available. It is also worth noting that this figure may be conservative as it may include incidents not specifically occurring on the road. In the absence of further detailed information from the FSD, the average goods vehicle fire rate of 2. 19x10^{-8} per km or 0.0219 pmvkm excluding 99% of arson and smokers material event, as per the DNV (1997) study, has been used in this study.

The vehicle fire incident rate derived specifically for Hong Kong conditions is about four times lower than the corresponding vehicle fire rate of 0.087 pmvkm reported in the Moreton (1993) study and used as the basis for the DNV (1997) study.

The average goods vehicle fire rate for Hong Kong is equivalent to 2% and 5%of the overall average reportable LGV involvement rate and 5% of the explosive vehicle reportable involvement rate. These ratios are about one order of magnitude lower than in the UK for HGVs, typically being 20% (Davies, 1992).

Adjustment Factors

The explosive truck will be provided with a fire screen between the cab and the explosive load and on the chassis. The Moreton (1993) and the DNV (1997) studies considered a risk reduction factor of 0.1 for the screen provided it is constructed, installed and operated to international standards. Since the set of screens will have a high effectiveness for all sources of fire, this factor has been uniformly applied to the non-crash fire frequency regardless of the cause.

Fire Severity

The fire must be significant to spread to the explosive load. Not all fires will be significant and have the ability to cause a thermal stimulus to the explosive load. A review of Hong Kong fire incident data provided by the Fires Service Department (FSD) did not permit the derivation of a probability of fire escalation to the explosive load. However, the analysis by Moreton (1993) derives a probability of 60% for a fire spreading beyond its initial ignition point (eg cab fire spreading to cargo area) and for less than 20% for the fire to spread to the cargo (eg fire engulfing the explosive load). This was derived for HGV trucks for which fire spreading may not systematically affect the load given the distances between vehicle components. For an LGV pick-up truck, given the proximity between the various vehicle parts, the explosives could initiate due to heat transferred by means of conduction and convection. This ratio may also vary considering Hong Kong conditions. A probability of fire escalating to the load of 60% has been conservatively retained for LGV trucks in absence of detailed FSD information. This is conservative compared to the Moreton (1993) and DNV (1997) studies which have assumed a fire escalation probability of less than 20% for HGVs.

Time to Fire Escalation

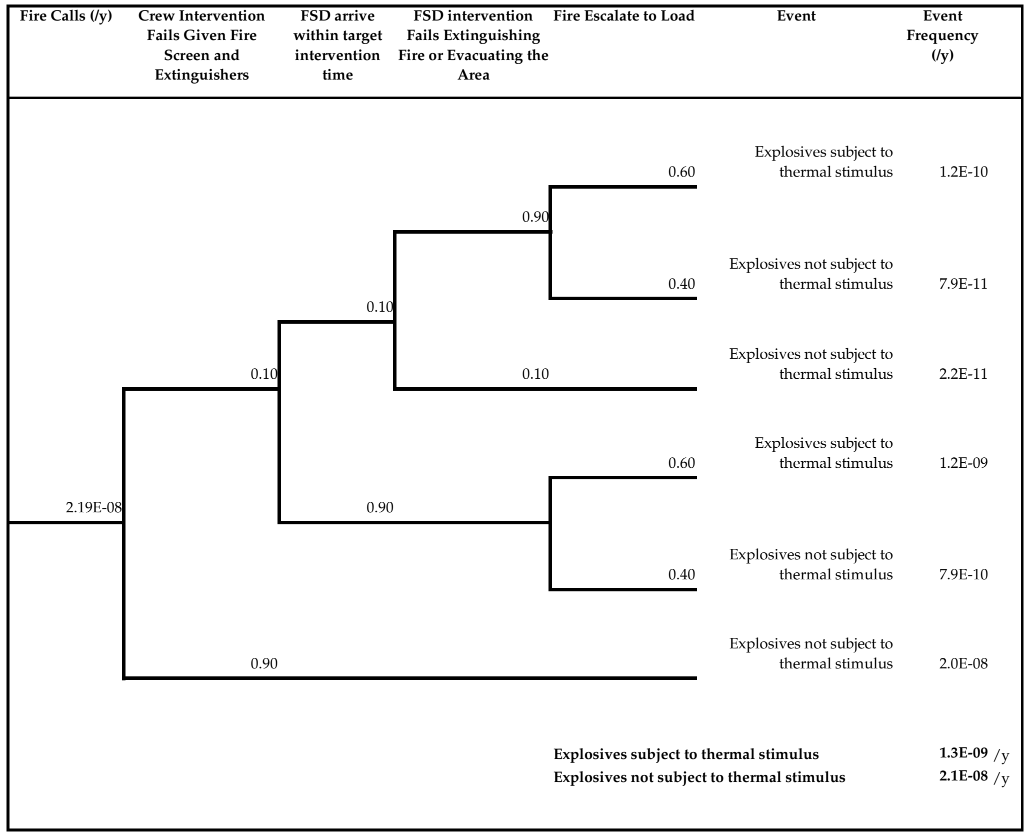
There is limited data available worldwide about how long it would take for a fire to spread to the load from the initial ignition point. Data from the MVFRI in the US suggests that it may take less than 5 min for a fire fully engulfing the vehicle. Similar information is not available for fires spreading to the cargo; however, based on standard heat transfer calculations, it could be estimated that the critical temperature within the cargo can be reached within a couple of minutes (less than 5 min). Given the limited time available, very limited credit could be considered for fire brigade intervention in this study. Credit may be taken for the intervention of the vehicle crew, however, given the size and type of the fire extinguishers provided on board no credit is taken in this study. This is considered included within the probability of 0.1 accounted for the fire screen.

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

For the XRL contractors' trucks, the overall non crash fire frequency where an event is likely to cause a thermal stimulus on the explosive load can therefore be estimated at 1.30 x 10^{-9} per km. The development of a non-crash fire scenario has also been expressed in the form of an event tree (*Figure 6.8*). Credit has been given to the truck crew intervention/ fire screen combination (successful probability of 0.9). As discussed above, little credit has been given for FSD intervention (probability of arriving on time: ~0.1 and successful intervention probability ~0.1) as even if FSD arrives within specified time, the fire on the LGV truck would likely be fully developed and explosive critical temperature of 140 °C could be reached (ERP, 2009). The overall explosion event frequency remains the same at 1.30 x 10^{-9} per km accounting for truck

crew/ FSD intervention. In absence of further FSD accident data, it is difficult to justify a higher credit for these measures.

Figure 6.8 Event Tree for Non-crash Fire Scenario



Frequency of Crash Fires – Explosives Subject to Thermal Stimulus

It could be argued that the crash fire probabilities have been included in the overall vehicle fire probability of 2.19 x 10^{-8} per km or 0.0219 pmvkm derived above based on fire call data collected for all goods vehicles. However, the effectiveness of the fire screens would most likely be limited following a crash impact and therefore a different approach is required to derive the frequency of crash fires escalating to the explosive load for the XRL contractors' explosive trucks.

In the DNV (1997) study, the crash fire frequency was derived from the UK HGV (also applicable to explosive vehicles) crash fire frequency in 1987-88 as the basis. This figure was appropriately factored by the HK to UK ratio of crash impact probabilities.

In the UK in 1987-88, the crash-fire frequency represented 2% of the overall fire involvements (Moreton, 1993). There is no relevant ratio which could be derived specifically from Hong Kong data. For consistency purposes, the same approach as the DNV (1997) study has been adopted in this study. It consists of factoring the UK HGV crash-fire frequency (2.64 10^{-10} per km) by the relevant HK to UK involvement rate ratio based on the original UK HGV reportable involvement rate of 0.62 pmvkm.

All crash fires are considered to be severe enough to cause damage to the explosive load.

Referring to *Figure 6.7*, the reportable involvement rate for expressways and non-expressways derived for the XRL contractors' explosive trucks is respectively:

- Expressways: 1.27×10^{-7} per km or 0.127 pmvkm; and
- Non-expressways: 4.68×10^{-7} per km or 0.468 pmvkm.

This corresponds respectively to 21% and 76% of the UK HGV reportable involvement rate (which is 0.62 pmvkm).

The crash fire frequency for which the fire is severe enough to involve the explosive load in the fire has therefore been estimated as:

- Expressways: 5.41×10^{-11} per km; and
- Non-expressways: 1.99×10^{-10} per km.

This is also equivalent to 0.04% of the explosive truck involvement rate which is consistent, although 50% lower than, the equivalent ratio for goods vehicles in the UK being typically 0.1% (Davies, 1992). This may be explained due to, on average, lower impact speeds in Hong Kong.

Also, when compared to overall Hong Kong goods vehicle fire rate, the crash-fire component is estimated to be around 1% of the total goods vehicle fire rate. This is consistent with equivalent ratios ranging from 1% to 5% reported in UK and US.

From 1996 to 2006, fire accidents in the UK have decreased from 5676 to 4296 for vans and from 2548 to 1859 for lorries (Fires Stats, UK, 2006). However, the crash fire frequency has remains unchanged. From this, it can be inferred that vehicle design improvements since 1988 has not caused a significant reduction in the UK crash fire frequency. Typical goods vehicle design improvements have therefore not been considered further in this assessment.

Response of Explosives to a Fire Situation

The initiation of explosives in the DNV (1997) study was assessed as 0.1 for any fire involvement. This value was based on the ACDS study (1995), which was derived from an expert judgement for heat insensitive explosive group which included a variety of explosives. Also the proportion of detonating cord and cartridged emulsion differs in this project. When considering packaged emulsion and PETN based explosives on their own, this probability may differ.

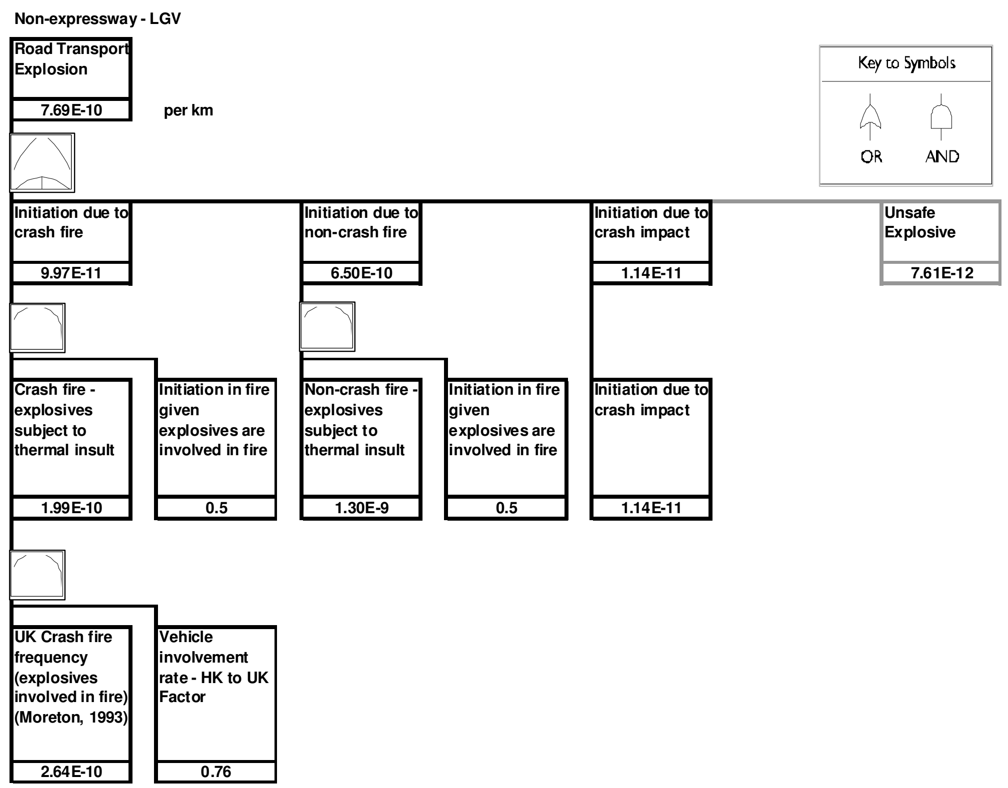
Referring to the expert review (ERP, 2009), the probability that the explosive melts and detonates once the fire impacts on the load is likely to be less than 0.5 but a lower figure could not be justified in the absence of further test data on the explosives to be transported.

A probability of 0.5 has been retained in this study as this figure would more appropriately represent the mix of explosive loads as applicable in this study (refer to Hazard Identification section).

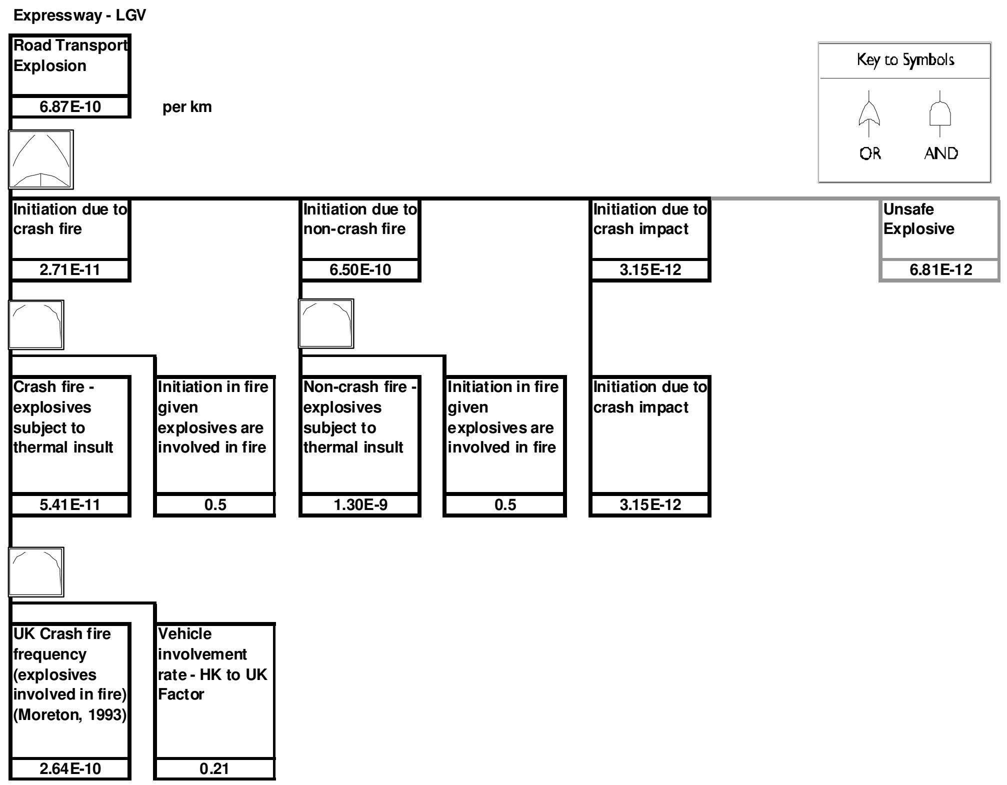
Explosion Frequency Fault Trees

The Fault Trees developed to assess the overall explosion rates as applicable to the XRL contractors' truck are shown in *Figure 6.9*. The expressway explosion rate of 6.87×10^{-10} per km has been applied to Tuen Mun Highway while the non-expressway explosion rate of 7.69×10^{-10} per km has been applied to other road sections.

Figure 6.9 XRL Contractor Truck Explosion Frequency per Truck Per km



Note: Vehicle involvement rate – HK to UK factor was calculated by dividing the crash frequency of 4.7E-7 per year (derived from *Figure 6.8 – Non-expressway*) by the UK frequency of 6.2E-7 per year (see discussion of crash fire in *Section 6.2.1*)



Note: Vehicle involvement rate – HK to UK factor was calculated by dividing the crash frequency of 1.3E-7 per year (derived from *Figure 6.8 – Expressway*) by the UK frequency of 6.2E-7 per year (see discussion of crash fire in *Section 6.2.1*)

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 emulsions 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 ERM (2008) study and considers all the effects associated with an above ground explosion including, fireball, overpressure, flying debris, broken glass, structure 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 of accidental explosion. The data on which the model is constructed does not distinguish between those killed by 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 little 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 456 kg (initiation of an entire store contents), a fireball radius of 13.5m 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 140 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):

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

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/m²), *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/m²) $^{4/3}$ 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/m².

