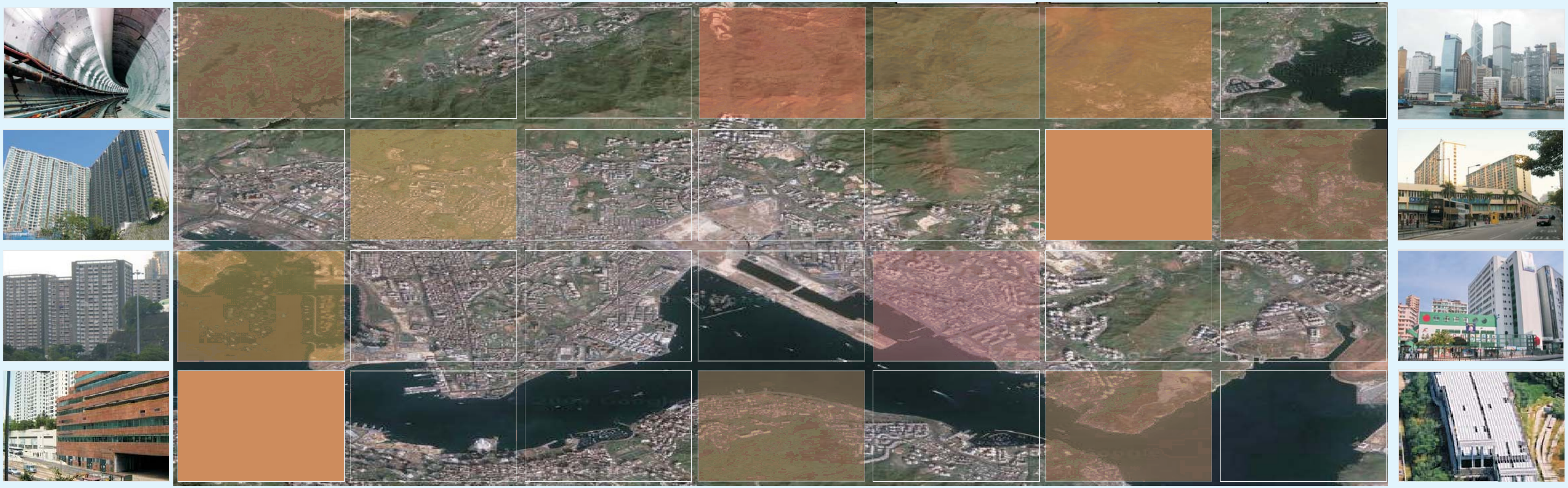
MTR 港鐵

Consultancy Agreement No. NEX/1042

Environmental Impact Assessment of Shatin to Central Link – Tai Wai to Hung Hom Section



Hazard to Life Assessment Final Report - Appendices 13 A - C

ERM

September 2011

FINAL REPORT

MTR Corporation Limited (MTRC)

Environmental Impact Assessment of Shatin to Central Link – Tai Wai to Hung Hom Section:

Hazard to Life Assessment FinalReport – Appendices 13 A - C Consultancy Agreement No. NEX/1042

September 2011

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Reference 0100476/0140543

For and on behalf of ERM-Hong Kong, Limited	
Approved by:	Venkatesh S.
Signed:	
Position:	Director
Date:	30 September 2011

Appendix 13 A

Storage and Transport of Explosives

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1 INTRODUCTION

1.1 BACKGROUND

The MTR Corporation Limited (MTR) is undertaking the design of the Shatin to Central Link (SCL), which when complete will form a strategic rail corridor comprising of two sections:

(i) The Tai Wai to Hung Hom Section: an 11 km extension of the Ma On Shan Line from Tai Wai Station, through Hin Keng, Diamond Hill, Kai Tak, To Kwa Wan, Ma Tau Wai, Ho Man Tin to Hung Hom. The link will connect to the West Rail Line at Hung Hom Station to form the East-West Corridor. This section will be referred to as SCL (TAW-HUH).

(ii) The Cross Harbour Section: a 6 km extension from the Hung Hom Station of the East Rail Line, will continue across the harbour to Admiralty, including a new station at Exhibition, to form the North-South Corridor. This section will be referred to as SCL (HUH-ADM).

This study report will consider the SCL (TAW-HUH) Section.

Construction is expected to commence in 2012. Major civil works will be completed by 2016, and all works will be completed by 2018. The envisaged method of excavation of the majority of the running tunnels is intended at the Preliminary Design Stage to be predominantly "Cut and Cover" however "Drill and Blast" will be used where tunnels have to be excavated in rock. Excavation by blasting will be generally ongoing from October 2013 until March 2015.

To enable a timely delivery of explosives to site and in order to meet the proposed construction work programme, an Overnight Explosives Storage Magazine (Magazine) is required. The purpose of the temporary Magazine is to maintain progress rates for construction activities, i.e. to meet multiple blasts per day and also act as a buffer in case of delivery interruptions by Mines Division (Mines Division) of the Geotechnical Engineering Office (GEO), Civil Engineering and Development Department (CEDD). Mines Division will deliver explosives and initiation devices (detonators) to the temporary Magazine by the shortest practicable route. This will be done on a daily basis and explosives and detonators will be withdrawn by the contractors as required. The transportation of explosives by Mines Division either to the temporary Magazine or directly to sites is under Mines Division's responsibility and falls outside the scope of this Environmental Impact Assessment (EIA).

The appointed Contractors of MTR will transport explosives, in Mines Division licenced trucks, from the temporary 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 Mines Division to a maximum of 200kg.

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

One temporary magazine for explosives is proposed to support the 3 delivery points namely Ma Chai Hang (MCH) Ventilation Building, Shansi Street Shaft and Hin Keng Portal. The temporary Magazine capacity is designed to support 2 blasts per day and be generally sufficient for 2 days blasting consumption.

ERM-Hong Kong Limited (ERM) was commissioned by MTR to undertake the Hazard to Life Assessment (also referred as Quantitative Risk Assessment (QRA)) for the storage, transport and use of explosives during the Project 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).

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-191/2008 for this project (EIA Study Brief). *Section 3.4.5* of the EIA Study Brief specifies that a Hazard to Life Assessment should be conducted for the Project. The relevant EIA Study Brief requirements for this study are quoted in *Table 1.1*.

Table 1.1 EIA Study Brief – Hazard to Life Requirements

3.4.5	**Hazard to Life**
3.4.5.1	The Applicant shall follow the criteria for evaluating hazard to life as stated in Annex 4 of the TM.
	<u>Explosives</u>
3.4.5.2	The Applicant shall investigate alternative construction method to avoid the use of explosives. If the Project will involve the use of explosives, the Applicant shall describe the statutory/licencing 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.

3.4.5.3 If there is use of explosives for the construction activities and the storage or blasting location is in close vicinity to populated areas, Potentially Hazardous Installation site(s) (e.g. Sha Tin Water Treatment Works and Ma Tau Kok Gas Production Plant and associated facilities) and town gas installations along the Project alignment such as the Beacon Hill North Offtake Station and underground town gas pipes, the Applicant shall carry out hazard assessment as follows:

(i) Identify hazardous scenarios associated with the storage, transport and use of explosives; and possible damage scenarios to the gas installations leading to catastrophic and non-catastrophic failures of the gasholder causing gas release; 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

3.4.5.3 (iv) Identify and assess practicable and cost-effective mitigation measures for reducing individual and societal risks. (e.g. selection of the shortest practicable road transport routes to and from the storage facility, reducing possibility of undue movement, differential settlement, ground instability, distortion, fracture, dislocation, damage and destruction to the town gas facilities.)

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

<u>Potentially Hazardous Installation (Sha Tin Water Treatment Works)</u>

3.4.5.4 The Applicant shall carry out hazard assessment to evaluate potential hazard to life during construction and operation stages of the Project due to Sha Tin Water Treatment Works.

The hazard assessment shall include the following :

(i) Identify hazardous scenarios associated with the on-site transport, storage and use of chlorine at Sha Tin Water Treatment Works 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 (e.g. "Reassessment of Chlorine Hazard for Eight Existing Water Treatment Works" commissioned by Water Supplies Department).