Comparing these with the fireball surface emissive power of 140 kW/m², 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 456 kg TNT Equivalence of Explosive***

Consequence	Receiver's location	Effect radius (m)
Shockwave and debris - ESTC model	Indoor	65.0
	Outdoor	24.7
Ground shock – Object falling threshold (PPV = 100mm/s)	Indoor / outdoor close by a structure	22.8

In addition, excessive ground vibration may lead to slope failure and creates 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 24.9 m for detonation of 456 kg TNT equivalence of explosives, which correspond to the maximum quantity of explosive (TNT equivalent) to be stored in each magazine store. From *Table 4.11*, all the slopes are either 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 summarized in *Table 7.2* and *Table 7.3*. Consequence distances for the storage scenarios (no. 1 -4) may be compared to the separation distances specified in the magazine designs, as follows: public footpaths must be at least 54m away (vehicle routes must be further); buildings must be at least 180m 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* Impact distance (m)	*Outdoor* Impact distance (m)
	Storage of Explosives				
01	Detonation of full load of explosives in one store in So Kwun Wat site	342	90%	21.5	17.3
			50%	24.9	17.9
			10%	36.6	19.8
			3%	49.1	21.2
			1%	63.0	22.1
02	Detonation of full load of explosives in one store in Tai Lam site	456	90%	23.7	19.0
			50%	27.5	19.7
			10%	41.0	21.8
			3%	53.6	23.2
			1%	65.0	24.7
03	Detonation of full load of explosives in one contractor truck on the access road within the So Kwun Wat magazine site boundary	91	90%	13.9	11.1
			50%	16.1	11.6
			10%	23.9	12.8
			3%	30.9	13.7
			1%	40.3	14.6
04	Detonation of full load of explosives in one contractor truck on the access road within the Tai Lam magazine site boundary	71	90%	12.8	10.3
			50%	14.9	10.7
			10%	21.9	11.8
			3%	28.6	12.6
			1%	37.1	13.3
	Transport of Explosives				
05	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2b Shek Yam	57	90%	11.9	9.6
			50%	13.8	9.9
			10%	20.2	11.0
			3%	27.0	11.8
			1%	34.4	12.3

No.	Scenario	TNT eqv. kg	Fatality Prob.	*Indoor* Impact distance (m)	*Outdoor* Impact distance (m)
06	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2c Shing Mun	28	90%	9.4	7.6
			50%	10.9	7.9
			10%	16.0	8.7
			3%	21.1	9.4
			1%	27.2	10.0
07	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2d Kwai Chung	91	90%	13.9	11.1
			50%	16.1	11.6
			10%	23.9	12.8
			3%	30.9	13.7
			1%	40.3	14.6
08	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2e Mei Lai Road	34	90%	10.0	8.1
			50%	11.7	8.4
			10%	17.4	9.3
			3%	23.6	10.0
			1%	29.1	10.5
09	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam site to delivery point 1b Pat Heung	71	90%	12.8	10.3
			50%	14.9	10.7
			10%	21.9	11.8
			3%	28.6	12.6
			1%	37.1	13.3
10	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam site to delivery point 1c Tai Kong Po	45	90%	11.0	8.8
			50%	12.8	9.2
			10%	18.9	10.2
			3%	25.8	10.9
			1%	31.2	11.6
11	Detonation of full load of explosives in one contractor truck on public roads – from Tam Lam site to delivery point 1d Ngau Tam Mei	45	90%	11.0	8.8
			50%	12.8	9.2
			10%	18.9	10.2
			3%	25.8	10.9
			1%	31.2	11.6

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 So Kwun Wat site	342	90%	21.5	17.3
			50%	24.9	17.9
			10%	36.6	19.8
			3%	49.1	21.2
			1%	63.0	22.1

No.	Scenario	TNT eqv. kg)	Fatality Prob.	*Indoor*	*Outdoor*
				Impact distance (m)	Impact distance (m)
02	Detonation of full load of explosives in one store in Tai Lam site	456	90%	23.7	19.0
			50%	27.5	19.7
			10%	41.0	21.8
			3%	53.6	23.2
			1%	65.0	24.7
03	Detonation of full load of explosives in one contractor truck on the access road within the So Kwun Wat magazine site boundary	148	90%	16.3	13.1
			50%	18.9	13.6
			10%	28.3	15.1
			3%	39.2	16.3
			1%	58.1	17.7
04	Detonation of full load of explosives in one contractor truck on the access road within the Tai Lam magazine site boundary	141	90%	16.1	12.9
			50%	18.6	13.4
			10%	27.9	14.9
			3%	38.6	16.0
			1%	57.3	17.5
<u>*Transport of Explosives*</u>					
05	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2b Shek Yam	129	90%	15.6	12.5
			50%	18.1	13.0
			10%	27.1	14.4
			3%	37.5	15.6
			1%	55.6	17.0
06	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2c Shing Mun	28	90%	9.4	7.5
			50%	10.9	7.9
			10%	16.4	8.7
			3%	22.6	9.4
			1%	33.6	10.2
07	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2d Kwai Chung	148	90%	16.3	13.1
			50%	18.9	13.6
			10%	28.3	15.1
			3%	39.2	16.3
			1%	58.1	17.7
08	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2e Mei Lai Road	81	90%	13.4	10.7
			50%	15.6	11.2
			10%	23.2	12.4
			3%	32.2	13.4
			1%	47.8	14.6
09	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam site to delivery point 1b Pat Heung	141	90%	16.1	12.9
			50%	18.6	13.4
			10%	27.9	14.9
			3%	38.6	16.0
			1%	57.3	17.5
10	Detonation of full load of explosives in one contractor truck on public roads – from Tai Lam site to delivery point 1c Tai Kong Po	46	90%	11.1	8.9
			50%	12.8	9.2
			10%	19.2	10.2
			3%	26.6	11.1
			1%	39.5	12.0

No.	Scenario	TNT eqv. kg)	Fatality Prob.	*Indoor*	*Outdoor*
				Impact distance (m)	Impact distance (m)
11	Detonation of full load of explosives in one contractor truck on public roads – from Tam Lam site to delivery point 1d Ngau Tam Mei	46	90%	11.1	8.9
			50%	12.8	9.2
			10%	19.2	10.2
			3%	26.6	11.1
			1%	39.5	12.0

7.4 *SECONDARY HAZARDS*

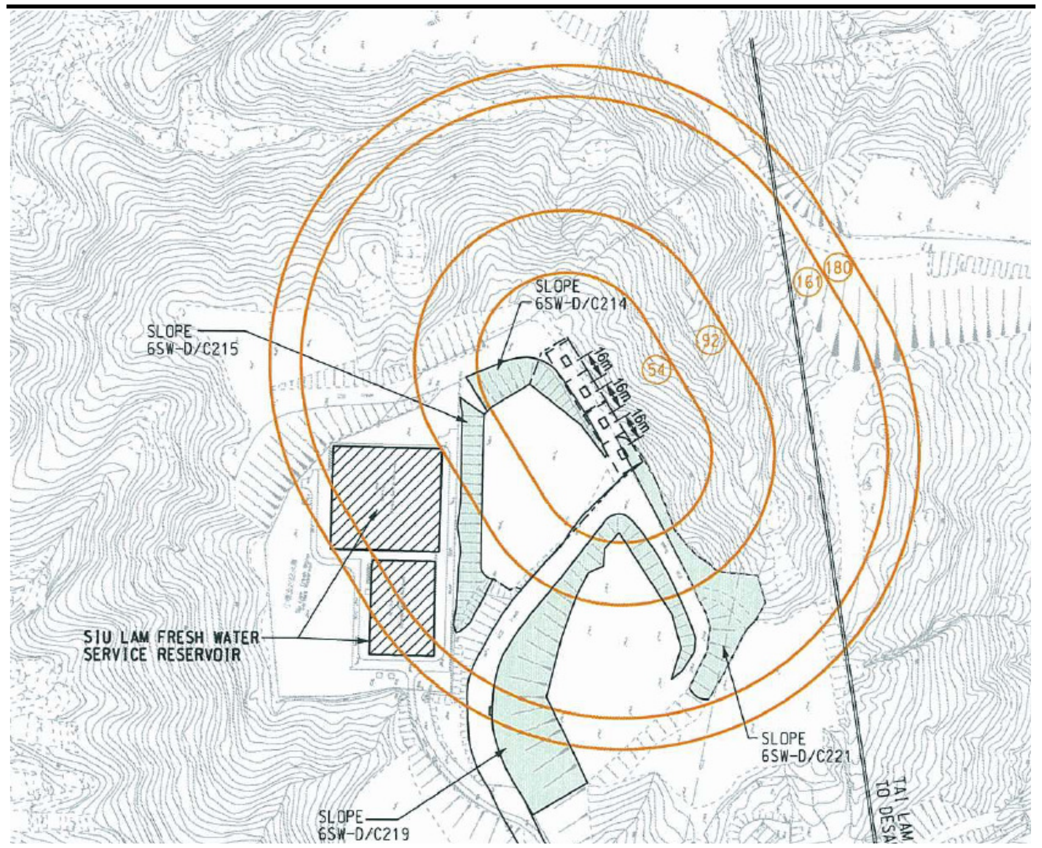
7.4.1 *WSD SERVICE RESERVOIR NEAR THE SO KWUN WAT MAGAZINE SITE*

The Siu Lam Fresh Water Reservoir is situated at about 92m from the proposed explosive magazine site at So Kwun Wat. In previous sections, the fatality consequence model (ESTC model) was used to assess hazard to life and it was concluded that there is no direct risk to workers at the WSD facility from the proposed magazine site based on this separation distance. However, if the WSD facility were to be damaged, secondary or knock-on effects may lead to additional hazards and loss of life. Potential damage to the WSD facilities is considered further in this section.

The WSD facility provides buffer storage for 41,000 m^3 of fresh water in two concrete tanks. The first tank has a capacity of 14,261 m^3 and is located more than 120m from the nearest explosive store. The second tank is slightly larger at 27,000 m^3 and is 92m from magazine at the closest point (*Figure 7.1*). The water tanks are constructed partly below ground level giving a maximum water level above ground of about 4.4m. The tanks are substantial structures with reinforced concrete walls of varying thickness from 0.9m at the base to 0.3m at roof level. The tanks are also shielded from the proposed magazine site by elevation differences and a 15m high rock face (*Figure 7.2* and *Figure 7.3*). There is no direct line-of-sight between the proposed magazine and the WSD water tanks.

The maximum storage quantity of explosives at a store will be 300 kg (equivalent to 356kg of TNT). The explosion overpressure from initiation of this quantity of explosives would create an overpressure of 1.6 psi at a distance of 92m, using the TNT explosion model (Yellow Book). This is a conservative upper limit that neglects to take into consideration the mitigation effects of the store barricades and the fact that the water tanks are shielded by elevation differences.

Figure 7.1 *Location of So Kwun Wat Magazine in Relation to Siu Lam Fresh Water Service Reservoir*



Some examples of the property damage expected for various levels of overpressure (Lees, 1996) are indicated in *Table 7.4*. An overpressure of 1.6 psi would break windows and damage panelling of buildings but will not cause any damage to the WSD water tanks. For comparison, a normal atmospheric storage tank as used for oil storage depots would fail under explosion pressures of between 3 to 4 psi. The WSD water tanks are constructed from reinforced concrete which are much more robust and would be able to withstand significantly higher pressures. The hydrostatic pressure alone from the 4.4m head of water within the tanks amounts to 6 psi. Registered professional structural engineers were consulted on the potential damage to the water tanks from 1.6 psi overpressure and they confirmed that there would not be any damage, especially considering the overpressure would be less in reality owing to the shielding from terrain.

Table 7.4 *Damage Effects Produced by a Blast Wave*

Overpressure (psi)	Description
0.5 – 1.0	Windows shattered
1.0 – 2.0	Connection failure of corrugated steel/asbestos/wood panelling
2.0	Partial collapse of walls & roofs of houses
2.5	50% destruction of brickwork of houses
3 – 4	Rupture of oil storage tanks
5 – 7	Nearly complete destruction of houses
7 – 8	Brick panels 8-12in. thick, not reinforced, fail by shearing or flexure

Figure 7.2 *Siu Lam Fresh Water Storage Tanks*

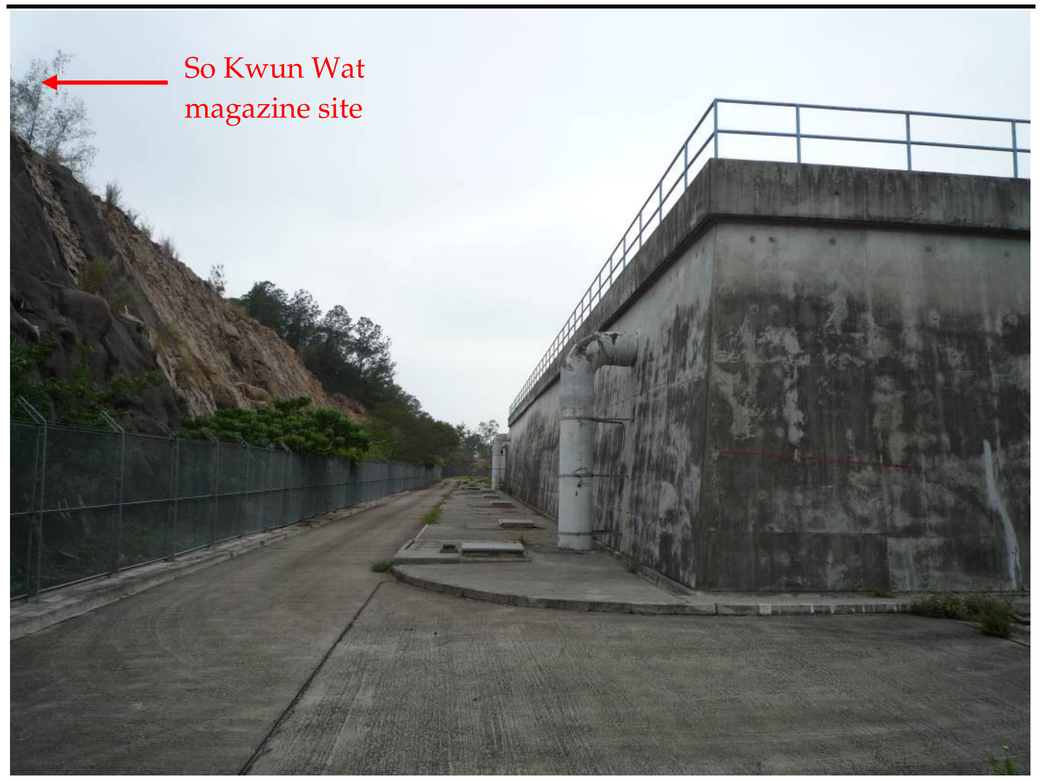
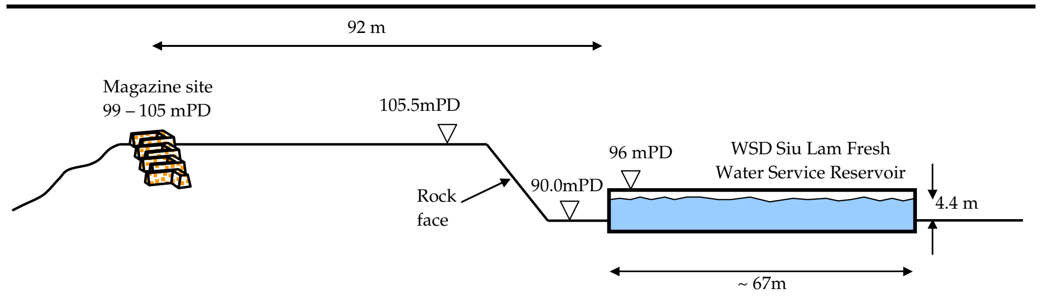


Figure 7.3 *Elevation Changes between Magazine Site and Siu Lam Facility*



In addition to the direct overpressure from the blast, any initiation of the explosives at the magazine would also create ground vibrations that may impact the water tanks. At a distance of 92m, the peak particle velocity (ppv) was calculated to be 16.3 mm/s. The ppv for the second tank at 120m would be 12 mm/s. These are conservative upper estimates since the calculation assumes underground storage of explosives in a chamber with air space around the explosives to reduce any coupling between the blast and the surrounding rock. For above ground storage, as proposed for So Kwun Wat magazine, the coupling to the ground will be weaker leading to lower ppv.