<u>Potentially Hazardous Installation (Ma Tau Kok Gas Production Plant and its associated gas facilities)</u>

3.4.5.5 The Applicant shall carry out hazard assessment to evaluate potential hazard to life during construction and operation stages of the Project due to operation of the Ma Tau Kok Gas Production Plant and its associated gas facilities. The hazard assessment shall include the following:

(i) Identify hazardous scenarios associated with the Ma Tau Kok Gas Production Plant and its associated gas facilities 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.

This Appendix, 13A, addresses the EIA Study Brief requirements (*Sections 3.4.5.1* to *3.4.5.5*) dealing with hazards to life posed by the storage and transport of explosives as part of this project. Appendix 13B addresses the requirements dealing with the "use" of explosives and Appendix 13C addresses the requirements dealing with the Shatin Water Treatment Works PHI assessment.

With reference to the study brief clause 3.4.5.5, there is no storage, transport or use of explosives within the consultation zone of the Ma Tau Kok Gas Production Plant PHI. Based on this, the PHI assessment is not considered applicable for this hazard to life assessment.

This section of the EIA presents:

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

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

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

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

- Storage of explosives at the proposed temporary Magazine (cartridged emulsion, detonating cord and detonators) including handling of explosives within the temporary 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 temporary Magazine to the construction sites.

Detonators are used in relatively small quantities and transported separately. Bulk emulsion 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 (i.e. Category 1 Dangerous Good) in Hong Kong (it is classified as Category 7 Dangerous Good, i.e. a strong supporter of combustion) until sensitised within the blast holes at the excavation face, and hence is out of the scope of this study.

To be consistent with previous projects (West Island Line Project (ERM 2008) and Express Rail Link Project (ERM 2009)), the risks associated with transport of explosives are limited to the delivery by Contractor trucks up to the blasting sites' boundaries and exclude the transport from the delivery point to the blast face. The latter is addressed in Appendix 13B.

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 Project 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.

1.3.1 *EIAO-TM Risk Criteria*

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

Individual Risk (IR)

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

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

Societal risk

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

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

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

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

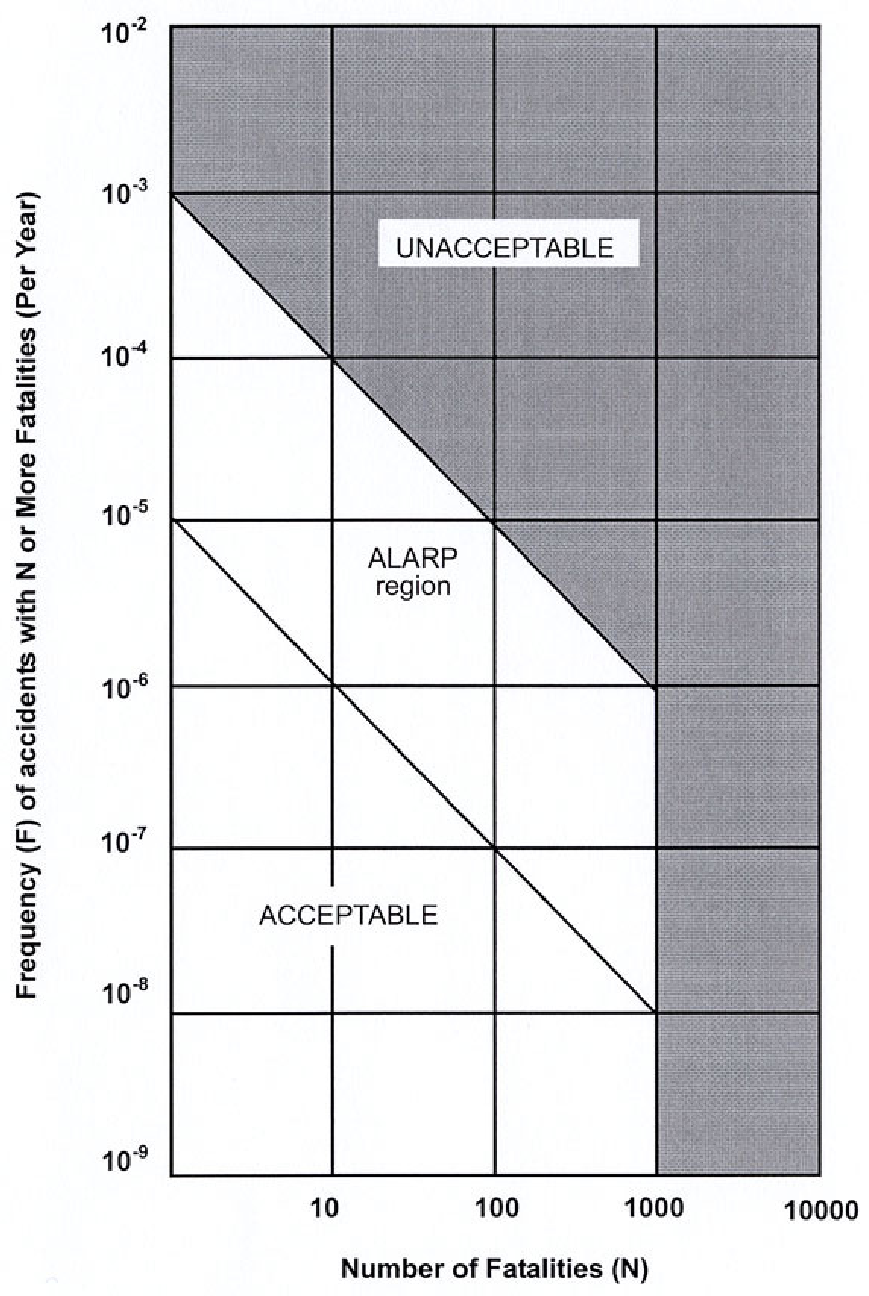
The risk guidelines incorporate a special requirement (as seen in *Figure 1.1*), that no hazardous scenario shall cause more than 1,000 fatalities. If so, the risks are deemed 'unacceptable' and need to be reduced regardless of the cost.

Application of Criteria

Making reference to other studies which involved the transportation of explosives in Hong Kong (ERM 2009, 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. Injuries are not considered in the assessment and similarly, hazards due to operations within the construction site and temporary Magazine operation other than those involving explosives are also not considered.

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

Figure 1.1 *Societal Risk Criteria in Hong Kong*



2 PROJECT DESCRIPTION AND BASIS FOR THE ASSESSMENT

2.1 PROJECT OVERVIEW

The proposed SCL (TAW-HUH) is an extension of the existing Ma On Shan Line connecting Tai Wai and the new Hung Hom station via Hin Keng, Diamond Hill, Kai Tak, To Kwa Wan, Ma Tau Wai and Ho Man Tin. The Shatin to Central Link is classified as a District Line of the MTR network. The designs of the horizontal and vertical alignments are based on Revision A5 of the New Works Design Standard Manual (NWDSM), Section 3: Railway Engineering, as issued in March 2009.

Construction is expected to commence in 2012. Major civil works will be completed by 2016, and all works will be completed by 2018. The Project involves nearly 9km to be constructed in tunnel. The route will encounter a variety of ground conditions, urban and rural environments, and a number of specific constraints in some localised areas. The majority of the tunneling will be by mechanical methods but there will be blasting required in certain sections. The tunnel construction starting from the Hung Hom Station includes:

- Hung Hom to Ho Man Tin: This section of tunnel will connect between the Winslow Garden portal and Ho Man Tin Station. It will be constructed by the cut & cover method.

- Ho Man Tin to Ma Tau Wai: The section of running tunnels between Shansi Street shaft and HOM Station is proposed to be constructed as two single track horse-shoe tunnels. This approximately 480m long section of twin tunnels would be excavated within granite using the drill & blast method.

- Ma Tau Wai to To Kwa Wan: The tunnels will be constructed with twin bored single track Tunnel Boring Machine (TBM) drives to be launched at the southern end of TKW Station and retrieved at the Shansi Street Shaft to the south of MTW Station.

- To Kwa Wan to Kai Tak: The tunnel in this section will be constructed in open cut with battered side slopes.