WSD, in their Departmental Instruction No. 1038, give guidance on construction activities involving excavation, blasting and pile driving. This guideline specifies a limit for ppv of 13 mm/s for water retaining structures such as reservoirs and dams. Water mains have a limit of 25 mm/s. These guidelines apply to repetitive type ground vibrations resulting from blasting and piling whereas any potential incident at the magazine would be a one off event.

Registered professional structural engineers were again consulted on the potential damage to the water tanks. No damage is expected for a ppv of 16.3 mm/s, especially considering the conservatism in the calculation of this value. At most, any damage would be limited to minor leaks at tank joints although it is noted that flexible joint sealant is used. The consequence is therefore not significant and will not pose further risk to life.

No damage would be incurred to the inlet piping since the calculated 16.3 mm/s ppv is below the allowed value of 25 mm/s for piping.

Any fragments/projectiles resulting from an explosion may impact the water tanks but again, no damage will result. Any such projectiles are most likely to land on the tank roofs but this will not lead to leakage of water or risk to life. A study by Giribone (1995) found that flying debris of 2000 kg mass travelling at 50 m/s would cause no significant damage to a reinforced concrete tank of 0.8m wall thickness and 0.5m roof thickness. These dimensions are very similar to those used in the Siu Lam water tanks. Fragments may impact workers directly leading to injuries but this is already incorporated in the probit equations adopted for the fatality probability from explosions and it has been concluded in earlier sections that workers at the WSD facility are beyond the effects radius and will not be impacted.

The rock face on the south side of the WSD facility is a registered slope (GEO 6SW-D/C215). As discussed in previous sections (Section 7.2.4 and 7.4.1), this slope was found not to be susceptible to failure from ground vibrations. A site visit did identify some loose stones and rocks at the top of this slope, however, these are generally small irregularly shaped rocks less than 0.5m in size. The fence at the foot of the slope would capture any falling rocks and prevent injury to the WSD personnel or damage to facilities. Even in the absence of the fence, a simple energy calculation demonstrates that damage to the tanks is not possible. For example, the largest rock identified had dimensions of about 0.5×0.5×0.2m. Assuming an elliptical shape with typical rock density of 3000 kg/m^3 gives a mass of about 60kg. Assuming all the potential energy is imparted to the water tank without any loses in the bounce would give a kinetic energy on impact about 1000 times smaller than the flying debris in Giribone's study.

It is therefore concluded that the magazine site poses negligible secondary risks for damage the fresh water storage tanks at the WSD Siu Lam facility.

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 Tuen Mun Road. There is a possibility that an explosion on 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 WIL study (ERM, 2008). 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 is expected.

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 sites with those from the transport of explosives to the work sites, 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 results for this worst case are also shown for comparison purpose.

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:

$$PLL = f_1N_1 + f_2N_2 + f_3N_3 + \ldots + f_nN_n$$

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 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 8.2 below show the PLL values for the transport of explosives to the blasting sites. As expected, the Worst Case (PLL = 1.27×10^{-3}/year) imposes a higher risk than the Base Case (PLL = 3.45×10^{-4}/year) because it combines the highest delivery frequency with the largest possible explosive delivery load.

To put these risks into perspective, Tuen Mun Road alone contributes about 57% of the risks for the southern transport routes with a PLL of 1.51×10^{-4}/year. This is negligible compared to a fatality rate of 4 persons on this expressway in 2007. The increased road risk due to transport of explosives therefore amounts to 0.004%.

The two proposed magazine storage sites (Tai Lam and So Kwun Wat) have negligible contribution to the overall risks since they are located in remote areas with very low population density nearby. The northern delivery routes (Tai Lam magazine to the three blasting work sites) account for almost 1/4 of the overall transport risk, with the remaining 3/4 attributed to the southern delivery routes (So Kwun Wat magazine to the four blasting work sites). The southern transport routes have nearly double the transport distances which explain this trend in the results.

Comparing the three work sites supplied by Tai Lam magazine, deliveries to Pat Heung show the highest risk. This is due to a higher frequency of deliveries to this work site, as well as a slightly longer transport route through populated areas.

Table 8.1 PLL for Base Case

Case: Base Case	PLL (per year)	Contribution (%)
Storage of Explosives		
Tai Lam Magazine	7.99E-09	0.002%
So Kwun Wat magazine	7.99E-09	0.002%
Transport of Explosives		
Tai Lam Magazine to Pat Heung	5.24E-05	15.21%
Tai Lam Magazine to Tai Kong Po	1.81E-05	5.26%
Tai Lam Magazine to Ngau Tam Mei	9.49E-06	2.75%
So Kwun Wat Magazine to Shek Yam	6.45E-05	18.72%
So Kwun Wat Magazine to Shing Mun	2.94E-06	0.85%
So Kwun Wat Magazine to Kwai Chung	1.14E-04	32.98%
So Kwun Wat Magazine to Mei Lai Road	8.35E-05	24.23%
Total	3.45E-04	100.00%

Similarly, comparisons between the work sites supplied from So Kwun Wat may be explained by delivery frequency and small differences in transport distances. The Shing Mun work sites, for example, shows a much lower transport risk than other work sites because the number of explosives deliveries is significantly less. Comparing all the delivery points, the PLL for Pat Heung, Shek Yam, Kwai Chung and Mei Lai have similar risk contributions, with Kwai Chung posing the highest risk.

Table 8.2 *PLL for Worst Case*

Case: Worst Case	PLL (per year)	Contribution (%)
Storage of Explosives		
Tai Lam Magazine	7.99E-09	0.001%
So Kwun Wat magazine	7.99E-09	0.001%
Transport of Explosives		
Tai Lam Magazine to Pat Heung	1.88E-04	14.87%
Tai Lam Magazine to Tai Kong Po	4.81E-05	3.80%
Tai Lam Magazine to Ngau Tam Mei	2.48E-05	1.96%
So Kwun Wat Magazine to Shek Yam	2.57E-04	20.26%
So Kwun Wat Magazine to Shing Mun	7.33E-06	0.58%
So Kwun Wat Magazine to Kwai Chung	4.08E-04	32.24%
So Kwun Wat Magazine to Mei Lai Road	3.33E-04	26.29%
Total	1.27E-03	100.00%

8.3.2 *F-N CURVES*

Figure 8.1 shows the overall F-N curves for explosives storage and transport combined. These include the two magazine sites at Tai Lam and So Kwun Wat and the associated transport routes to the 7 work sites.

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 to account for construction uncertainties. It can be seen that for both cases the risks lie in the upper ALARP region. For the worse case, the curve below N=10 is rather flat; this is caused by explosions affecting other road users. For scenarios under traffic jam conditions, the population density is similar and essentially every explosion event causes about 10 fatalities among other road users.

Figure 8.1 *F-N Curve for Storage and Transport of Explosives*

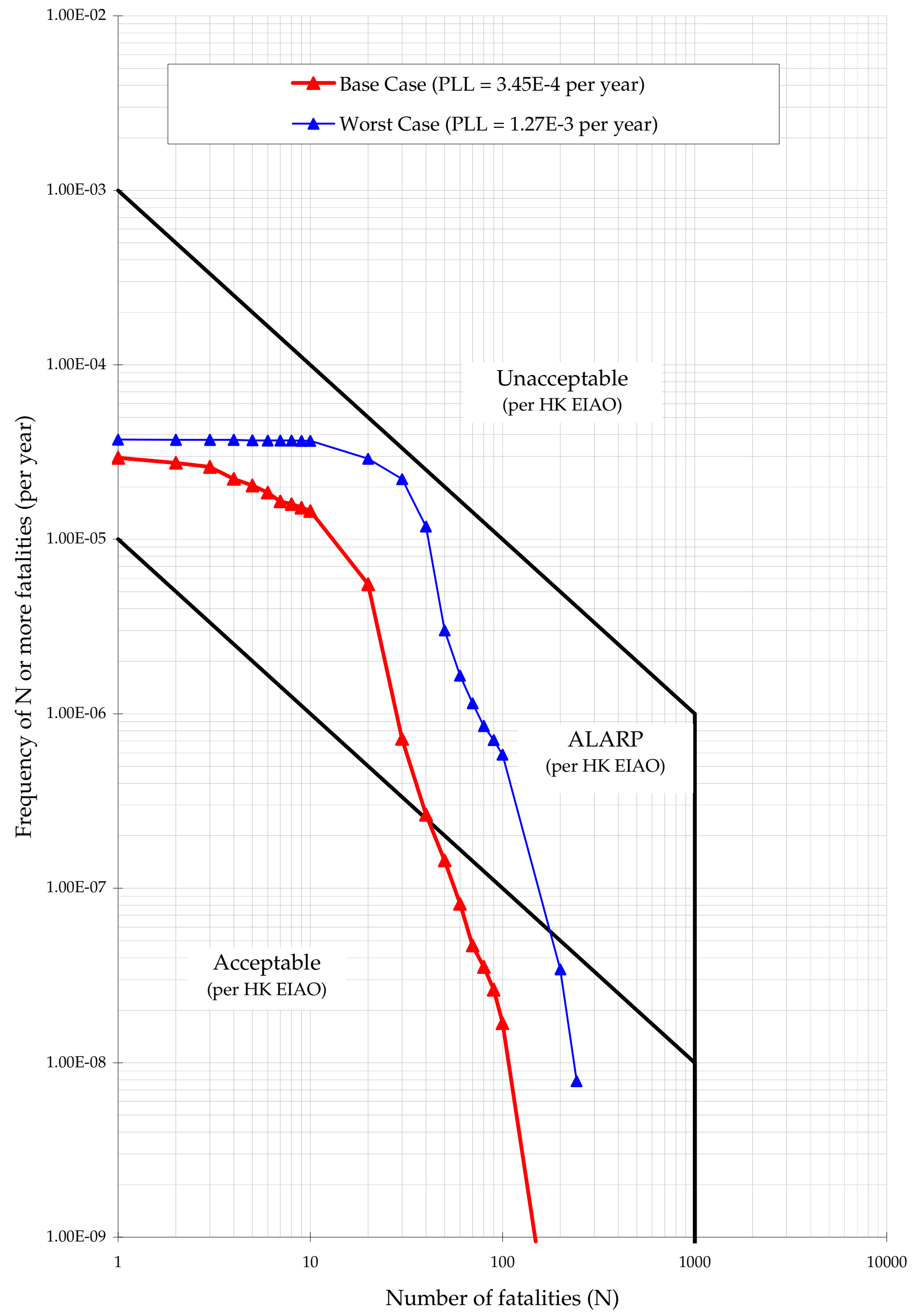


Figure 8.2 shows the F-N curve for the Base Case with a breakdown by storage and transport. It can be seen that risks from the magazine are negligible compared to transport risks. This is consistent with the comments made in relation to the PLL. Population in the vicinity of the magazine sites is very low and hence the societal risks are small. The southern transport routes show higher risks compared to the northern transport routes by a factor of about 2 to 3. The higher frequency for small *N* scenarios of the southern routes is due to a higher transport frequency and longer travel distances. The higher risks for the large *N* scenarios may be attributed to higher population densities in Kowloon, through which these transport routes need to pass.

Figure 8.3 provides a breakdown by population type for Base Case. As expected, the highest risks are associated with other road users and this dominates the overall F-N curve, particularly for the low *N* scenarios. 90% of the PLL (3.12×10^{-4} per year compared to the total of 3.45×10^{-4} per year) is related to population in vehicles. This is to be expected since the hazard effects from explosions diminish quickly with distance from the explosives truck. Scenarios involving high numbers of fatalities are related to fatalities in buildings and occur in areas of dense urban development where buildings are generally closer to the road.

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*.

Figure 8.2 F-N Curve for the Base Case with Breakdown by Storage and Transport

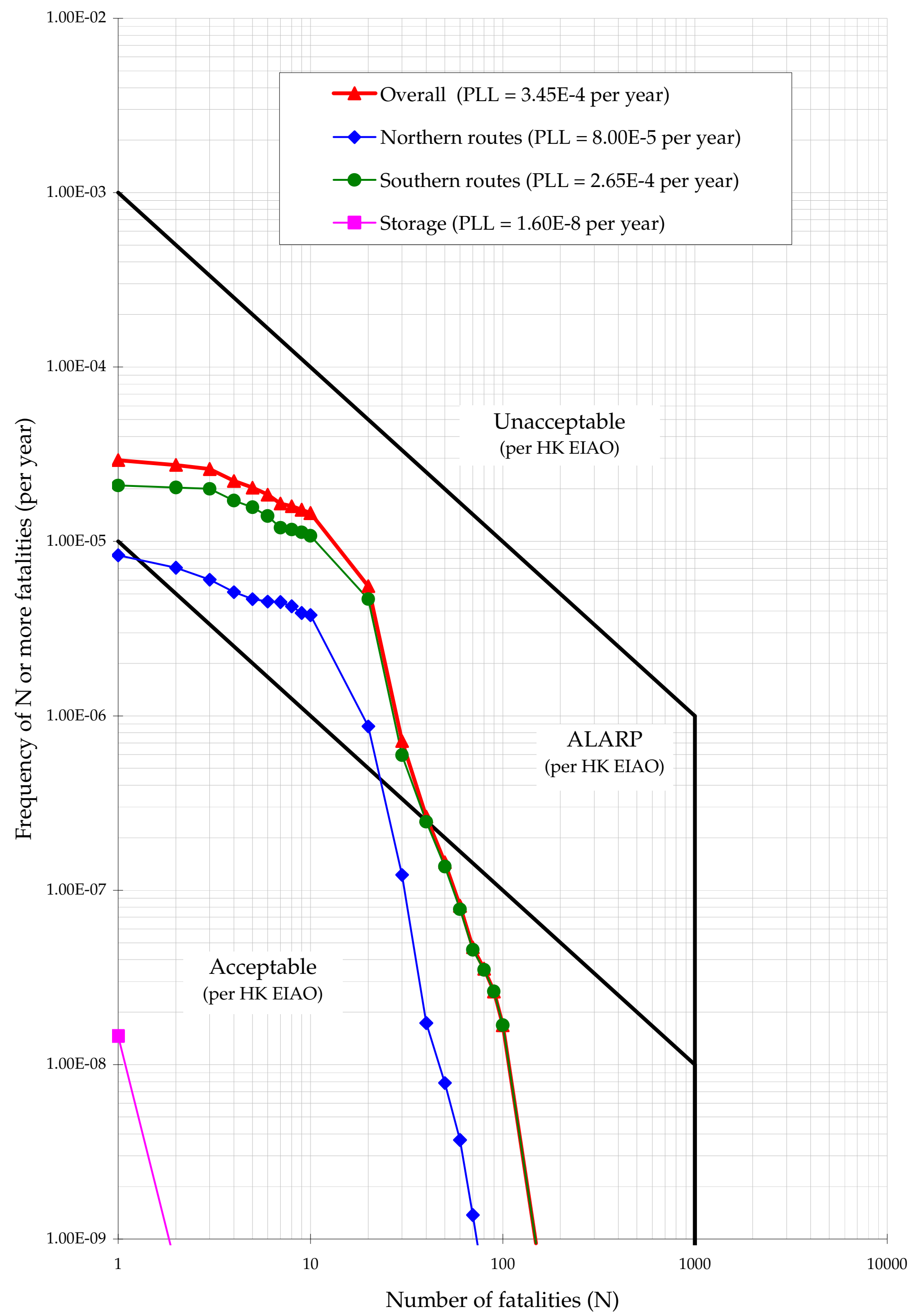
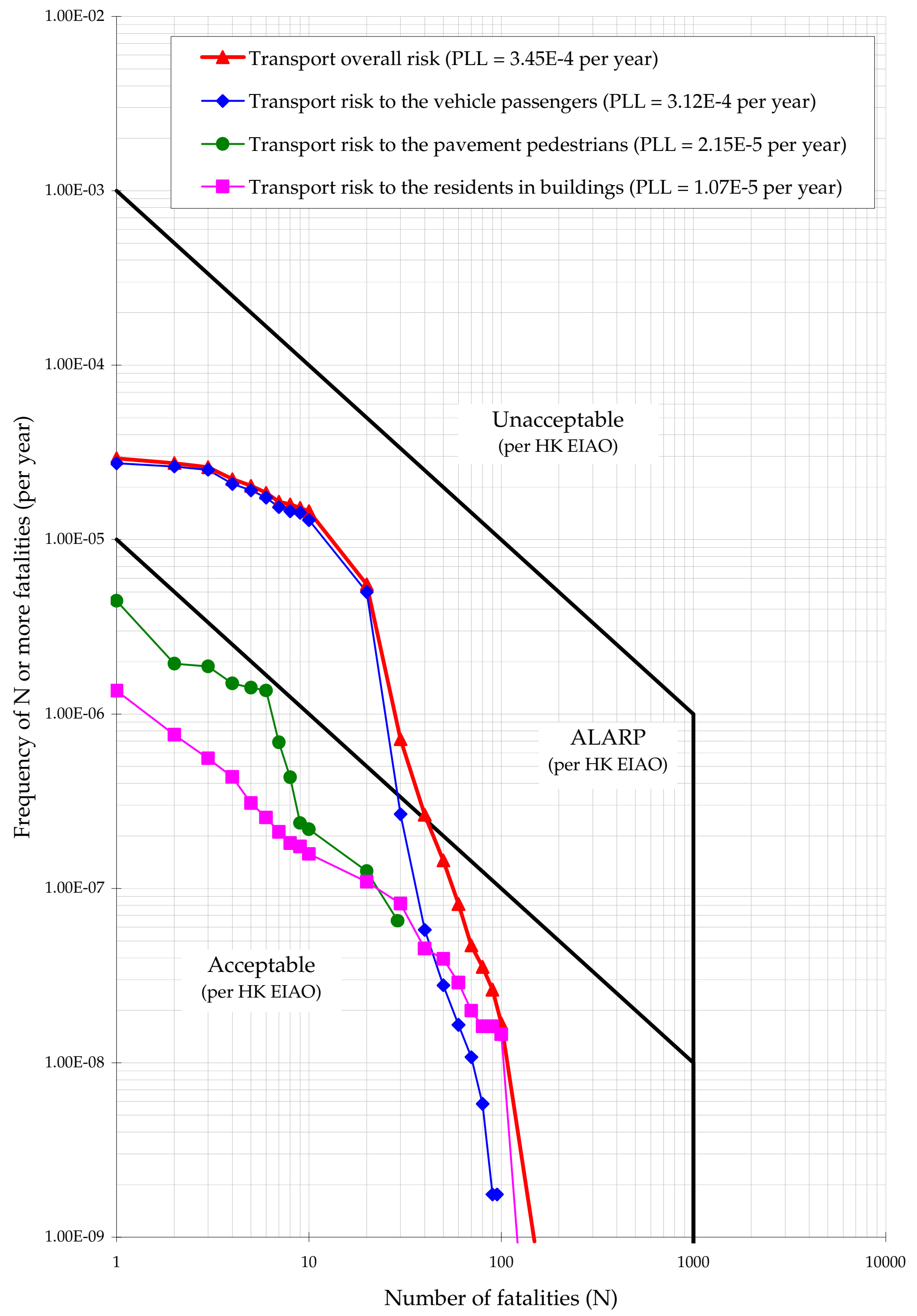


Figure 8.3 F-N Curve for the Base Case with Breakdown by Population Type



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 public on road but not the explosive truck crew.

8.4 INDIVIDUAL RISK

The individual risk (IR) for each section of the transport route is listed in *Table 8.3* and *Table 8.4*. The same data is shown graphically in *Figure 8.4* and *Figure 8.5*. These data take into account that some road sections are common to several transport routes; the IR essentially being proportional to the frequency

of explosives trucks travelling along the road. The IR data 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 4.6×10^{-8} 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 8.3 Maximum Individual Risk for Each Section of the Transport Routes from Tai Lam Magazine (Base Case)

Section ID	Description	Maximum IR (per year)
Route 1b (Tai Lam Magazine M2 - Pat Heung)		
Road 1b1	Access road toward Tai Shu Ha Rd West	2.56E-08
Road 1b2	Tai Shu Ha Road West 1	2.54E-08
Road 1b3	Tai Shu Ha Road West 2	2.93E-08
Road 1b4	Shap Pat Heung Road (Tai Shu Ha Rd - Shap Pat Heung Interchange)	3.05E-08
Road 1b5	Yuen Long Highway (Shap Pat Heung Interchange - Pok Oi Interchange)	2.29E-08
Road 1b6	Castle Peak Road - Yuen Long (Pok Oi Interchange - Kam Tin Rd)	2.24E-08
Road 1b7	Kam Tin Road (Castle Peak Rd - Yuen Long - Kam Tin Bypass)	2.17E-08
Road 1b8	Kam Tin Bypass Road	2.16E-08
Road 1b8a	Kam Tin Bypass Road (2nd section)	2.06E-08
Road 1b9	Tung Wui Road	1.39E-08
Road 1b10	Kam Sheung Road	1.46E-08
Road 1b11	proposal haul road towards PHV off Kam Sheung Rd	1.57E-08
Route 1c (Tai Lam Magazine M2 - Tai Kong Po)		
Road 1c1	Access road toward Tai Shu Ha Rd West	2.56E-08
Road 1c2	Tai Shu Ha Road West 1	2.54E-08
Road 1c3	Tai Shu Ha Road West 2	2.93E-08
Road 1c4	Shap Pat Heung Road (Tai Shu Ha Rd - Shap Pat Heung Interchange)	3.05E-08
Road 1c5	Yuen Long Highway (Shap Pat Heung Interchange - Pok Oi Interchange)	2.29E-08
Road 1c6	Castle Peak Road - Yuen Long (Pok Oi Interchange - Kam Tin Rd)	2.24E-08
Road 1c7	Kam Tin Road (Castle Peak Rd - Yuen Long - Kam Tin Bypass)	2.17E-08
Road 1c8	Kam Tin Bypass Road	2.16E-08
Road 1c9	Kam Hing Rd	1.68E-08
Road 1c10	Chi Ho Rd	8.45E-09
Road 1c11	proposed haul road towards TPV off Chi Ho Rd	3.42E-09
Route 1d (Tai Lam Magazine M2 - Ngau Tam Mei)		
Road 1d1	Access road toward Tai Shu Ha Rd West	2.56E-08
Road 1d2	Tai Shu Ha Road West 1	2.54E-08
Road 1d3	Tai Shu Ha Road West 2	2.93E-08
Road 1d4	Shap Pat Heung Road (Tai Shu Ha Rd - Shap Pat Heung Interchange)	3.05E-08
Road 1d5	Yuen Long Highway (Shap Pat Heung Interchange - Pok Oi Interchange)	2.29E-08
Road 1d6a	Yuen Long Highway	1.48E-08
Road 1d6b	Yuen Long Highway (to Tsing Long Highway)	3.44E-09
Road 1d7	Tsing Long Highway	3.44E-09
Road 1d8	San Tin Highway (San Tin Interchange)	3.45E-09
Road 1d9	San Tam Rd (San Tin Interchange - Chun Shin Rd)	3.95E-09
Road 1d10	Chuk Yau Rd	3.83E-09

Section ID	Description	Maximum IR (per year)

Table 8.4 ***Maximum Individual Risk of Each Section of the Transport Route from So Kwun Wat Magazine (Base Case)***

Section ID	Description	Maximum IR (per year)
Route 2b (So Kwun Wat Magazine M3 - Shek Yam)		
Road 2b1	Siu Lam Magazine site track	4.32E-08
Road 2b2	Kwun Fat Street	4.57E-08
Road 2b3	Castle Peak Road - Tai Lam	3.97E-08
Road 2b4	Tuen Mun Road - Siu Lam Interchange slip road	3.68E-08
Road 2b5	Tuen Mun Road (Siu Lam - Sham Tseng)	3.65E-08
Road 2b6	Tuen Mun Road (Sham Tseng - Ting Kau Bridge)	3.67E-08
Road 2b7	Tuen Mun Road (Ting Kau Bridge - Castle Peak Rd - Tsuen Wan)	3.58E-08
Road 2b7a	Tuen Mun Road (2nd section of 7)	3.65E-08
Road 2b8	Tsuen Wan Road (Tuen Mun Rd - Hoi Hing Rd Interchange)	3.59E-08
Road 2b9	Tai Chung Road (Tsuen Wan Rd - Castle Peak Rd Tsuen Wan)	3.06E-08
Road 2b10	Castle Peak Road - Tsuen Wan (Tai Chung to Tai Ho Rd)	1.05E-08
Road 2b11	Castle Peak Road - Tsuen Wan (Tai Ho to Chung On St)	1.03E-08
Road 2b12	Castle Peak Road - Tsuen Wan (Chung On St to Texaco Rd)	1.03E-08
Road 2b13	Castle Peak Road - Kwai Chung (Texaco Rd)	1.02E-08
Road 2b14	Castle Peak Road - Kwai Chung (Ting Kwok St to Kwai Chung Rd RA)	1.03E-08
Road 2b15	Cheung Wing Road (Kwai Chung Rd RA - Yau Ma Hom Rd Shek Yam workarea)	1.00E-08
Route 2c (So Kwun Wat Magazine M3 - Shing Mun)		
Road 2c1	Siu Lam Magazine site track	4.32E-08
Road 2c2	Kwun Fat Street	4.57E-08
Road 2c3	Castle Peak Road - Tai Lam	3.97E-08
Road 2c4	Tuen Mun Road - Siu Lam Interchange slip road	3.68E-08
Road 2c5	Tuen Mun Road (Siu Lam - Sham Tseng)	3.65E-08
Road 2c6	Tuen Mun Road (Sham Tseng - Ting Kau Bridge)	3.67E-08
Road 2c7	Tuen Mun Road (Ting Kau Bridge - Castle Peak Rd - Tsuen Wan)	3.58E-08
Road 2c7a	Tuen Mun Road (2nd section of 7)	3.65E-08
Road 2c8	Castle Peak Road - Tsuen Wan (Tuen Mun Rd - Castle Peak Rd Tsuen Wan)	1.71E-08
Road 2c9	Castle Peak Road - Tsuen Wan (Sha Tsui Rd - Tsuen King Circuit)	5.70E-10
Road 2c10	Castle Peak Road - Tsuen Wan (Tsuen King Circuit - Tai Chung Rd)	9.36E-09
Road 2c11	Castle Peak Road - Tsuen Wan (Tai Chung to Tai Ho Rd)	1.04E-08
Road 2c12	Castle Peak Road - Tsuen Wan (Tai Ho to Chung On St)	1.01E-08
Road 2c13	Castle Peak Road - Tsuen Wan (Chung On St to Texaco Rd)	1.06E-08
Road 2c14	Castle Peak Road - Kwai Chung (Texaco Rd)	1.02E-08
Road 2c15	Castle Peak Road - Kwai Chung (Ting Kwok St to Kwai Chung Rd RA)	1.03E-08
Road 2c16	Cheung Wing Road (Kwai Chung Rd - Wo Yi Hop Rd)	1.05E-08
Road 2c16a	Cheung Wing Road (2nd section)	3.99E-09
Road 2c17	Wo Yi Hop Road (Cheung Wing Rd - Lei Shu Rd)	5.65E-10
Road 2c17a	Wo Yi Hop Road (Lei Shu Rd - Ngong Hom Rd)	5.74E-10
Road 2c18	Wo Yi Hop Road (Ngong Hom Rd - Wo Yi Hop Interchange)	5.56E-10
Road 2c19	Wo Yi Hop Interchange (Wo Yi Hop Rd - Sam Tung Uk Rd)	5.33E-10
Road 2c20	Cheung Shan Estate Road West (Cheung Shan Est Rd E -	5.61E-10

Section ID	Description	Maximum IR (per year)
	Wo Yi Hop Rd)	
Route 2d (So Kwun Wat Magazine M3 - Kwai Chung)		
Road 2d1	Siu Lam Magazine site track	4.32E-08
Road 2d2	Kwun Fat Street	4.57E-08
Road 2d3	Castle Peak Road - Tai Lam	3.97E-08
Road 2d4	Tuen Mun Road - Siu Lam Interchange slip road	3.68E-08
Road 2d5	Tuen Mun Road (Siu Lam - Sham Tseng)	3.65E-08
Road 2d6	Tuen Mun Road (Sham Tseng - Ting Kau Bridge)	3.67E-08
Road 2d7	Tuen Mun Road (Ting Kau Bridge - Castle Peak Rd - Tsuen Wan)	3.58E-08
Road 2d7a	Tuen Mun Road (2nd section of 7)	3.65E-08
Road 2d8	Tsuen Wan Road (Tuen Mun Rd - Hoi Hing Rd Interchange)	3.59E-08
Road 2d9	Tsuen Wan Road (Hoi Hing Rd Interchange - Texaco Rd RA)	2.71E-08
Road 2d10	Tsuen Wan Road (Texaco Rd - Kwai Tsing Rd)	2.66E-08
Road 2d11a	Hing Fong Road (Kwai Tsing Interchange to Kwai Fuk Rd)	1.61E-08
Road 2d11	Hing Fong Road (Kwai Fuk Rd - Kwai Foo Rd)	1.78E-08
Road 2d12	Kwai Foo Road (Hing Fong Rd - Kwai Chung Rd)	1.83E-08
Road 2d13	Kwai Chung Road (Kwai Foo Rd - Kwai On Rd)	1.90E-08
Road 2d13a	Kwai On Rd (Kwai Chung Rd - Tai Lin Pai Rd)	1.90E-08
Road 2d14	Tai Lin Pai Road (Kwai On Rd to Wing Yip St)	1.94E-08
Road 2d15	Wing Yip Street	1.72E-08
Route 2e (So Kwun Wat Magazine M3 - Mei Lai Road)		
Road 2e1	Siu Lam Magazine site track	4.32E-08
Road 2e2	Kwun Fat Street	4.57E-08
Road 2e3	Castle Peak Road - Tai Lam	3.97E-08
Road 2e4	Tuen Mun Road - Siu Lam Interchange slip road	3.68E-08
Road 2e5	Tuen Mun Road (Siu Lam - Sham Tseng)	3.65E-08
Road 2e6	Tuen Mun Road (Sham Tseng - Ting Kau Bridge)	3.67E-08
Road 2e7	Tuen Mun Road (Ting Kau Bridge - Castle Peak Rd - Tsuen Wan)	3.58E-08
Road 2e7a	Tuen Mun Road (2nd section of 7)	3.65E-08
Road 2e8	Tsuen Wan Road (Tuen Mun Rd - Hoi Hing Rd Interchange)	3.59E-08
Road 2e9	Tsuen Wan Road (Hoi Hing Rd Interchange - Texaco Rd RA)	2.71E-08
Road 2e10	Tsuen Wan Road (Texaco Rd - Kwai Tsing Rd)	2.66E-08
Road 2e11	Tsuen Wan Road (Kwai Tsing Rd - Tsuen Wan Rd section over container port rd)	1.27E-08
Road 2e12	Tsuen Wan Road (Tsuen Wan Rd - Kwai Tsing Rd)	1.25E-08
Road 2e13	Kwai Chung Road (up to Lai Chi Kok Bridge)	1.27E-08
Road 2e14	Kwai Chung Road (Lai Chi Kok Bridge - Cheung Sha Wan Rd)	1.26E-08
Road 2e15	Cheung Sha Wan Rd (Cheung Sha Wan Rd - butterfly valley Rd)	1.90E-08
Road 2e16	Castle Peak Road (Lai Chi Kok Interchange to Butterfly Valley Interchange)	1.88E-08

Figure 8.4 Maximum IR for Northern Delivery Routes (Base Case)