- Kai Tak Diamond Hill: From Kai Tak Station to Prince Edward Road East approximately 400m of tunnel will be constructed by cut & cover method, including a launching shaft for a TBM to construct the tunnels towards Diamond Hill Station.

- Diamond Hill to Ma Chai Hang Ventilation Building: Excavation here would start with open cut methods, followed by cut and cover and eventually use of a TBM.

- Ma Chai Hang Ventilation Building to Hin Keng Portal: Drill & blast methods to be used, although at certain sections at reduced rates due to vibration restrictions (sensitive receivers).

- Construction works include a number of new stations and modifications to existing stations

It is recognised that, from a risk point of view, blasting is not a desirable construction method; however, due to the impracticalities with using other techniques, blasting is required for certain sections of the alignment.

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. However, a significant amount of explosives will be required for the construction of tunnels and adits. It is envisaged that the following items of works for SCL (TAW-HUH) will involve blasting:

- Twin (two) single track tunnels from Shansi Street Shaft to Ho Man Tin station; and

- A twin track tunnel between Ma Chai Hang Ventilation Building and Hin Keng Portal.

Excavation by blasting will be generally ongoing from October 2013 until March 2015.

Drill and Blast Excavation

The excavation works requiring the use of the Drill and Blast Construction Method are summarised below (MTR 2):

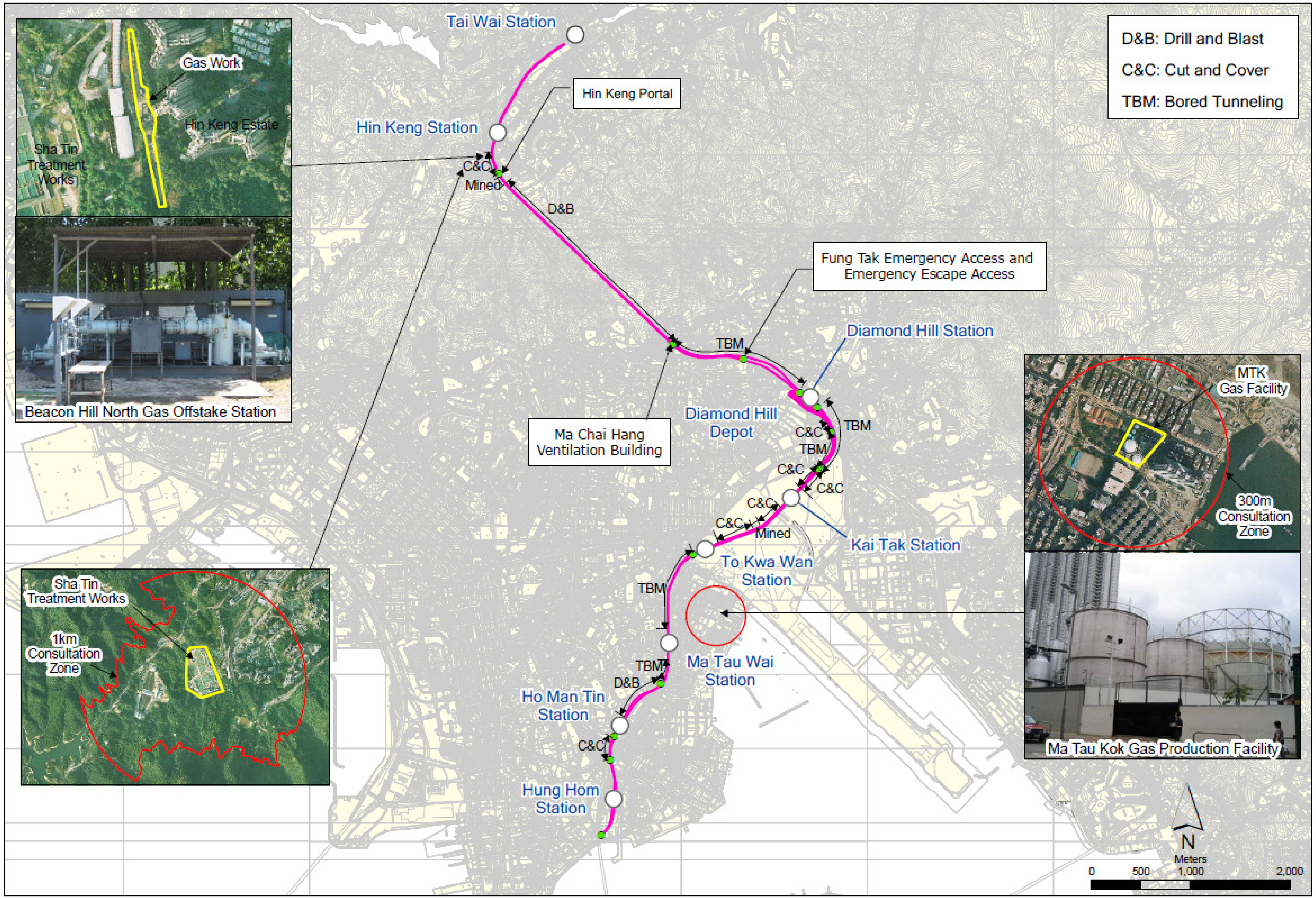
- Ma Chai Hang Ventilation Building to Hin Keng Portal: approximately 2450 m long twin track tunnel; and

- Shansi Street shaft to Ho Man Tin station: approximately 480 m long twin (two) single track tunnels.

The shafts themselves will be mechanically excavated.

The alignment can be seen in Figure 2.1:

Figure 2.1 SCL (TAW-HUH) Proposed Alignment



Two work contracts are envisaged for the construction of the SCL (TAW-HUH) (one for Ho Man Tin Tunnels and one for Lion Rock Tunnel). Drill and Blast method will be used for rock blasting activities for a number of tunnel and adit sections. The explosives required for the three work areas are envisaged to be delivered from one temporary magazine site. The work areas are shown in *Table 2.1* below. The quantities (kg) of explosives mentioned in the report are represented in gross weight, unless they are clearly specified as TNT eqv. kg.

Table 2.1 ***SCL (TAW-HUH) Works Areas Requiring Delivery by Contractor***

Magazine Storage Requirement per contract	Works Area	Blast Faces	Delivery Point
500 kg (250 kg x 2 stores)	Ma Chai Hang (MCH) Ventilation Building	- Twin track tunnel towards Hin Keng (Lion Rock Tunnel)	Ma Chai Hang Road
	Hin Keng Portal	- Twin track tunnel towards Ma Chai Hang (Lion Rock Tunnel)	Hin Keng Estate Access Road
500 kg (250 kg x 2 stores)	Shansi Street Shaft	- Twin (two) single track tunnel drives to Ho Man Tin (Ho Man Tin Tunnels)	Shansi Street

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

To enable a timely delivery of explosives to work sites and in order to meet the proposed construction work programme and allow for a buffer, in the event of delays to replenishment of the temporary magazine, an explosive storage magazine is required. Several temporary magazine locations have been investigated and the most suitable magazine site location has been identified at the Tseung Kwan O (TKO) Area 137. The proposed temporary magazine will have four stores of 250kg. Two stores will be under the control of each of the two Contractors. Detonators will be stored in a separate chamber within each store. Mines Division will deliver explosives and detonators to the temporary Magazine on a daily basis.

The appointed Contractors of MTR will transport explosives in licenced trucks (licenced by Mines Division) to be operated by the Contractors, from the temporary 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 Mines Division to a maximum of 200kg.

The explosives to be stored and transported from the temporary Magazine to the construction sites will include detonators, detonating cord and cartridged emulsion. Detonators will be stored in dedicated chambers and transported separately on dedicated trucks.

A Drill and Blast construction method will be used for a range of tunnel profiles and adits. Bulk emulsion will be used as far as practicable; however, in close proximity to sensitive receivers, Mines Division generally does not recommend the use of bulk emulsion where the Maximum Instant Charge (MIC) envisaged for a particular blast is below 2 kg. This prevents the occurrence of excessive vibrations due to potential bulk emulsion dosing inaccuracy (referring to the WIL QRA for the "use" of explosives (ERM, 2008)). Bulk emulsion is proposed to be used extensively for the twin track tunnel (Lion Rock Tunnel) from Ma Chai Hang Ventilation Building to Hin Keng Portal, and for some sections of the Ho Man Tin Tunnels.

For the tunnels that require blasting, the construction will follow a two blast per day working cycle from Ma Chai Hang Ventilation Building, and one blast per day from Shansi Street Shaft and Hin Keng Portal.

The Ho Man Tin tunnel will require an average full face excavation area of approximately 70 m^2. Each blast would require, on average 40 production holes and 30 perimeter holes. If a pull length of 4.5 m per blast is assumed, then each blast would need approximately: 11 kg of detonating cord with a PETN load density of 40 g/m, 9 kg of cartridged emulsion (assuming the use of 125 g cartridged emulsion), ~ 450 kg bulk emulsion (sensitised on site) and 70 detonators (Non-electric detonators (1 g/detonator) e.g. Nonels).

The Lion Rock tunnel will require an average full face excavation area of approximately 140 m^2. Each blast would require, on average 105 production holes and 55 perimeter holes. If a pull length of 4.5 m per blast is assumed, then each blast would need approximately: 20 kg of detonating cord with a PETN load density of 40 g/m, 30 kg of cartridged emulsion (assuming the use of 125 g cartridged emulsion), ~ 900 kg bulk emulsion (sensitised on site) and 160 detonators (Non-electric detonators (1 g/detonator) e.g. Nonels).

2.2 *EXPLOSIVE TYPES FOR SCL (TAW-HUH)*

2.2.1 *Proposed Explosives*

Two types of explosives will be used for the construction of SCL (TAW-HUH) tunnels by Drill and Blast methods. These are:

- Initiating explosives: cartridged emulsion explosives, detonating cord and detonators; and
- Blasting explosives: site-sensitised bulk emulsion explosives.

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.

Cartridged emulsion will be delivered from the temporary Explosive Magazine to the various construction sites by the appointed Contractor using Mines Division licenced 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 sensitised 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.

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, i.e. initiated by shock tube.

2.2.2 *Explosives Properties and Regulations*

Explosives that are relevant to the SCL (TAW-HUH) 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, Cartridged emulsion in closed proximity to sensitive receivers
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, i.e. 0.96 kg of TNT per 1 kg of emulsion.

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

2.2.4 *Bulk Emulsion Precursor*

Bulk Emulsion has a similar composition to Cartridged Emulsion, except that it does not contain aluminium and is non-sensitised. The bulk emulsion precursor has a density of 1.38-1.40 gms/cc. Prior to sensitising, it is not considered as an explosive and is classified as UN 5.1 oxidising agent and Dangerous Goods Ordinance (Cap. 295) Category 7, i.e. 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 sensitisation. Hazards associated with bulk emulsion precursor are mainly due to its oxidising 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 *Blasting Explosive: Bulk Emulsion*

Bulk emulsion will be used as the main or 'bulk' blasting explosive to excavate rock by rock blasting. It will be manufactured onsite and requires 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 the delivery pump.

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. This is based on our explosives expert consultant's experience. The actual accuracy will however be vendor specific.

For emulsion, a gassing solution is injected into the precursor to reduce the density to 0.8 to 1.1 g/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.

2.2.6 *Detonating devices (detonators, detonating cord)*

Detonators

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

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

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

The delay time of a detonator is controlled by the burning time of a pyrotechnic ignition mixture pressed into a 6.5 mm diameter steel tube, which is the delay element. This element causes the primary explosive, which is typically a small amount of lead azide, to detonate. This in turn, causes the secondary, or output, explosive to detonate, which is usually PETN

(Pentaerythritol Tetranitrate). The quantity of PETN within each detonator is approximately 0.9 g. Each detonator has a delay time that is based upon the length of steel tube and the compaction of the pyrotechnic mixture within it. In designing the blasting of a tunnel face, the general principle is to select the required detonators to ensure that no two blastholes will detonate less than 8 ms apart.

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

Detonating Cord

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

2.3 *STATUTORY/LICENCING REQUIREMENTS AND BEST PRACTICE*

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

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

2.3.1 *Transport of Explosives*

Supply of Detonators and Cartridged Emulsion Explosives

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

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

Approved Explosives for Blasting in Hong Kong

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

Blast Design

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

Blast Loading and Execution

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

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

Application for Removal of Explosives

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

- the removal of safety cartridges for industrial fastening tools not exceeding 5,000 rounds or 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 licenced under the Firearms and Ammunition Ordinance (Cap. 238).

Application for Approval of an Explosives Delivery Vehicle

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

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

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

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

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

(d) The names of the driver and attendant with documentation indicating basic knowledge of safe handling of explosives, fire fighting and emergency procedures. The driver should be over the age of 25 years and hold a current driving licence for the appropriate class of vehicle.

Explosives Delivery Vehicle Design Features and Safety Requirements

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

Condition of Vehicle:

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

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

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

(d) The vehicle shall be licensed to carry the maximum number of persons required for the delivery convoy.

Condition of Cargo Compartment:

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

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

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

(d) The door of the cargo compartment shall be capable of being locked.

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

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

"EMERGENCY ENGINE STOP 緊急死火掣".

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

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

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

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

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

(i) A hand-held lightning detector shall be provided in the vehicle for detection of lightning before and during loading and unloading of explosives.

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

Signage on Vehicle:

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

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

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

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

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

"DANGER – EXPLOSIVES" and "危險 – 爆炸品"

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

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

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

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

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

2.3.2 *Storage and Use of Explosives*

Temporary Explosive Magazine

The temporary Magazine 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" (CEDD 3). Each temporary 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 temporary 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 summarised 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 temporary 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 to be taken for the prevention of accidents 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 storey 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 1 m 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 Blast Sites

Bulk emulsion explosives 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 respect 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 Category 7 Dangerous Goods

Ammonium nitrate (AN) is used for manufacturing bulk emulsion explosives 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 licencee/user must confirm in writing to the Department that he is in fact in receipt of the approved plans and set of FSD requirements.

(j) The actual layout of the installation is to be in accordance with the plans approved by the 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) Lightning rod and earthing connections shall be provided to the store.

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

For an 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 TEMPORARY EXPLOSIVE MAGAZINE*