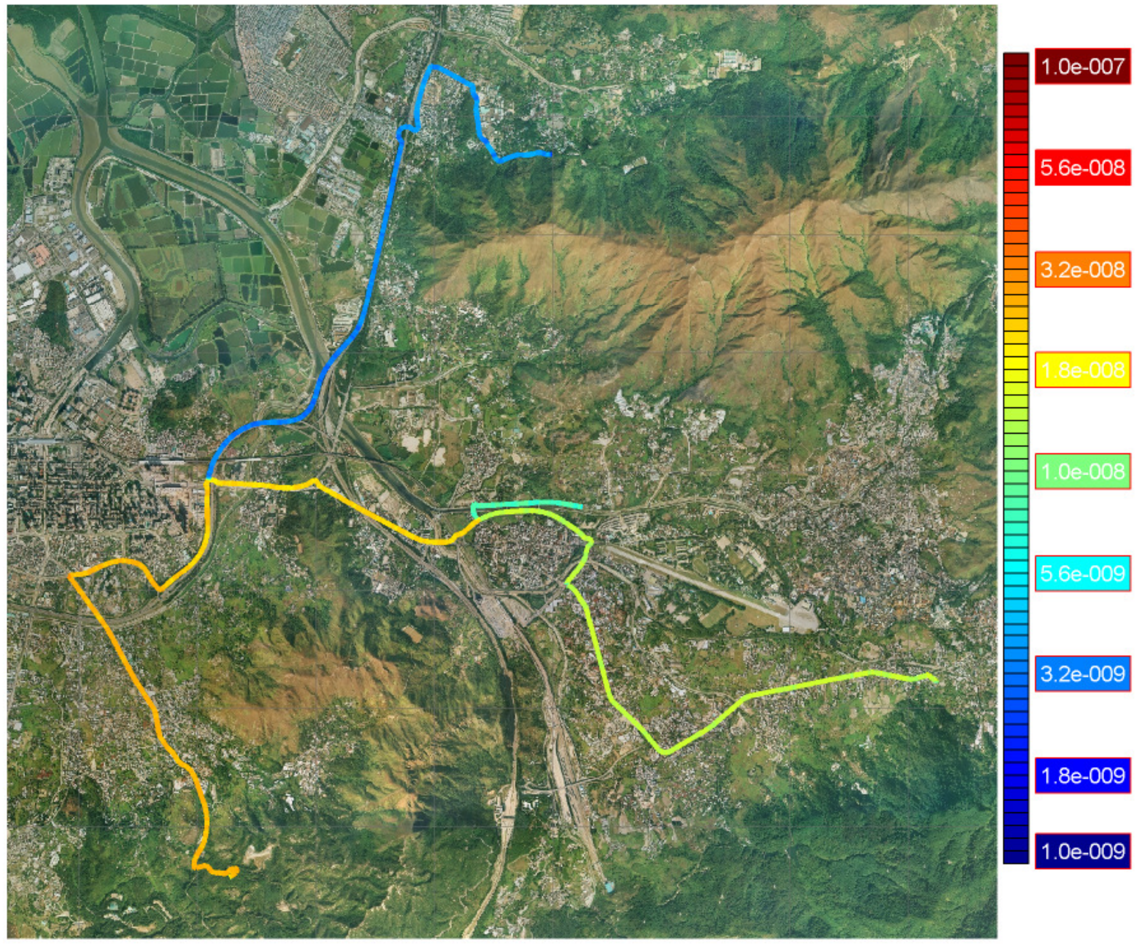
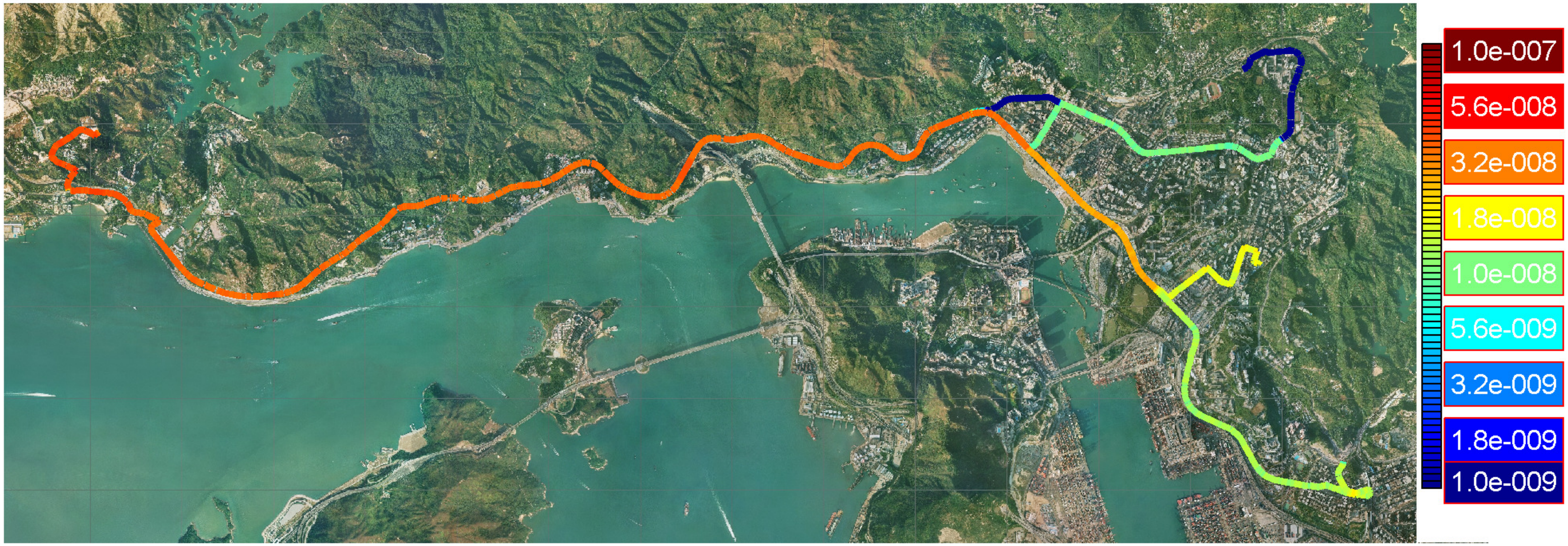


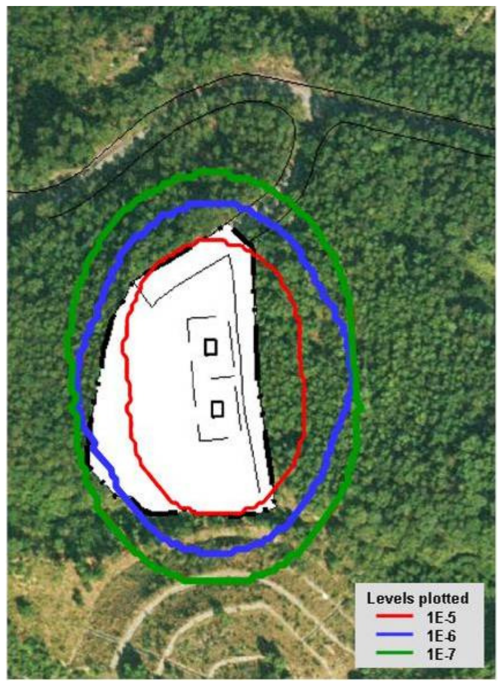
Figure 8.5 Maximum IR for Southern Delivery Routes (Base Case)



For storage magazines, individual risk contours have been plotted and overlaid on plot layouts for Tai Lam and So Kwun Wat sites (*Figures 8.6* and *8.7*). 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 10^{-4} per year for each site since this is the base frequency used in the analysis for explosion at a magazine. This however, neglects to take into account presence factors. Both magazine sites are in remote areas and the 10^{-5} per year contours impacts 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 smaller than 10^{-5} per year and is deemed to be acceptable.

Figure 8.6 ***IR of the Tai Lam Magazine***

Indoor



Outdoor

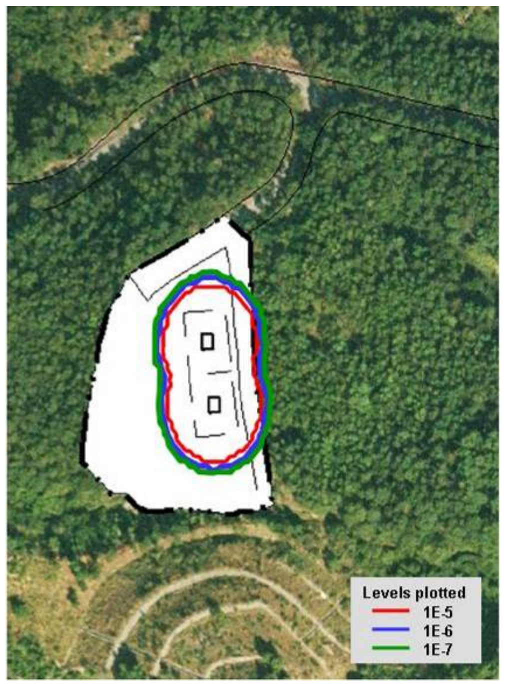
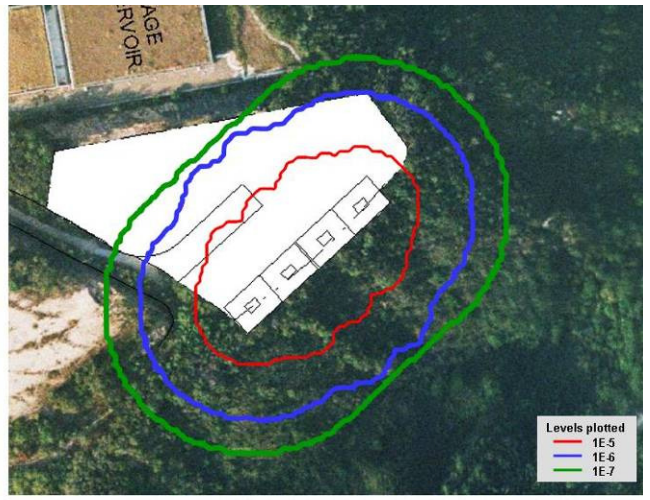
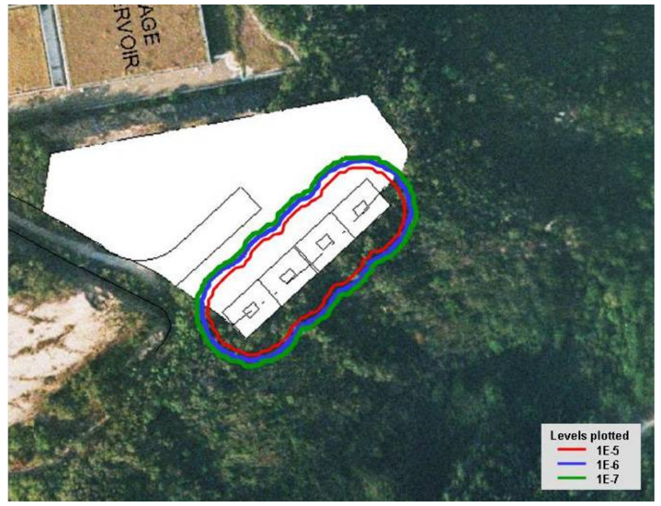


Figure 8.7 ***IR of So Kwun Wat Magazine***

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 location, 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 of 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

By the time, the fire brigade arrives at the scene in case of a fire incident involving an explosive vehicle, most likely a fire would have already fully developed. 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 consequence 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 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 more sensitive than emulsions and transported in different manner. In absence of test data, this assumption may be conservative.

9 ALARP ASSESSMENT

9.1 RISK RESULTS AND APPROACH TO ALARP

The hazard to life assessment of the XRL project has assessed the risks arising from the proposed magazine sites in So Kwun Wat and Tai Lam as well as the risks associated with the road transport from these sites to the work areas. From *Section 8*, the risks posed by the project, for both base case and worst case considered, are within the ALARP (As Low As Reasonably Practicable) region specified in EIAO-TM Annex 4.

The risk, in terms of PLL, associated with the Worst Case, corresponding to a scenario of worst deliveries and peak combined load at each delivery point, is estimated at 1.27×10^{-3} per year, 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 risks arising from explosive transport are much more significant than that of explosive 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 any 'practicable' options regardless of their cost. A mitigation option is considered 'practicable' if an engineering solution exists and can be implemented on the XRL 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, ie 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 (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 by 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 recognized 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:

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 20x 1.27 x 10^{-3} x 3
= HK$ 2.51M.

The design life of a mitigation measure is assumed as 3 years based on the construction phase of the XRL project 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 in 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 use of hard rock TBM or alternatives to cartridged emulsion;
- Options reducing significantly the distance run by contractors' explosive trucks such as closer magazine sites and alternative routes;
- Options reducing significantly the number of trips to be carried out by contractors' explosive trucks;
- Options considering improved explosive 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 MTRC and explosive 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*

According to the XRL Preliminary Design Final Report (D3.25A) (MTRC 4), the development of the project alignment and the associated infrastructure has been driven by the high speed nature of the railway. The constraints within urban Shenzhen and the mountainous topography of Hong Kong's New Territories dictated that the railway shall be wholly underground between Futian Station and West Kowloon Terminal. To achieve the required line operating speed of 200km per hour, large diameter horizontal curves and shallow gradients have generally been adopted in accordance with the Mainland alignment design criteria. The railway generally runs in a north south direction from Huanggang Park (chainage113+650) in the Mainland,

beneath Mai Po, Ngau Tam Mei, Kam Tin Valley, Tai Mo Shan, Kwai Chung, Lai Chi Kok, Nam Cheong and Tai Kok Tsui to the new terminus station in West Kowloon. Within the Kam Tin Valley a pocket track has been provided for emergency use forming part of the ERS, along with an at grade stabling and maintenance facility. The Shek Kong Stabling Sidings is connected to the mainline with a twin track approach ramp connecting to the south of the pocket track. Several alignment options were examined, considering engineering, environment, and other factors. These have been discussed in Chapter 2 of this EIA. Opting for an alternative alignment option will cost significantly more than the Maximum Justifiable Expenditure.

9.4.2 *MAGAZINE REQUIREMENT AND SELECTION PROCESS*

Magazine Requirement

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

Magazine Selection Process

The Magazine site selection process is documented in Working Paper No 13A (MTRC 5). A long list of sites has been screened by the Preliminary Design Consultant based on the following factors:

External Separation Distances

External separation distance refers to the distance from the explosive stores to inhabited areas and sensitive receivers. Amongst all the requirements from Mines Division described in Section 2.3.2, the Commissioner of Mines require that the minimum separation distances to sensitive receivers stipulated in the UK Manufacture and Storage of Explosives Regulations 2005 are met. For the XRL project, the minimum separation distances described below shall be, at least, maintained (the main separation requirements are listed although other requirements also apply):

- Class A Receivers: Footpaths, lightly used road, waterways - 68 m;
- Class B Receivers: Minor Road, Railway Line - 102 m;
- Class C Receivers: Major road, place of public resort - 204 m;
- Class D Receivers: Buildings- 259 m;
- Class E Receivers: Vulnerable Building- 337 m;

There has not been any site identified within 4 km of the alignment meeting these stringent requirements.

To minimize the distance from Magazine to Site, due to geographical locations of the work areas, two magazines have been proposed to minimize the distance from the Magazine to site: one serving the northern work areas while the other serving the southern work areas.

For the magazine serving the northern work areas, the closest magazine to site have been identified at average distances of 5 km (Pat Heung site), 6 km (Lam Kam Road / Helicopter site) and 12 km (Tai Lam/ Quarry site). However, the site at Pat Heung and Lam Kam Road has some further restrictions.

For the magazine serving the southern work areas, the closest magazine to the worksites identified was the Gin Drinkers' Bay (4 km), Firing Range at Golden Hill (12 km), CLP OHL Training School (15 km), So Kwun Wat (18 km), CAS Yuen Tun Camp (15 km). However, most sites except So Kwun Wat have a number of restrictions.

Other factors

Other factors have been considered in the site selection process which may render the site unsuitable for the project due to the constraints posed. Such factors are:

- Access for Mines Division explosive delivery vehicles;
- Site constraints such as existing conditions;
- Land availability; and
- Environment and heritage impact.

Site Selection

The magazine site selection has considered a total of 13 candidate sites and they are depicted in *Figure 9.1*. This selection process has adopted a scoring approach which takes into account the following aspects:

- external separation distances,
- distance from mines delivery pier to magazine site,
- average distance from magazine to XRL work site,
- environmental and heritage impact,
- land availability, site constraints, and
- access of Mines explosives delivery vehicles

On this basis, most sites were found some constraints which make them unsuitable for the project. The key issues for each candidate site are summarized in *Table 9.1*.