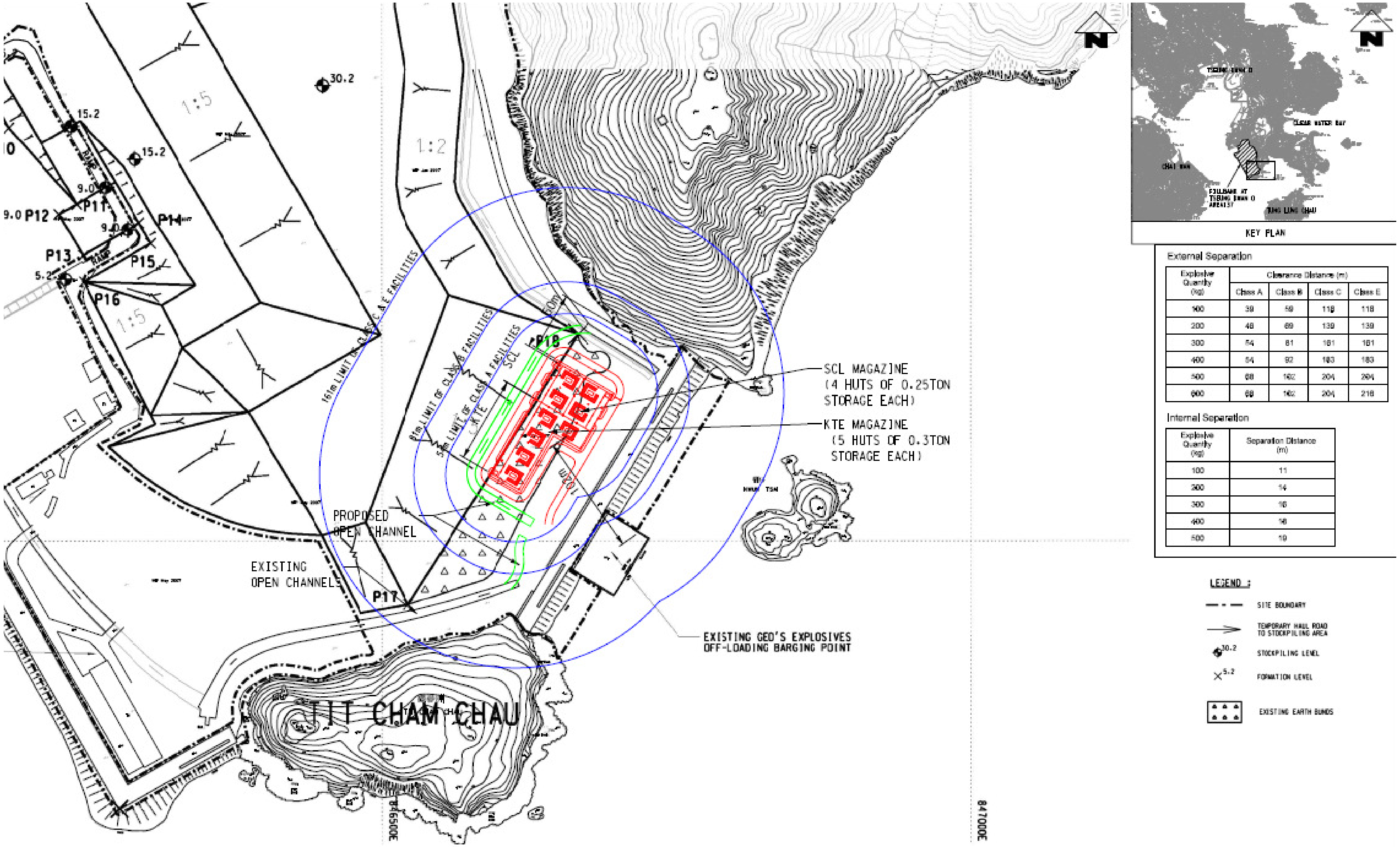
The Magazine is required to serve the delivery points at Ma Chai Hang (MCH) Ventilation Building, Shansi Street Shaft and Hin Keng Portal. Potential magazine site locations in Hong Kong close to the blasting locations have been investigated. Based on SCL/KTE Magazine Site Selection Report (MTR 4), one site has been identified as suitable for locating the Magazine in compliance with the separation requirements of Mines Division. This is Tseung Kwan O (TKO) Area 137.

The temporary magazine is generally designed to store sufficient quantities of explosives for two days so as to allow blasting to be carried out 24 hours per day and provide a buffer in the event of delivery interruption to the Magazine by Mines Division. The storage quantity for each temporary magazine store has been determined with sufficient margin by the design consultant based on estimated project explosives consumption. For the SCL (TAW-HUH) project there are 2 tunnels requiring a temporary magazine site with 4 stores each capable of storing 250kg.

TKO Area 137

This site is in a remote area with no public access nearby. It would be required to supply all blasting sites within the Kowloon area, and by dividing the temporary magazine site into several buildings with adequate internal separation distances, this site can provide sufficient storage capacity. The site is very convenient for the Mines Delivery with a pier nearby for deliveries. It is generally remote from the blasting sites, but due to the location of the delivery points any temporary magazine site would require a certain amount of overland transport to the blasting locations. TKO Area 137 temporary magazine site layout is shown in Figure 2.3.

Figure 2.3 TKO Area 137 Temporary Magazine Site Layout



External Separation

Explosive Quantity (kg)	Clearance Distance (m)			
	Class A	Class B	Class C	Class E
100	39	59	118	118
200	48	69	139	139
300	54	81	161	161
400	54	92	183	183
500	68	102	204	204
600	68	102	204	216

Internal Separation

Explosive Quantity (kg)	Separation Distance (m)
100	11
200	14
300	16
400	18
500	19

2.5 CONSTRUCTION CYCLE AND PROGRAMME OF THE SCL (TAW-HUH) TUNNELS AND ADITS

2.5.1 *Construction Cycle*

After commissioning of the temporary Magazine the proposed delivery-storage-blasting cycle will consist of the following elements:

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

2. Storage in the temporary magazine store(s). Each of the tunnels will have a dedicated store (the two delivery points for Lion Rock Tunnel will share one store, and the delivery point for Ho Man Tin Tunnels will have a dedicated store).

3. Transfer from the explosives store(s) to the delivery points of the construction areas utilizing public roads via routes as indicated in *Figure 2.5* and *Table 2.10*.

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

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

2.5.2 *Drill and Blast Explosive Requirements*

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

Table 2.3 SCL (TAW-HUH) Drill and Blast Explosive Requirements (Summary)

Works Area	Delivery Point	Blast Face	Approximate No of Blasts	Explosive Load (kg/blast)
Ma Chai Hang (MCH) Ventilation Building	MCH Rd	- Twin track tunnel towards Hin Keng (Lion Rock Tunnel)	598	21-162
Shansi Street Shaft	Shansi St	- Single track tunnel drive to Ho Man Tin – Uptrack	284	18-203
		- Single track tunnel drive to Ho Man Tin – Downtrack	267	18-194
Hin Keng Portal	Hin Keng Estate Access Rd	- Twin track tunnel towards Ma Chai Hang (Lion Rock Tunnel)	384	28-321

Table 2.4 SCL (TAW-HUH) Drill and Blast – Typical Tunnel Profiles

Profile Description	Section Area (m^2)	No of production holes	No of perimeter holes	Cartridged Emulsion (kg)	Detonating Cord (kg per metre drilled)	Detonators (kg)
- Twin track tunnel towards Hin Keng – Lion Rock Tunnel (CE)	140	230	55	247.6	0.08	0.26
- Twin track tunnel towards Hin Keng – Lion Rock Tunnel (BE)	140	105	55	29.62	0.08	0.14
- Single track tunnel drive to Ho Man Tin – Uptrack (CE)	70	110	30	123.6	0.08	0.13
- Single track tunnel drive to Ho Man Tin – Uptrack (BE)	70	40	30	14	0.08	0.06
- Single track tunnel drive to Ho Man Tin – Downtrack (CE)	70	110	30	123.6	0.08	0.13
- Single track tunnel drive to Ho Man Tin – Downtrack (BE)	70	40	30	14	0.08	0.06
- Twin track tunnel towards Ma Chai Hang Lion Rock Tunnel (CE)	110	220	50	194	0.08	0.24
- Twin track tunnel towards Ma Chai Hang Lion Rock Tunnel (BE)	110	40	30	14	0.08	0.06

Note 1: The following abbreviations apply: CE - Cartridged Emulsion, BE - Bulk Explosives
Note 2: Typical tunnel profile given for an assumed pull length of 4.5m. For some tunnel sections, this is not achievable due to the proximity of sensitive receivers.
Note 3: 140m^2 is the sectional area for LRT tunnel section with ventilation duct, 110m^2 is for the section without ventilation duct

Table 2.5 SCL (TAW-HUH) Drill and Blast – Initiating Explosive Types

Explosive	Quantity per Production/Perimeter Hole
Cartridged emulsion	0.125 kg (125 g per cartridged emulsion) [1]
Detonating Cord	0.080 kg/m based on density of 0.040 kg/m (40 g/m)
Detonator	0.001 kg (.9 g each)

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

2.5.3 *Explosive Transport Requirements Based on Blasting Programme*

Current Construction Programme

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

- As far as practicable, the explosives (cartridged emulsion and detonating cord) required for all the blast faces of a given work area operated by the same Contractor will be transported on the same explosives delivery truck. Note that detonators are transported on dedicated trucks.
- Due to potential progress issues during the construction stage, arising from programme delay or change, it may not be possible to adhere strictly to the envisaged construction programme. This will result in blasts carried out at a different time for the various faces and separate deliveries.
- Loads will be limited to a maximum of 200 kg per truck in accordance with the Removal Permit issued by Mines Division.
- The quantity of Category 1 explosives on the roads has been minimised by using bulk emulsion, which will be manufactured on-site. The on-site manufacture of bulk emulsion will require the transportation of Cat. 7 Oxidising Substances which falls outside the scope of this study.
- It has been assumed in this report that the project will mostly require a separate explosives delivery from the temporary 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 site specific conditions (e.g. geology). To consider the uncertainty in the envisaged construction programme, a Base Case, which accounts for expected programme variations, and a Worst Case, which represents the worst programme scenario, have been considered for the assessment.

Base Case for the Hazard to Life Assessment

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 December 2013 and November 2014, as shown in *Table 2.7*. This period is referred to the peak explosive delivery period which is taken to represent the Base Case scenario

for the Hazard to Life Assessment. Within this period, the annual number of deliveries is 1,127 while the explosive trucks travel distance is around 28,000km. The delivery frequency has been estimated on the basis that, for a given delivery point, each delivery will be made to each blast face (or for a twin-track tunnel each two blast faces in the same direction) independently of the other blast faces even if the load could be transported on the same truck. This approach, although slightly conservative, accounts for envisaged delivery variations during the peak delivery period, within which, separate deliveries will be generally undertaken. The total number of trips has been estimated based on the typical licencing limit of 200 kg explosives per truck.

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

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

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

Table 2.6 Travel Distance from TKO Temporary Magazine Site to Each Delivery Point

Delivery Points	MCH Ventilation Building	Shansi St Shaft	Hin Keng Portal
Travel distance (km) from temporary Magazine Site to Delivery Point	20.71	21.55	31.42

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

12-Month Delivery Period	Total Explosive Delivery Trips within the 12-Month Period			Total No. of trips	Total Distance Travelled (km)
	MCH	Shansi St	Hin Keng		
Oct 2013 - Sep 2014	413	374	232	1019	23,902
Nov 2013 - Oct 2014	465	358	252	1075	25,263
Dec 2013 – Nov 2014 (1)	513	334	280	1127	26,620
Jan 2014 – Dec 2014	562	292	266	1120	26,289
Feb 2014 – Jan 2015	572	232	239	1043	24,355
Mar 2014 – Feb 2015	598	184	215	997	23,105
Apr 2014 – Mar 2015	554	132	189	875	20,256

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)**
MCH Ventilation Building	162
Shansi St Shaft	200
Hin Keng Portal	200

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.

Since, the maximum permissible explosive load that can be transported is 200kg (licencing limit) for Shansi Street Shaft and Hin Keng Portal, any additional quantities may result in additional trips. This additional number of trips is addressed by the 20% increase in deliveries described above.

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). Therefore 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 bearing in mind the licencing limit of 200kg for the truck. In the Worst Case Scenario, explosives could also 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)**	**Length of Period Considered**
MCH Ventilation Building	162	12 months
Shansi St Shaft	200	12 months
Hin Keng Portal	200	12 months

2.6 TRANSPORT OF BLASTING EXPLOSIVES AND INITIATION SYSTEMS

2.6.1 *Overview*

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

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

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

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

Mines Division allows any unused explosives or detonators from a blast to be returned to their temporary 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 temporary magazine.

2.6.2 *Transport Strategy*

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

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

No more than one truck convoy loaded with explosives (made up of the truck carrying the cartridged emulsion and the detonating cord and the truck carrying the detonators) is generally expected within the temporary 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 temporary magazine to the designated access shafts / blasting sites by the contractors' licenced delivery vehicles under the escort of armed security guards.

To minimise the transport risk, the following principles have been observed in planning delivery routes between the temporary 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 Category 1 Explosives on the roads has been minimised by using bulk emulsion wherever possible, which will be manufactured on-site. The manufacture of bulk emulsion will require the transportation of Category 7 Oxidizing Substances, which fall outside the scope of this study.

2.6.4 *Safety Features of Transport Vehicles*

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

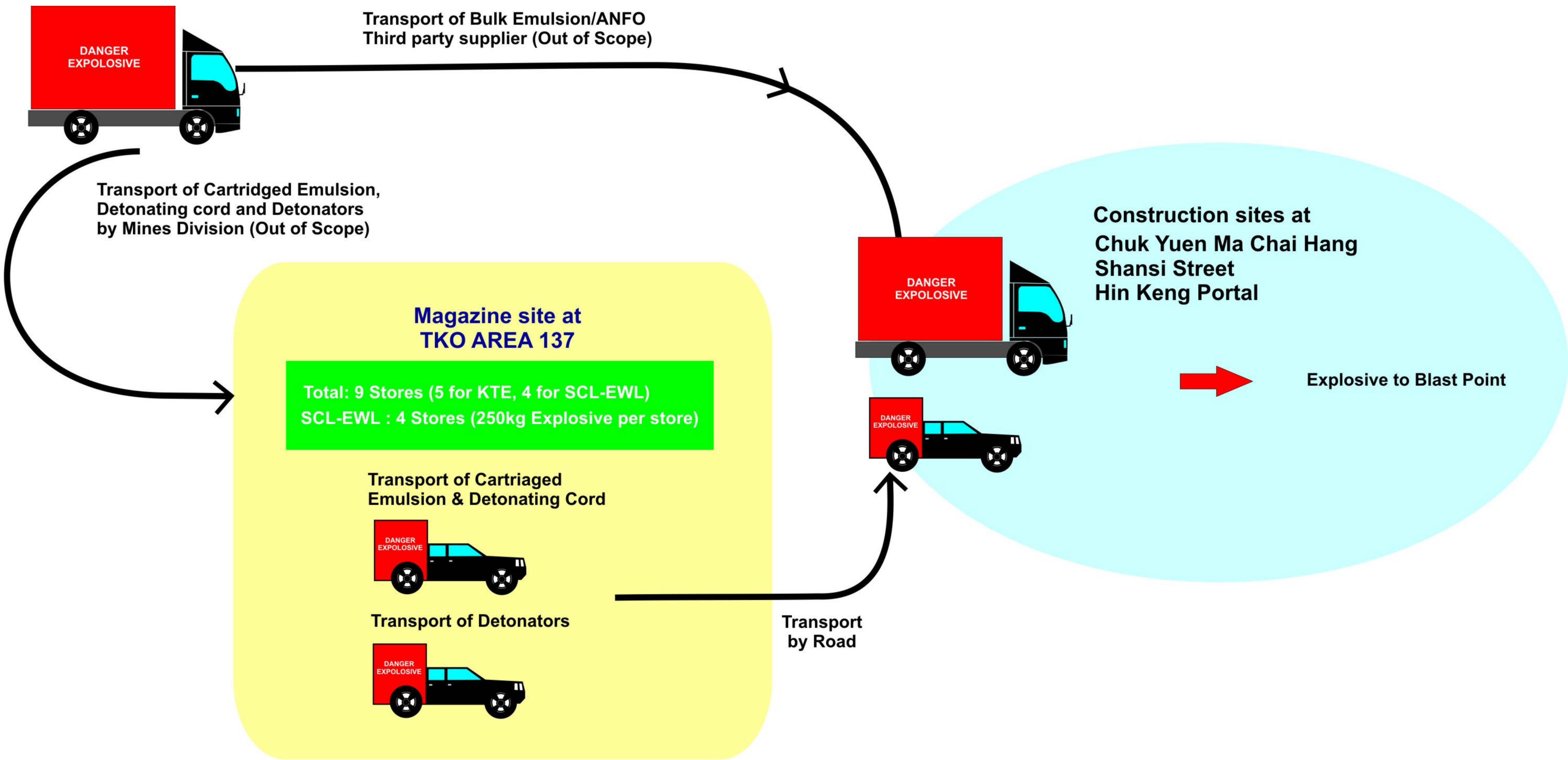
The proposed contractors' explosives delivery vehicle design, used as the basis for the QRA, will have the following safety features:

- Diesel powered;
- Driver's cabin is separated by a distance of not less than 150mm from the cargo compartment of the vehicle;
- Manual fuel isolation switch;
- The exhaust system is located as far from the cargo compartment as possible. The modification of the exhaust system will be approved by the Transport Department;
- All electrical wiring and fittings will be shrouded in fire resisting conduits;
- Fuel tank will be protected from accidental damage, and designed to prevent accumulation of spilt fuel on any part of the vehicle;
- The required number of fire extinguishers shall be agreed with Mines Division;
- Fire resistant material shall be fitted between the wheel arches and the goods compartment;

- Hand-held lightning detector provided in the vehicle for lightning detection during loading and unloading of explosives;
- Lockable wood lined steel or aluminium receptacles mounted on the vehicle tray; and
- Fold down/ up explosives warning signs and red strobe beacons.