Figure 9.1 Candidate Magazine Sites for XRL Project

Table 9.1 Summary of Issues for Each Candidate Site

Site Ref	Site Name	Summary of Key Issues	Overall Selection Score
1	Helicopter site (Lam Kam)	▪ Adjacent structures and Lam Kam Road are within separation distance. Reduced storage quantity to be considered. Land available however existing structures will need to be relocated subject to land user conditions. Although, this site is a potential candidate, it requires additional expenditure.	62
2	Pat Heung	▪ No public road access (closest road approx 200 away) ▪ Roads through village to site area are very narrow (single lane) with tight bends and constricted crossings over open nullah. Access road not considered possible for Mines delivery vehicles. ▪ Land is private and will need to be resumed	48
3	Quarry (Tai Lam)	▪ No special concerns	78
4	Firing Range (Golden Hill)	▪ Single lane access road with passing places that cross the Kowloon Reservoir with blind bends. Access road not considered suitable for Mines delivery vehicles. ▪ Existing structures will need to be relocated	44
5	Ying Wa Street	▪ The site is too close to the road (<50m). External separation distance not acceptable.	0
6	CLP OHL Training School	▪ Access Road is very narrow, steep and twisty. Not considered suitable for mines delivery vehicles. ▪ Land is private and will need to be resumed ▪ Existing OHL Training facility will need to be relocated	46
7	Kau Wa Keng	▪ Storage reservoir is within 75; building structures are within 100m, it is not considered practical to reduce the storage capacity enough to meet the separation distance requirement. Separation distances not acceptable.	0
8	Gin Drinkers' Bay	▪ Adjacent to a former landfill site which still producing large volumes of explosives methane gas. Potential implications with respect to landfill gases / explosion hazard.	68
9	Kowloon Reservoir	▪ The site is close to Tai Po Road (<50m). Not considered practical to reduce the storage capacity to meet the separation distance. ▪ Moving the site further from road requires significant vegetation clearance (trees) and formation works on a sloping hillside. Separation distances not acceptable.	0
10	Route Twisk	▪ Distance to Route Twisk is <50m. It is not considered practical to reduce the storage capacity to meet the separation distance. ▪ Moving the site further from the road requires substantial formation works and increases the access problems. Separation distances not acceptable.	0
11	So Kwun Wat	▪ Siu Lam storage reservoirs are within the separation distance. Reduced storage quantity to be considered	63
12	CAS Yuen Tun Camp	▪ The site is currently used for outdoor training and activities. It is assumed that the camp would need to be closed and relocated while magazine is in operation. ▪ Access road is steep, narrow and poorly maintained. May not be suitable for Mines vehicles. ▪ Camp is thought to be in Tai Lam Country Park. Strong objection from Country Park Board anticipated.	43
13	Lo Wai	▪ Numerous temporary & permanent structures within 100m from the centre of the site. It is not considered practical to reduce the storage capacity to meet the separation distance. Separation distances not acceptable.	0

Notes:

(1) Details refer to Working Paper No 13A (MTRC 5)
(2) Separation distance requirements referred above are in accordance with the UK *"Manufacture and Storage of Explosives Regulations, 2005"* published by the UK Health & Safety Executive, as specified by the Hong Kong Commissioner of Mines in their document "*How to Apply for a Mode A Explosives Store Licence*".
(3) Score 0 is used where the site does not meet the minimum separation distance criteria and the option of reducing the storage capacity is not practical.

The magazine site selection process has been taken forward to this ALARP assessment. Those candidate sites scored 0 due to non-compliance of the Commissioner of Mines' external separation requirements can be translated into 'impracticable' and therefore ruled out on that basis. Remaining sites with a non-zero score, namely the Lam Kam site (scored 62), the Pat Heung site (scored 48), Quarry at Tai Lam (scored 78), CLP OHL Training School (scored 46), the Firing Range site (scored 44), the Gin Drinkers' Bay (scored 68), So Kwun Wat (scored 63), and the CAS Yuen Tun Camp site (scored 43) have been selected for further site evaluation. The additional implementation cost due to site constraints for each of these candidate sites is presented in *Table 9.2*.

All the candidate sites meeting the separation distance criteria, except the Lam Kam site and the two magazine sites selected as the basis for the Hazard to Life Assessment (ie. So Kwun Wat and Tai Lam), require an implementation cost significantly greater than the maximum justifiable expenditure for risk mitigation of HK$ 2.51M. Therefore, only the Lam Kam Road sites has been retained as an alternative magazine site option for the ALARP assessment.

Table 9.2 Additional Implementation Cost due to Site Constraints for Candidate Sites

Site Ref.	Site Name	Score	Land Cost (1)		Existing Structures Relocation (2)		Road Works (3)		Slope / Retaining Works (for road widening)		Miscellaneous Costs		Estimated Total
			HK$		HK$		HK$		HK$		HK$		HK$
1	Helicopter Site (Lam Kam)	62	Assume no cost (Govt Land)		-	0.8 M	15 m	0.1 M	-	0.3 M (4)	Extra-over Quarry site	0.1 M	**HK$ 1.3 M**
2	Pat Heung	48	Private land	10.0 M	5 houses	25.0 M(7)	218 m	1.4 M	-	5.0 M (5)	-	-	**HK$ 41.4 M**
3	Quarry (Tai Lam)	78	No additional cost. Site selected as basis for Hazard to Life Assessment										
4	Firing Range (Golden Hill)	44	Assume no cost (Govt Land)		Firing range facility	15.0 M	450 m	2.9 M	Slope works at passing bays	23.0 M (6)	-	-	**HK$ 40.9 M**
5	Ying Wa Street	0	Not Studied further - Site Failed Separation Distance Criteria										
6	CLP OHL Training School	46	Private land	10.0 M	OHL training facility	10.0 M	292 m	1.9 M	Slope works at passing bays	15.0 M(6)	-	-	**HK$ 36.9 M**
7	Kau Wa Keng	0	Not Studied further - Site Failed Separation Distance Criteria										
8	Gin Drinkers' Bay	68	-	-	-	-	72 m	0.5 M	-	-	Vent fans Sealed floor Gas detectors EIA landfill backup generator UPS system	0.5 M 1.0 M 0.5 M 0.5 M 0.5 M 0.2 M	**HK$ 3.7 M**
9	Kowloon Reservoir	0	Not Studied further - Site Failed Separation Distance Criteria										
10	Route Twisk	0	Not Studied further - Site Failed Separation Distance Criteria										
11	So Kwun Wat	63	No additional cost. Site selected as basis for Hazard to Life Assessment										

Site Ref.	Site Name	Score	Land Cost (1)		Existing Structures Relocation (2)		Road Works (3)		Slope / Retaining Works (for road widening)		Miscellaneous Costs		Estimated Total
			HK$		HK$		HK$		HK$		HK$		HK$
12	CAS Yuen Tun Camp	43	Assume no cost (Govt Land)		Camp facility	15.0 M	520 m	3.4 M	Slope works at passing bays	26.0 M(6)	-	-	**HK$ 44.4 M**
13	Lo Wai	0	Not Studied further - Site Failed Separation Distance Criteria										

Note:

1. Resumption of private land will lead to additional cost estimated at HK$ 10 M
2. Like-for-like replacement will be required
3. Total length of route to be widened (at passing bays). Route widening cost has been estimated at HK$ 6.5 M per km.
4. For the Lam Kam site, minor works are envisaged, estimated at HK$ 0.3M.
5. For the Pat Heung site, only works on retaining walls are envisaged, estimated at HK$ 0.5 M.
6. Slope works have been estimated at HK$ 50 M per km of road sections to be widened.
7. Houses should be removed to widen access road ($5 M per property)

9.4.3 *Use of Magazines Closer to the Construction Sites*

Amongst the initially proposed list of Magazine sites, only 3 sites were retained as practicable; which are So Kwun Wat, Tai Lam and Lam Kam Road.

The preferred magazine sites are So Kwun Wat and Tai Lam.

A site at Lam Kam (*Figure 9.2*) was identified as a potential alternative site for the Tai Lam magazine site. As compared to the Tai Lam site, the Lam Kam site is in close vicinity to the northern area work sites, which minimizes public road transport and of the risk arising from it. In terms of the risk from magazine itself, it is expected to be low since the site is located in a relative remote area surrounded by minor roads and minimum population.

The Lam Kam magazine would have to be designed to have 4 explosive stores with each store containing 200kg of explosive. This design would be different from that in Tai Lam which is designed with 2 stores with 400kg explosive each store.

In addition to the costs associated with the higher number of stores, implementing the Lam Kam Road option will require additional expenditure for resiting the existing facility owned by the Lands Department and vested to the Planning Department. This is evaluated as not less than HK$ 1,000,000.

The alternative Magazine Site of Lam Kam is closer to the construction sites and therefore presents some safety benefits; although in the wider picture, those safety benefits may be offset by a longer travel distance required for Mines Division trucks carrying explosives to reach the Magazine.

This option is selected for further analysis.

9.4.4 *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.

It should be noted that, even if TBMs were used for tunneling, substantial quantities of explosives will still be required for shafts and adits excavation.

Finally, immediate availability of such TBMs for Hong Kong plus the additional blasting required for non-circular sector 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.

9.4.5 *Use of Alternative Routes*

The shortest route has generally been selected for explosive deliveries to site. Selecting an alternative route has negligible costs and therefore presents a viable option. Based on the review of the possible transport routes for this project, Castle Peak Road has been presented as an alternative route.

The possibility of using Caste Peak Road instead of Tuen Mun Road for road transport for the So Kwun Wat site is explored in the context of risk. The alternate route is depicted in *Figure 9.3*.

This option has been analysed further.

9.4.6 *Use of Different Explosive Types*

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

The detonating cord in this project use a PETN core with 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. This option is therefore not considered further.

9.4.7 *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 project has also considered the smallest cartridge type available on the market (125 g type).

It is possible to use smaller explosive charges for initiating explosives such as ‘cast boosters’. The main explosive component of ‘cast boosters’ is PETN. Using such explosives will reduce the weight of explosives to be transported. However, PETN has a higher TNT equivalency. This will also not eliminate the need for detonating cord.

The cost of this option is estimated to be at least HK$ 6,000,000 higher than using the cartridged emulsion for initiating bulk explosives. This is based on a typical 3 times increase in sale price but a lower storage and transport cost per unit when compared to cartridge emulsion.

The additional cost of utilizing cast boosters would be much higher than the Maximum Justifiable Expenditure and therefore not justifiable on a cost basis.

Also, there are some limitations in availability of 'cast boosters' since the number of suppliers who can provide this material is limited.

9.4.8 *SAFER EXPLOSIVE 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, ie more than 200kg. However, this measure has been recommended for the Contractors' trucks in this project, as an improvement measure, although the quantity transported will be much less, about 100kg.

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.

9.4.9 *LOWER FREQUENCY OF EXPLOSIVE 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/ANFO. No further options have been identified. The possibility of reducing the frequency of explosive transport has not been evaluated further.

9.4.10 *REDUCTION OF ACCIDENT INVOLVEMENT FREQUENCY*

It is possible to reduce the explosive accident probability though the implementation of 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 recommendation section of this report.

9.4.11 *REDUCTION OF FIRE INVOLVEMENT FREQUENCY*

It is possible to carry better types of fire extinguishers onboard of the explosive trucks and with bigger capacity eg. AFFF-type extinguishers.

Adequate emergency plans and training could be also provided to make sure the adequate fire extinguishers are used and attempt is 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 recommendation section of this report.

9.4.12 *SUMMARY*

In summary, the following options have been considered for cost-benefit analysis.

Option 1: Alternative Magazine Site in Lam Kam

Option 2: Alternative Route – Castle Peak Road

Other options have been either recommended for implementation or assessed comparing the implementation cost with the maximum justifiable expenditure.

Figure 9.2 Alternative Magazine Site at Lam Kam and the Explosives Transport Routes to Work areas (Route 3)

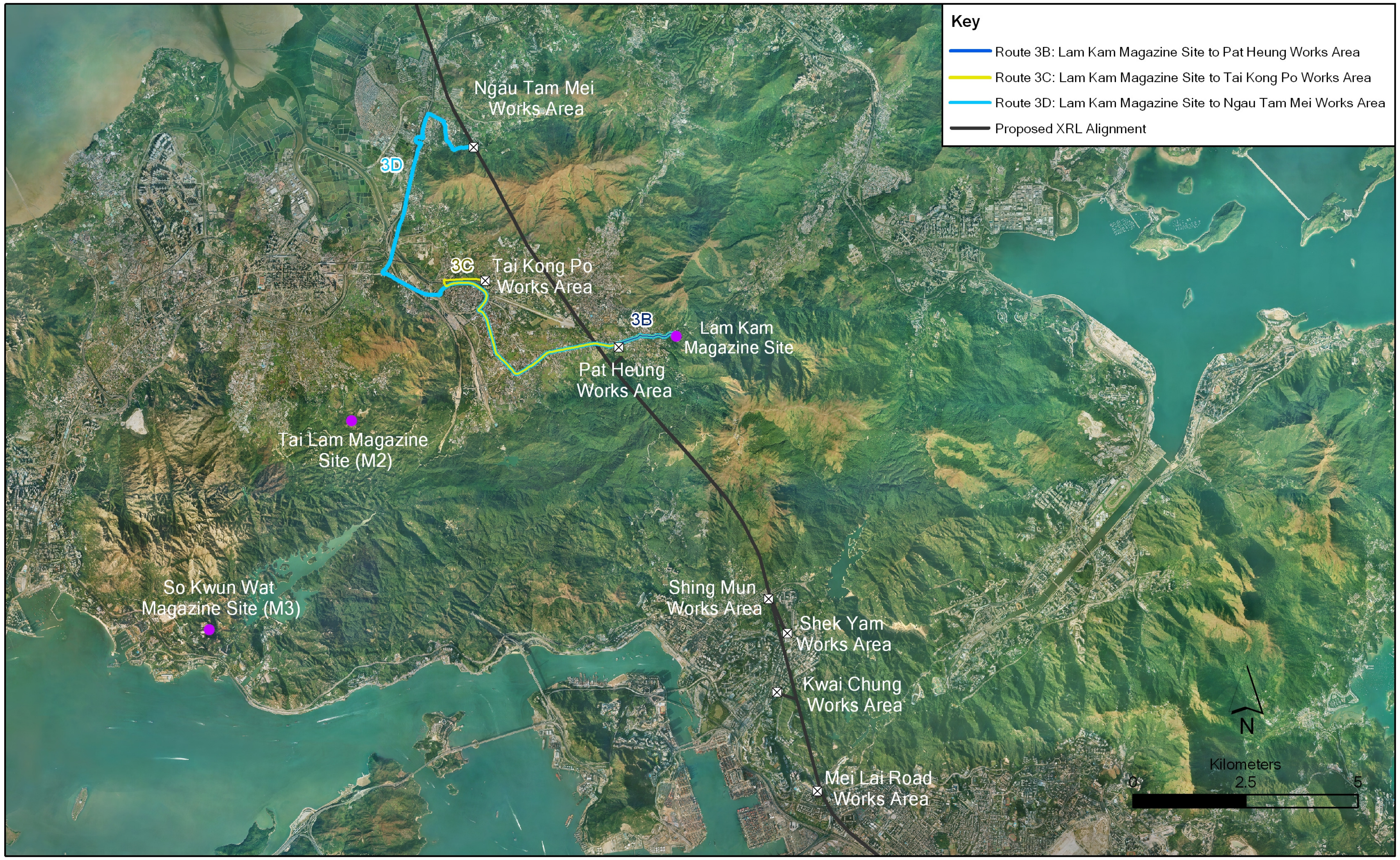


Figure 9.3 Alternate Transport Route (Route 4) from So Kwun Wat to Work Areas

9.5 *OPTION CASE 1 - ALTERNATIVE MAGAZINE SITE IN LAM KAM*

9.5.1 *SITE DESCRIPTION AND POPULATION*

The alternate magazine site (Figure 9.4) is located east of Shek Kong, next to Lam Kam Road. The separation between the proposed site and public footpaths is more than 54m and from buildings is more than 180 m. There is a private helicopter pad owned and operated by 'Heliservices' about 70 m from the site. All structures associated with the helipad are located more than 100m from the magazines. Nevertheless, possible impact on the helicopters from explosions at the magazine and possible consequences from helicopter crashes into the store are considered in the assessment.

Population on roads and pavements were estimated in terms of population density figures as described in *Section 4.2*. A summary of the population considered for the Lam Kam Road Site is provided in *Table 9.3*.

The magazine is designed to have 4 magazine stores with each containing 200kg of explosives. The layout plan of the magazine is provided in *Figure 9.5*.