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

Figure 2.4 Transport Strategy for the Explosives



2.6.5 *Details of Explosive Delivery Routes*

The Explosives will be delivered from the temporary Magazine to the three work areas using the public roads as shown in *Figure 2.5*.

To ensure that the transport risk has been minimised, the shortest delivery routes from the TKO Area 137 temporary magazine have been selected.

The explosive delivery routes from the temporary magazine to the work sites (Ma Chai Hang Ventilation Building, Shansi Street Shaft and Hin Keng Portal) will involve transportation on roads passing through mainly residential areas and commercial districts which can occasionally be crowded.

Following the current work programme, the three work sites are expected to be in operation simultaneously during the 18 months period from October 2013 to March 2015.

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

The explosive delivery routes are listed in *Table 2.10.*

Figure 2.5 SCL (TAW-HUH) Temporary Magazine Location and Explosives Transport Routes

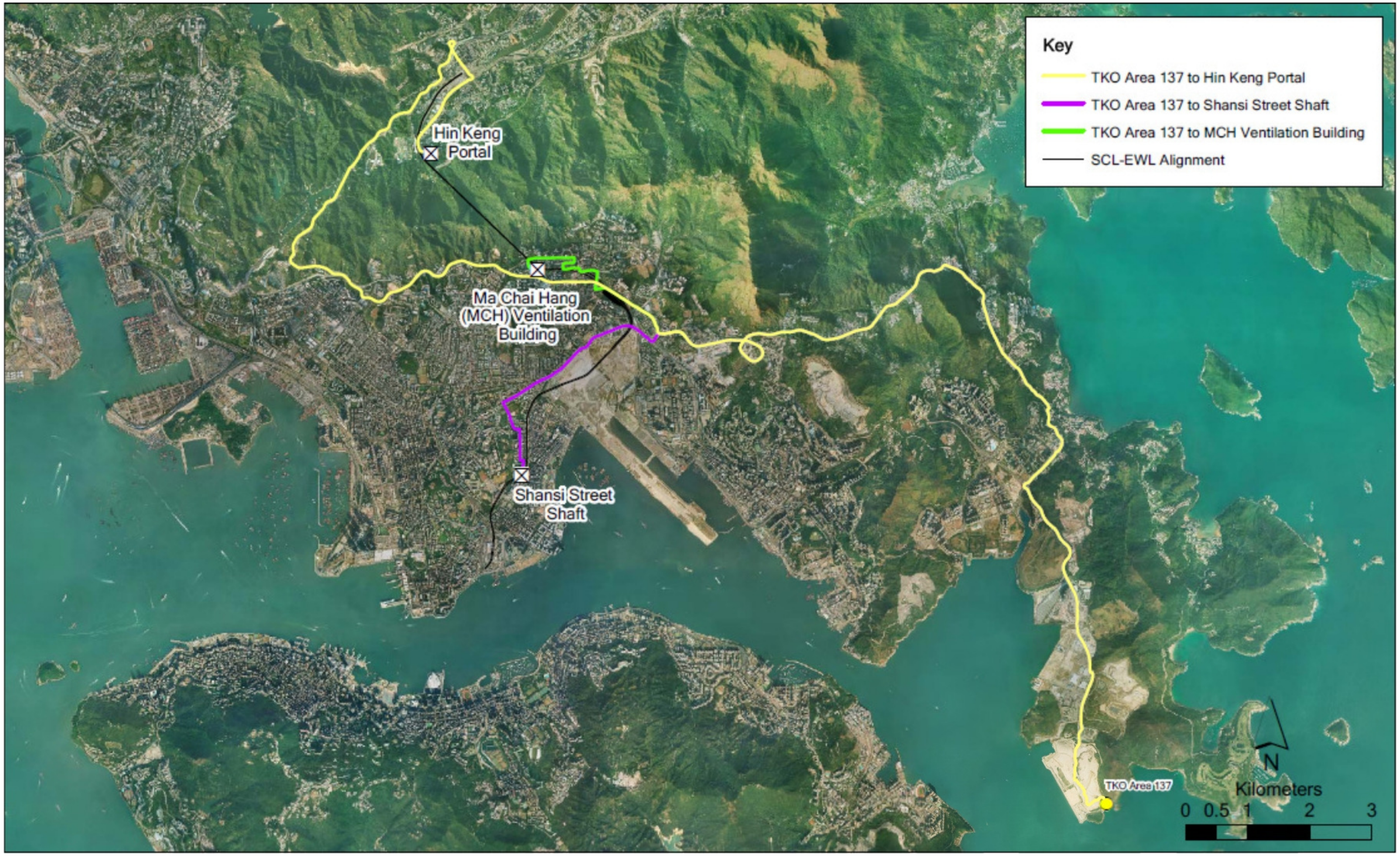


Table 2.10 Delivery Routes from TKO Area 137 Magazine

Section ID	Description
Route 1d (TKO Area 137 – Ma Chai Hang (MCH) Ventilation Building)	
Road 1d1	TKO Area 137 Magazine Site Track
Road 1d2	Wan Po Road (Chun Yat St- Chiu Shun Rd)
Road 1d3a	Chiu Shun Road (Wan Po Rd - Ngan O Rd)
Road 1d3b	Chiu Shun Road (Ngan O Rd - Po Ning Rd)
Road 1d4	Hang Hau Road
Road 1d5	Clear Water Bay Road (Hang Hau - Hiram's Highway)
Road 1d6a	Clear Water Bay Road (Hiram's Highway - Anderson Road)
Road 1d6b	Clear Water Bay Road (Anderson Road - New Clear Water Bay Rd Eastern Junction)
Road 1d7	New Clear Water Bay Road (Eastern Junction - Shun Lee Street)
Road 1d8	New Clear Water Bay Road (Shun Lee Street - Western Junction)
Road 1d9	Clear Water Bay Road (New Clear Water Bay Rd Western Junction - Lung Cheung Rd)
Road 1d10a	Lung Cheung Rd (Clear Water Bay Rd - Wong Kuk Ave)
Road 1d10b	Lung Cheung Rd (Wong Kuk Ave - Hammer Hill Rd)
Road 1d10c	Lung Cheung Rd (Hammer Hill Rd - Po Kong Village Rd)
Road 1d11	Po Kong Village Rd (Lung Cheung Rd - Fung Tak Rd)
Road 1d12	Fung Tak Rd (Po Kong Village Rd - Sheung Fung St)
Road 1d13	Wong Tai Sin Rd + Fung Tak Rd (Sheung Fung St - Ma Chai Hang Rd)
Road 1d14	Nga Chuk St
Road 1d15	Chuk Yuen Rd (Nga Chuk St - Ma Chai Hang Rd)
Road 1d16	Ma Chai Hang Rd (Chuk Yuen St - Ma Chai Hang Rd Ra)
Route 1e (TKO Area 137 – Shansi St Shaft)	
Road 1e1	TKO Area 137 Magazine Site Track
Road 1e2	Wan Po Road (Chun Yat St- Chiu Shun Rd)
Road 1e3a	Chiu Shun Road (Wan Po Rd - Ngan O Rd)
Road 1e3b	Chiu Shun Road (Ngan O Rd - Po Ning Rd)
Road 1e4	Hang Hau Road
Road 1e5	Clear Water Bay Road (Hang Hau - Hiram's Highway)
Road 1e6a	Clear Water Bay Road (Hiram's Hw - Anderson Road)
Road 1e6b	Clear Water Bay Road (Anderson Road-New Clear Water Bay Rd East Junct)
Road 1e7	New Clear Water Bay Road (Eastern Junction - Shun Lee Street)
Road 1e8	New Clear Water Bay Road (Shun Lee Street - Western Junction)
Road 1e9	Clear Water Bay Road (Western Junction - Lung Cheung Rd)
Road 1e10	Clear Water Bay Road (Lung Cheung Rd - Kwun Tong Rd)
Road 1e11a	Prince Edward Road INT (Kwun Tong Rd - Kwun Tong Bypass)
Road 1e11b	Prince Edward Road INT (Kwun Tong Bypass - Prince Edward Rd)
Road 1e11c	Prince Edward Road INT (Prince Edward Rd East - Choi Hung Rd)
Road 1e11d	Prince Edward Road East (Choi Hung Rd - The Nullah)
Road 1e11e	Prince Edward Road East & FO (The Nullah-Prince Edward Rd W)-1st Section
Road 1e11f	Prince Edward Road East & FO (The Nullah-Prince Edward Rd W)-2nd Section
Road 1e12a	Argyle Street (Prince Edward Road W - Kowloon City INT)
Road 1e12b	Argyle Street (Kowloon City INT - Fu Ning St)
Road 1e12c	Argyle Street (Fu Ning St - Lomond Rd)
Road 1e12d	Argyle Street (Lomond Rd - Tin Kwong Rd)
Road 1e13	Tin Kwong Rd (Argyle St - Sheung Shing St)
Road 1e14	Kau Pui Lung Rd
Road 1e15a	Chi Kiang St
Road 1e16	Ko Shan Rd (Chi Kiang St - Pak Kung St)
Road 1e17	Shansi St