Figure 9.4 Aerial Photo of the Lam Kam Road Site

Figure 9.5   Lam Kam Magazine Site Layout

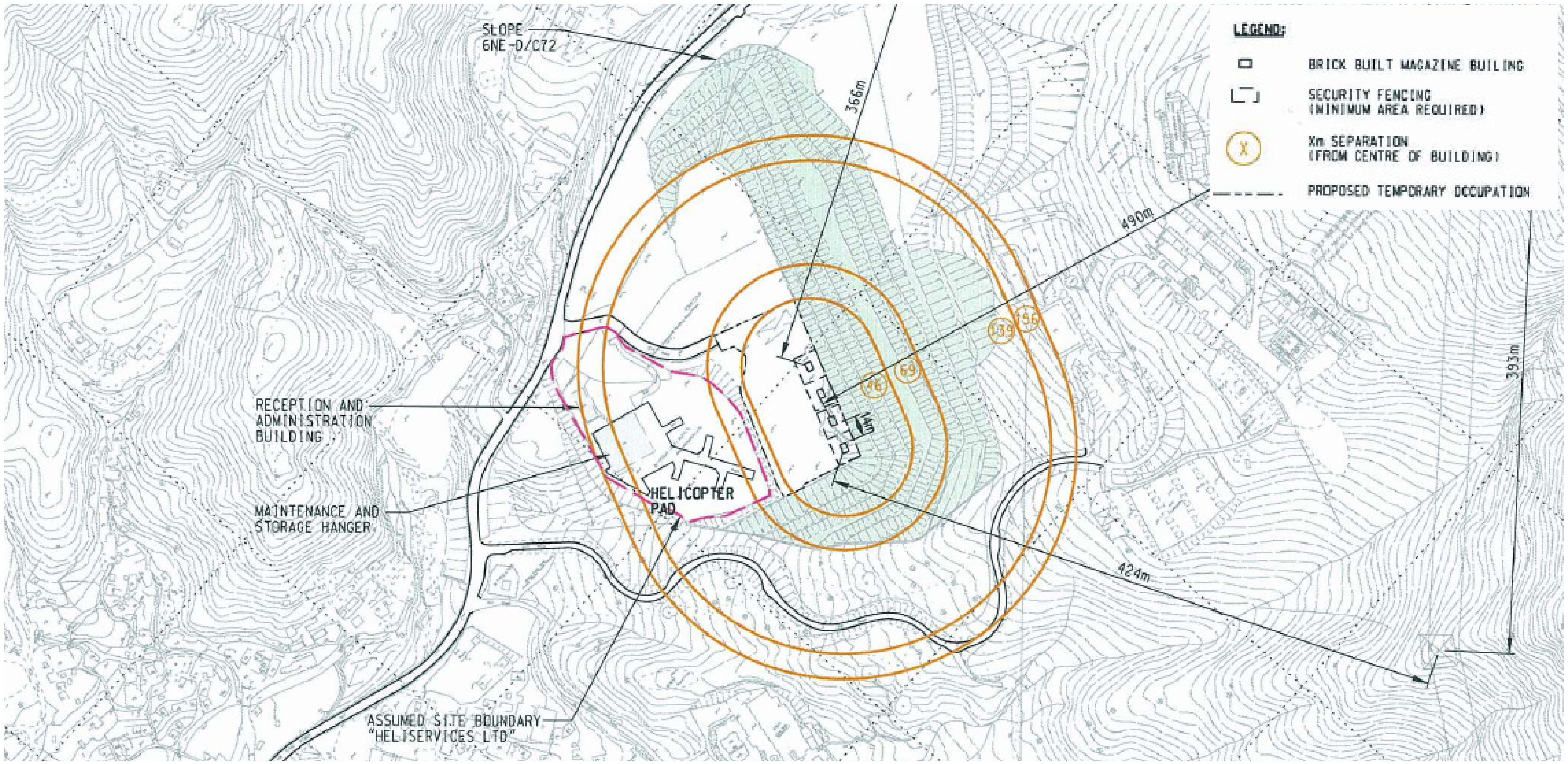


Table 9.3 Population Considered Near Lam Kam Magazine Site

Name	Weekday AM Peak	Weekday Daytime	Weekday PM Peak	Weekday Night	Saturday AM Peak	Saturday Daytime	Saturday PM Peak	Saturday Night	Sunday AM Peak	Sunday Daytime	Sunday PM Peak	Sunday Night
Helipad	25	15	0	0	25	15	0	0	25	15	0	0
Heliservice Reception & Administration building	15	65	15	15	15	65	15	15	15	65	15	15
Access road pavement (persons/m^2)	0	0	0	0	0	0	0	0	0	0	0	0
Access Road vehicle (persons/m^2)	0.00123	0.00116	0.00133	0.00116	0.00123	0.00116	0.00133	0.001156	0.00123	0.00116	0.00133	0.001156

9.5.2 *Transport Routes*

Lam Kam Magazine is proposed to deliver explosive to the work sites at Pat Heung, Tai Kong Po & Ngau Tam Mei. Details of the routes are provided in *Table 9.4.* The population estimate methodology along the transport routes is the same as the base case described in *Section 4.*

Table 9.4 ***Delivery Routes for the Lam Kam Road Magazine Site***

Tag	Description
Route 3b (Lam Kam Magazine - Pat Heung)	
Road 3b1	Access road to Lam Kam Magazine
Road 3b2	Lam Kam Road
Road 3b2a	Kam Tin Road (Lam Kam Rd - Kam Sheung Rd)
Road 3b3	Kam Sheung Road (Kam Tin Rd - Access Road of Pat Heung Magazine)
Road 3b4	proposal haul road towards PHV off Kam Sheung Rd
Route 3c (Lam Kam Magazine - Tai Kong Po)	
Road 3c1	Access road to Lam Kam Magazine
Road 3c2	Lam Kam Road
Road 3c2a	Kam Tin Road (Lam Kam Rd - Kam Sheung Rd)
Road 3c3	Kam Sheung Road (Kam Tin Rd - Access Road of Pat Heung Magazine)
Road 3c4	Kam Sheung Road (Access Road of Pat Heung Magazine - Tung Wui Rd)
Road 3c5	Tung Wui Road
Road 3c6	Kam Tin Bypass Road
Road 3c7	Kam Hing Rd
Road 3c8	Chi Ho Rd
Road 3c9	proposed haul road towards TPV off Chi Ho Rd
Route 3d (Lam Kam Magazine - Ngau Tam Mei)	
Road 3d1	Access road to Lam Kam Magazine
Road 3d2	Lam Kam Road
Road 3d2a	Kam Tin Road (Lam Kam Rd - Kam Sheung Rd)
Road 3d3	Kam Sheung Road (Kam Tin Rd - Access Road of Pat Heung Magazine)
Road 3d4	Kam Sheung Road (Access Road of Pat Heung Magazine - Tung Wui Rd)
Road 3d5	Tung Wui Road
Road 3d6	Kam Tin Bypass Road
Road 3d7	Kam Tin Road (Castle Peak Rd - Yuen Long - Kam Tin Bypass)
Road 3d8	Castle Peak Road - Tam Mei
Road 3d8a	San Tam Road (Castle Peak Rd - San Tin Interchange)
Road 3d9	San Tam Rd (San Tin Interchange - Chun Shin Rd)
Road 3d10	Chuk Yau Rd

9.5.3 *Scenarios Considered*

All the descriptions for Tai Lam Site with the regards to explosive delivery schedule and hazards are applied to the alternative Lam Kam site. The following table summarized all the scenarios considered for option case 1 assessment:

Table 9.5 ***Scenarios Considered in Option Case 1 Assessment***

Tag	Scenario	Explosives load (TNT eqv. kg)	Remarks
Storage of Explosives			
01	Detonation of full load of explosives in one store in Lam Kam site	228	Total of 4 stores to be considered
02	Detonation of full load of explosives in one contractor truck on the access road within the Lam Kam magazine site boundary	141*	
Transport of Explosives			
03	Detonation of full load of explosives in one contractor truck on public roads – from Lam Kam site to delivery point 3b Pat Heung	141*	
04	Detonation of full load of explosives in one contractor truck on public roads – from Lam Kam site to delivery point 1c Tai Kong Po	46*	
05	Detonation of full load of explosives in one contractor truck on public roads – from Lam Kam site to delivery point 1d Ngau Tam Mei	46*	

Note:
* The explosives load considered here are identical to the load applied in Worst Case Scenario

9.5.4 *Frequency Assessment*

Explosive Storage

The same generic explosive initiation frequency of $1x\ 10^{-4}$ per magazine site year as described in *Section 6* has been used as the base explosion frequency. This frequency includes initiation due to generic causes including lightning strike, surroundings fire, earthquake, etc.

Since the location of the Lam Kam site is further away from the airport than the other sites for which the likelihoods of aircraft crash have already been estimated below 1×10^{-9} per year, no further consideration was made regarding aeroplane crash for Lam Kam Site.

A helicopter pad is located at around 70 m distance from the Lam Kam magazine site. Based on the information provided by Heliservices operator, the usage of the helipad is 12 flight stages per day on average.

The approach, landing and take-off stages of a flight are associated with the highest risk of helicopter crashes. Historical incidents show that helicopter accidents during take-off and landings are confined to a small area around the helipad (Byrne, 1997). 93% of accidents occur within 100m of the helipad, and the remaining 7% occur between 100 and 200m of the helipad.

Data from offshore helicopter activities (Spouge, 1999), as adopted in the ERM (2006) study, gives a helipad related helicopter crash frequency of 2.9×10^{-6} per flight stage (i.e. per take-off and landing). However, most of these incidents are minor such as heavy landings. For a helicopter incident to damage a facility leading to explosive initiation, it must be a serious, uncontrolled impact.

Only accidents involving fatalities were therefore considered in the analysis. 4% of incidents resulted in one or more fatalities and so the frequency of uncontrolled crashes was estimated at $2.9\times10^{-6}\times0.04 = 1.16\times10^{-7}$ per flight stage.

The Lam Kam Site has a helicopter pad located about 70 m from the explosive magazine. Based on the usage of this helipad of 12 flight stages per day on average, and area of the magazine stores is about 480m², the helicopter crashing can be estimated by:

$$12\times365\times1.16\times10^{-7}\times0.93\times\frac{480}{\pi100^{2}}=7.2\times10^{-6}\ \text{per year}$$

This frequency of 7.2×10^{-6} per year has been added to the base explosion frequency for Lam Kam site to account for the additional risk due to helicopter accident.

The magazine site explosion frequencies considered in option case 1 are listed below:

Table 9.6 Frequency of explosion for each proposed magazine site

Magazine	Base frequency per explosive magazine (/yr)	Adjustment due to the local conditions (/yr)	Total frequency per explosive magazine (/yr)	No. of stores (no.)	Total frequency per store (/yr)
So Kwun Wat	1.00e-4	0	1.00e-4	4	2.50e-5
Lam Kam	1.00e-4	7.2e-6	1.07e-4	4	2.68e-5

Explosive Transport

This is the same as the base case.

9.5.5 CONSEQUENCE ASSESSMENT

The ESTC model has been used for consequence assessment as described in the base case. In addition, due to the air traffic near the Lam Kam site, a specific assessment of debris striking a helicopter was carried.

The UK HSE defines the safety distance from an explosion in respect of fragment attack based on the following formula (Moreton, 1993):

$$R = 515 \times Q^{0.21}$$

where
R is the safety distance (ft)
Q is the weight of explosives (lbs)

The probability of a fragment hitting a target of 4ft²at the safety distance has been estimated to be 10^{-5}. Thus, the probability of a fragment hitting a target

of area A situated at distance d from an explosion can then be estimated using the following equation:

$$P = A \times 0.1 \times R^{-1} \times d^{-1} \times (1 - (d / R)^2)^{-0.5}$$

In the present case of 228kg storage, R is estimated at 1900 ft (580m). If it is assumed that the magazine store disintegrates to produce 100 missiles and a helicopter with an area of 40m² is flying 100m from the explosion, the probability of that helicopter being hit is estimated at 1.40e-4 per year per explosion event. Considering the explosion frequency of one magazine is 1e-4 per year, the frequency of debris striking a helicopter becomes 1.4e-8 per year. Applying a presence factor of 3.33%, which corresponds to 12 helicopter flight stages per day with 2-minute exposure each for the approach and departure, it yields an overall frequency of 4.7e-10 per year for a helicopter being hit by the debris generated by an explosion.

Furthermore, it should be noted that the above assessment was performed with a large degree of conservatism, eg. in reality helicopters are flying from all directions and may not necessarily pass through the hazardous zone near the magazine. Also barricades around the stores could provide significant shielding. Another report published by UK HSE (Moreton, 2002) also suggests that in the case of brick and concrete stores, the debris produced from the break up of the walls would be propelled mostly horizontally outwards and hence helicopters at height are unlikely to be affected. Given that frequency is below 10^{-9} per year, the risks of explosions affecting helicopters are considered negligible and are not considered further.

The consequence results for each transport and storage scenario are summarized in *Table 9.7*.

Table 9.7 Summary of Consequence Results for Option Case 1 Scenarios

No.	Scenario	TNT (eqv. kg)	*Indoor*		*Outdoor*	
			Fatality Prob.	Impact distance (m)	Fatality Prob.	Impact distance (m)
	Storage of Explosives					
01	Detonation of full load of explosives in one store in Lam Kam site	228	90%	18.8	90%	15.0
			50%	21.8	50%	15.7
			10%	32.4	10%	17.3
			3%	42.7	3%	18.6
			1%	55.1	1%	19.9
02	Detonation of full load of explosives in one contractor truck on the access road within the Lam Kam magazine site boundary	141*	90%	16.1	90%	12.9
			50%	18.6	50%	13.4
			10%	27.9	10%	14.9
			3%	38.6	3%	16.0
			1%	57.3	1%	17.5
	Transport of Explosives					

No.	Scenario	TNT (eqv. kg)	*Indoor*		*Outdoor*	
			Fatality Prob.	Impact distance (m)	Fatality Prob.	Impact distance (m)
03	Detonation of full load of explosives in one contractor truck on public roads – from Lam Kam site to delivery point 3b Pat Heung	141*	90% 50% 10% 3% 1%	16.1 18.6 27.9 38.6 57.3	90% 50% 10% 3% 1%	12.9 13.4 14.9 16.0 17.5
04	Detonation of full load of explosives in one contractor truck on public roads – from Lam Kam site to delivery point 3c Tai Kong Po	46*	90% 50% 10% 3% 1%	11.1 12.8 19.2 26.6 39.5	90% 50% 10% 3% 1%	8.9 9.2 10.2 11.1 12.0
05	Detonation of full load of explosives in one contractor truck on public roads – from Lam Kam site to delivery point 3d Ngau Tam Mei	46*	90% 50% 10% 3% 1%	11.1 12.8 19.2 26.6 39.5	90% 50% 10% 3% 1%	8.9 9.2 10.2 11.1 12.0

Note:
* The explosives load considered here are identical to the load applied in Worst Case Scenario

9.5.6 *RISK ANALYSIS FOR OPTION CASE 1*

The PLL obtained from implementing this option is estimated to be 1.08 x 10^{-3} per year. This can be compared to the PLL of 1.27 x 10^{-3} per year for Tai Lam magazine.

The safety benefits over the construction period are:

Safety Benefits: HK$ 33M x 20 x 1.90 x 10^{-4} x 3 = HK$ 0.38M

The cost of this installation is higher than the safety benefits achieved over the construction period and therefore this option is not justifiable.

9.6 *OPTION CASE 2 - ALTERNATIVE ROUTES FROM SO KWUN WAT*

9.6.1 *POPULATION ALONG THE ALTERNATE TRANSPORT ROUTES*

Details of the alternate routes from So Kwun Wat magazine site are provided in *Table 9.8*. The population estimation methodology along the transport routes is the same as the base case described in *Section 4*. *Table 9.9* provides a comparison of transport distances to each work site between Tuen Mun Highway and Caste Peak Road.

Table 9.8 Alternate Delivery Routes for the So Kwun Wat Magazine Site

Tag	Description
Route 4b (So Kwun Wat M3 - Shek Yam)	
Road 4b1	Siu Lam Magazine site track
Road 4b2	Kwun Fat Street
Road 4b3	Castle Peak Road (Tai Lam)
Road 4b3a	Castle Peak Road (Tsing Lung Tau)
Road 4b3b	Castle Peak Road (Sham Tseng)
Road 4b4	Castle Peak Road (Sham Tseng-Ting Kau-Tsuen Wan)
Road 4b5	Hoi On Road (Castle Peak Rd-Hoi Hing Rd)
Road 4b6	Ho Hing Road (to Hoi Hing Rd RA)
Road 4b7	Tai Chung Road (Tsuen Wan Rd - Castle Peak Rd Tsuen Wan)
Road 4b8	Castle Peak Road - Tsuen Wan (Tai Chung to Tai Ho Rd)
Road 4b9	Castle Peak Road - Tsuen Wan (Tai Ho to Chung On St)
Road 4b10	Castle Peak Road - Tsuen Wan (Chung On St to Texaco Rd)
Road 4b11	Castle Peak Road - Kwai Chung (Texaco Rd)
Road 4b12	Castle Peak Road - Kwai Chung (Ting Kwok St to Kwai Chung Rd RA)
Road 4b13	Cheung Wing Road (Kwai Chung Rd RA - Yau Ma Hom Rd Shek Yam workarea)
Route 4c (So Kwun Wat M3 - Shing Mun)	
Road 4c1	Siu Lam Magazine site track
Road 4c2	Kwun Fat Street
Road 4c3	Castle Peak Road (Tai Lam)
Road 4c3a	Castle Peak Road (Tsing Lung Tau)
Road 4c3b	Castle Peak Road (Sham Tseng)
Road 4c4	Castle Peak Road (Sham Tseng-Ting Kau-Tsuen Wan)
Road 4c5	Hoi On Road (Castle Peak Rd-Hoi Hing Rd)
Road 4c6	Ho Hing Road (Hoi On Rd - Castle Peak Rd-Tsuen Wan)
Road 4c7	Castle Peak Road (Sham Tseng-Ting Kau-Tsuen Wan)
Road 4c8	Castle Peak Road - Tsuen Wan (Sha Tsui Rd - Tsuen King Circuit)
Road 4c9	Castle Peak Road - Tsuen Wan (Tsuen King Circuit - Tai Chung Rd)
Road 4c10	Castle Peak Road - Tsuen Wan (Tai Chung to Tai Ho Rd)
Road 4c11	Castle Peak Road - Tsuen Wan (Tai Ho to Chung On St)
Road 4c12	Castle Peak Road - Tsuen Wan (Chung On St to Texaco Rd)
Road 4c13	Castle Peak Road - Kwai Chung (Texaco Rd)
Road 4c14	Castle Peak Road - Kwai Chung (Ting Kwok St to Kwai Chung Rd RA)
Road 4c15	Cheung Wing Road (Kwai Chung Rd - Wo Yi Hop Rd)
Road 4c16	Wo Yi Hop Road (Cheung Wing Rd - Lei Shu Rd)
Road 4c16a	Wo Yi Hop Road (Lei Shu Rd - Ngong Hom Rd)
Road 4c17	Wo Yi Hop Road (Ngong Hom Rd - Wo Yi Hop Interchange)
Road 4c18	Wo Yi Hop Interchange (Wo Yi Hop Rd - Sam Tung Uk Rd)
Road 4c19	Cheung Shan Estate Road West (Cheung Shan Est Rd E - Wo Yi Hop Rd)
Route 4d (So Kwun Wat M3 - Kwai Chung)	
Road 4d1	Siu Lam Magazine site track
Road 4d2	Kwun Fat Street
Road 4d3	Castle Peak Road (Tai Lam)
Road 4d3a	Castle Peak Road (Tsing Lung Tau)
Road 4d3b	Castle Peak Road (Sham Tseng)
Road 4d4	Castle Peak Road (Sham Tseng-Ting Kau-Tsuen Wan)
Road 4d5	Hoi On Road (Castle Peak Rd-Hoi Hing Rd)
Road 4d6	Ho Hing Road (to Hoi Hing Rd RA)
Road 4d7	Tsuen Wan Road (Hoi Hing Rd Interchange - Texaco Rd RA)
Road 4d8	Tsuen Wan Road (Texaco Rd - Kwai Tsing Rd)
Road 4d9	Hing Fong Road (Kwai Tsing Interchange to Kwai Fuk Rd)
Road 4d10	Hing Fong Road (Kwai Fuk Rd - Kwai Foo Rd)
Road 4d11	Kwai Foo Road (Hing Fong Rd - Kwai Chung Rd)
Road 4d12	Kwai Chung Road (Kwai Foo Rd - Kwai On Rd)
Road 4d13	Kwai On Rd (Kwai Chung Rd - Tai Lin Pai Rd)
Road 4d14	Tai Lin Pai Road (Kwai On Rd to Wing Yip St)
Road 4d15	Wing Yip Street

Tag	Description
Route 4e (So Kwun Wat M3 - Mei Lai Road)	
Road 4e1	Siu Lam Magazine site track
Road 4e2	Kwun Fat Street
Road 4e3	Castle Peak Road (Tai Lam)
Road 4e3a	Castle Peak Road (Tsing Lung Tau)
Road 4e3b	Castle Peak Road (Sham Tseng)
Road 4e4	Castle Peak Road (Sham Tseng-Ting Kau-Tsuen Wan)
Road 4e5	Hoi On Road (Castle Peak Rd-Hoi Hing Rd)
Road 4e6	Ho Hing Road (to Hoi Hing Rd RA)
Road 4e7	Tsuen Wan Road (Hoi Hing Rd Interchange - Texaco Rd RA)
Road 4e8	Tsuen Wan Road (Texaco Rd - Kwai Tsing Rd)
Road 4e9	Tsuen Wan Road (Kwai Tsing Rd - Tsuen Wan Rd section over container port rd)
Road 4e10	Tsuen Wan Road (Tsuen Wan Rd - Kwai Tsing Rd)
Road 4e11	Kwai Chung Road (up to Lai Chi Kok Bridge)
Road 4e12	Kwai Chung Road (Lai Chi Kok Bridge - Cheung Sha Wan Rd)
Road 4e13	Cheung Sha Wan Rd (Cheung Sha Wan Rd - butterfly valley Rd)
Road 4e14	Castle Peak Road (Lai Chi Kok Interchange to Butterfly Valley Interchange)

Table 9.9 Transport Distance to each work site via Tuen Mun Highway and Castle Peak Road

Work site	Transport Distance (km)	
	Via Tuen Mun Road	Via Castle Peak Road (alternative route)
Shek Yam	17.2	17.0
Shing Mun	18.8	18.7
Kwai Chung	17.8	17.6
Mei Lai Road	20.3	20.3

9.6.2 SCENARIOS CONSIDERED

The scenarios considered are identical to the Worst Case Scenario although the route is different.

Table 9.10 Scenarios Considered in Option Case 2 Assessment

Tag	Scenario	Explosives load (TNT eqv. kg)
Storage of Explosives		
01	Detonation of full load of explosives in one store in So Kwun Wat site	342
02	Detonation of full load of explosives in one contractor truck on the access road within the So Kwun Wat magazine site boundary	148*
Transport of Explosives		
03	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 4b Shek Yam	129*
04	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 4c Shing Mun	28*
05	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 4d Kwai Chung	148*
06	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 4e Mei Lai Road	81*

Note:
* The explosives load considered here are identical to the load applied in the Worst Case Scenario

Table 9.11 Summary of Consequence Results for Option Case 2 Scenarios

No.	Scenario	TNT eqv. kg)	Indoor		Outdoor	
			Fatality Prob.	Impact distance (m)	Fatality Prob.	Impact distance (m)
Storage of Explosives						
01	Detonation of full load of explosives in one store in So Kwun Wat site	342	90%	21.5	90%	17.3
			50%	24.9	50%	17.9
			10%	36.6	10%	19.8
			3%	49.1	3%	21.2
			1%	63.0	1%	22.1
02	Detonation of full load of explosives in one contractor truck on the access road within the So Kwun Wat magazine site boundary	148*	90%	16.3	90%	13.1
			50%	18.9	50%	13.6
			10%	28.3	10%	15.1
			3%	39.2	3%	16.3
			1%	58.1	1%	17.7
Transport of Explosives						
03	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2b Shek Yam	129*	90%	15.6	90%	12.5
			50%	18.1	50%	13.0
			10%	27.1	10%	14.4
			3%	37.5	3%	15.6
			1%	55.6	1%	17.0
04	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2c Shing Mun	28*	90%	9.4	90%	7.5
			50%	10.9	50%	7.9
			10%	16.4	10%	8.7
			3%	22.6	3%	9.4
			1%	33.6	1%	10.2
05	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2d Kwai Chung	148*	90%	16.3	90%	13.1
			50%	18.9	50%	13.6
			10%	28.3	10%	15.1
			3%	39.2	3%	16.3
			1%	58.1	1%	17.7

No.	Scenario	TNT eqv. kg)	Indoor		Outdoor	
			Fatality Prob.	Impact distance (m)	Fatality Prob.	Impact distance (m)
06	Detonation of full load of explosives in one contractor truck on public roads – from So Kwun Wat site to delivery point 2e Mei Lai Road	81*	90% 50% 10% 3% 1%	13.4 15.6 23.2 32.2 47.8	90% 50% 10% 3% 1%	10.7 11.2 12.4 13.4 14.6

Note:
* The explosives load considered here are identical to the load applied in applied in the Worst Case Scenario

9.6.3 *RISK ANALYSIS FOR OPTION CASE 2*

For this option, there is a marginal increase in risk of 6.9×10^{-6} per year. Although the travel distance is marginally less, the population distribution is different and the accident involvement frequency is greater. This explains that there is little difference between this Castle Peak Road option and the Tuen Mun Highway option.

The risk is higher than the Tuen Mun Highway option. Tuen Mun Highway is therefore retained.

9.7 *ALARP ASSESSMENT RESULTS*

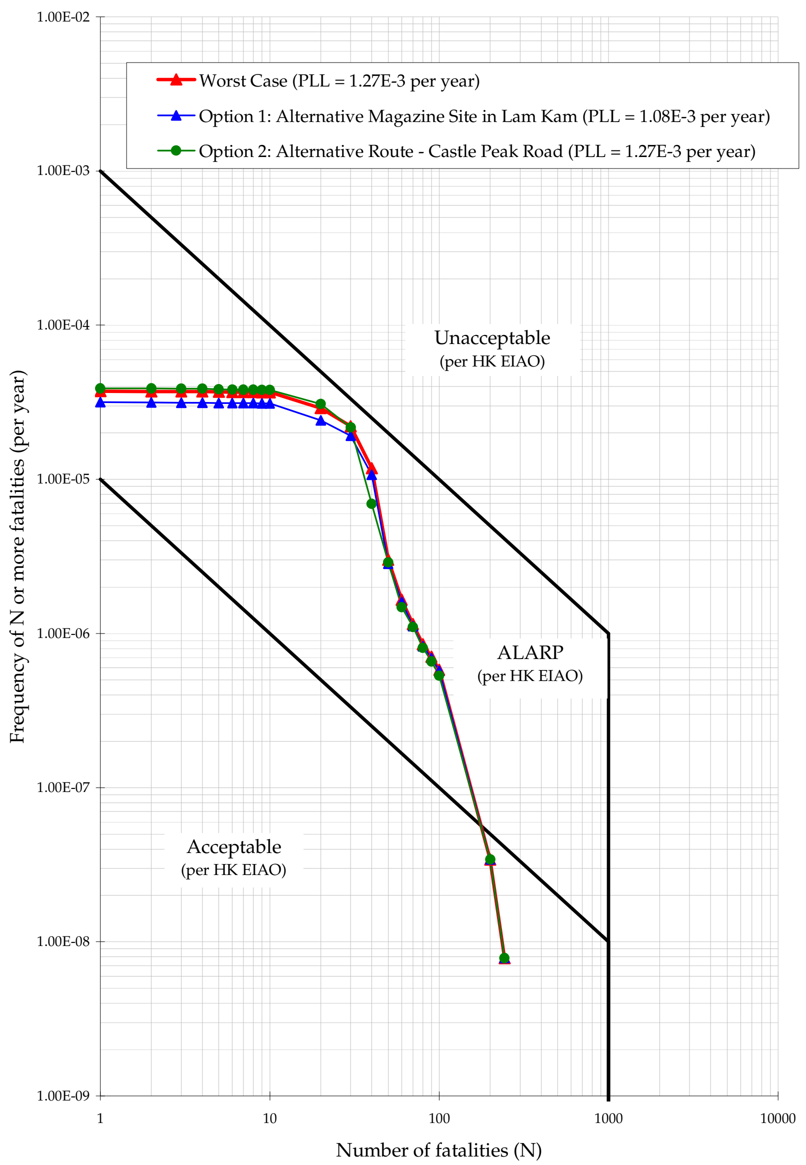
The evaluation of each option considered is summarized in *Table 9.12*. The F-N curves of the two mitigation options are shown in *Figure 9.6*.

Table 9.12 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$ 2.51M	Not Justified
Use of Magazines Closer to the Construction Sites (Lam Kam Road) (Option Case 1)	Practicable	> HK$ 1M	HK$ 380k	Not Justified
Use of Alternative Route (Castle Peak Road) (Option Case 2)	Practicable	< HK$ 10k	Negative	Tuen Mun Highway is the preferred option
Use of different explosive types (different types of detonating cord)	Pose some limitations	HK$ 1M	No safety benefit	Not Justified
Use of smaller quantities of explosives	Not Practicable	HK$ 6M	HK$ 2.51M	Not Justified
Safer explosive truck (reduced fire load)	Practicable	-	-	Based on low implementation costs, this option has been directly incorporated in recommendations
Lower Frequency of Explosive Transport	Not Practicable	-	-	Option considered but ruled out as not practicable. Not Justified
Reduction of Accident Involvement Frequency (training programme etc.)	Practicable	-	-	Based on low implementation costs, this option has been directly incorporated in recommendations

Option Description	Practicability	Implementation Cost	Safety Benefits or Justifiable Expenditure	ALARP Assessment Result
Reduction of Fire Involvement Frequency (better emergency response, extinguisher types etc.)	Practicable	-	-	Based on low implementation costs, this option has been directly incorporated in recommendations

Figure 9.6 F-N Curve for the Two Mitigation Options



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 during construction of the XRL Project.

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 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 be improved to reduce 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 minimized by implementing a dedicated training programme for both the driver and his attendants, including regular briefing sessions, implementation of a defensive driving attitude. In addition, drivers should be selected based on good safety record, 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 magazines.
- Whenever practicable, a minimum headway between two consecutive truck convoys of 10 min is recommended; and
- The explosive truck fire involvement frequency should be minimized by implementing a better emergency response and training to make sure the

adequate fire extinguishers are used and attempt is made to evacuate the area of the incident or securing the explosive load if possible. All explosive vehicles should also be equipped with bigger capacity AFFF-type extinguishers.

10.2.2 *General Recommendations*

Blasting activities including storage and transport of explosives should be supervised and audited by competent site staff to ensure strict compliance with the blasting permit conditions.

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

1. The security plan should address different alert security level 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 plan (ie magazine operational manual) shall be developed to address uncontrolled fire in magazine area and transport. The case of fire near an explosive carrying truck in jammed traffic should also be covered. Drill of the emergency plan should be carried out at regular intervals.
3. Adverse weather working guideline should be developed to clearly define procedure for transport explosives during thunderstorm.

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

10.2.3 *Storage of Explosives in Magazine Store*

The magazine should be designed, 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 introduced, 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.

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 explosive 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. During transport of the explosives within the tunnel, hot work or other activities should not be permitted in the vicinity of the explosives offloading or charging activities.
5. Ensure lining is provided within the transportation box on the vehicle and in good condition before transportation.
6. Ensure that packaging of detonators remains intact until handed over at blasting site.
7. 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.
8. Use only experienced driver(s) with good safety record.
9. Ensure that cartridged emulsion packages are damage free before every trip.

Contractors Licensed 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 150mm behind the drivers cab and 100mm from the steel cargo compartment, the vertical screen shall protrude 150mm 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 brand new, dedicated explosive transport vehicles and should be maintained in good operating condition;
- Daily checks on tyres 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 Explosive Vehicles:

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 License 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 is assessed as fit to drive explosives vehicles;
- 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 recognized 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;
- has attended 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 aboard 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 Explosive 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
  - 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;

- 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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