Section ID	Description
Route 1v (TKO Area 137 – Hin Keng Portal)	
Road 1v1	TKO Area 137 Magazine Site Track
Road 1v2	Wan Po Road (Chun Yat St- Chiu Shun Rd)
Road 1v3a	Chiu Shun Road (Wan Po Rd - Ngan O Rd)
Road 1v3b	Chiu Shun Road (Ngan O Rd - Po Ning Rd)
Road 1v4	Hang Hau Road
Road 1v5	Clear Water Bay Road (Hang Hau - Hiram's Highway)
Road 1v6a	Clear Water Bay Road (Hiram's Highway - Anderson Road)
Road 1v6b	Clear Water Bay Road (Anderson Road - New Clear Water Bay Rd Eastern Junction)
Road 1v7	New Clear Water Bay Road (Eastern Junction - Shun Lee Street)
Road 1v8	New Clear Water Bay Road (Shun Lee Street - Western Junction)
Road 1v9	Clear Water Bay Road (New Clear Water Bay Rd Western Junction - Lung Cheung Rd)
Road 1v10a	Lung Cheung Rd (Clear Water Bay Rd - Wong Kuk Ave)
Road 1v10b	Lung Cheung Rd (Wong Kuk Ave - Hammer Hill Rd)
Road 1v10c	Lung Cheung Rd (Hammer Hill Rd - Po Kong Village Rd)
Road 1v11a	Lung Cheung Rd (Po Kong Village Rd - Fung Mo St)
Road 1v11b	Lung Cheung Rd (Fung Mo St - Waterloo Rd)
Road 1v11c	Lung Cheung Rd (Lion Rock Tunnel Rd - Nam Cheong St)
Road 1v11d	Lung Cheung Rd / Cornwall St (Nam Cheong St - Tai Po Rd)
Road 1v12a	Tai Po Rd (Lung Cheung Rd - Tai Po Rd Int)
Road 1v12b	Tai Po Rd (Tai Po Rd Int - Caldecott Rd)
Road 1v12c	Tai Po Rd - Shatin Heights (Caldecott Rd - Keng Hau Rd)
Road 1v12d	Tai Po Rd - Shatin Heights (Keng Hau Rd - Shing Ho Rd)
Road 1v13a	Mei Tin Rd (Tai Po Rd (Tai Wai) - Tsuen Nam Rd)
Road 1v13b	Mei Tin Rd (Tsuen Nam Rd - Che Kung Miu Rd)
Road 1v14a	Che Kung Miu Rd (Mei Tin Rd - Tin Sam St)
Road 1v14b	Che Kung Miu Rd (Tin Sam St – Hin Keng St)
Road 1v15	Hin Keng Estate Access Rd

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

The following preliminary design documentation for SCL (TAW-HUH) forms the basis of this assessment:

- SCL Tai Wai to Hung Hom Section Preliminary Design Draft Final Report (MTR 1);
- SCL - Tai Wai to Hung Hom Section: WP GE09 Blasting Assessment Report Rev C (MTR 2);
- SCL - Tai Wai to Hung Hom Section: WP GE05 Ground Movement and Site Impact Assessment Report (MTR 3)
- SCL / KTE temporary Magazine Site Selection Report (MTR 4);
- Preliminary Boulder Assessment on the Natural Hillside above the Proposed Temporary Explosive Magazine at TKO Area 137 (MTR 5)
- Blasting schedule: 090615 TAW-HUH Chargeweight calc Rev 2a 125g booster.xls provided on 18 June 2009

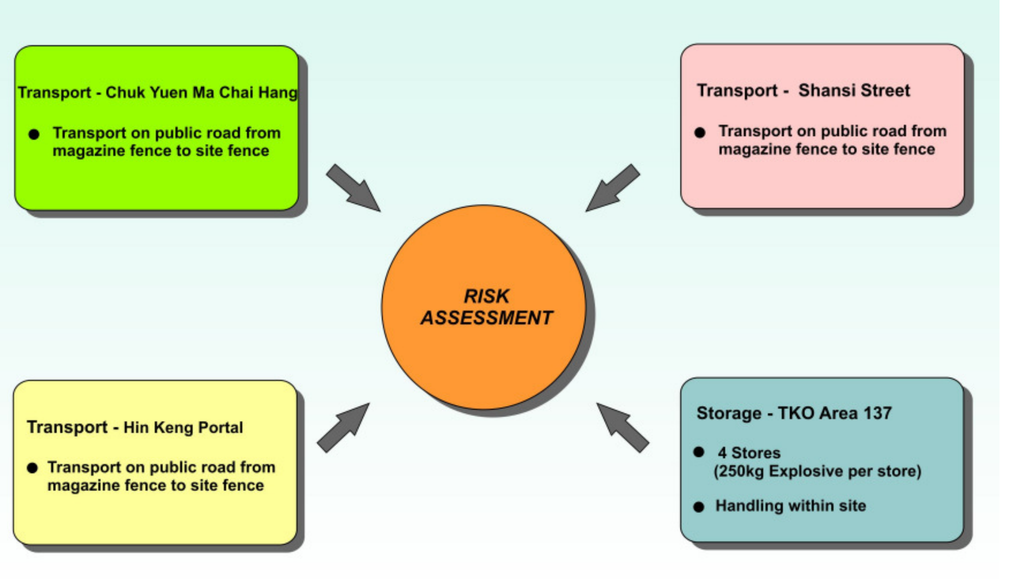
- Shatin to Central Link – Tai Wai to Hung Hong Section: Supplementary Report on Blasting Assessment for QRA (MTR 6)

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 SCL (TAW-HUH) construction (see *Figure 3.1*).

Figure 3.1 Components of the Risk Assessment



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

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

- Collection and review of relevant data for the proposed temporary Magazine, the transport from the temporary Magazine, 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 SCL (TAW-HUH) project and to reflect the current knowledge on the explosives' properties, these frequencies were modified or updated making reference, as far as possible

to published references; such as the previous Hong Kong studies, UK HSE, US DoD, Dutch TNO (TNO Purple Book), latest accident statistics from the Transport Department and Fire Services Department, etc.;

- For all identified hazards, the frequency assessment has been documented and the consequences of the event were modelled;
- The consequence model employed in this study is the ESTC model (ESTC, 2000) developed by the UK Health and Safety Commission (HSC). Although, there have been a number of recent studies suggesting that the ESTC (2000) models should be reviewed for applicability to explosive stores and transport, these models are still the recommended models in the UK and have been adopted in previous Hong Kong EIAs;
- The same frequency model was adopted in this study as that of ERM (2009) study, which has been derived to reflect the current Transport Department statistics, Fire Services Department statistics, specific design features applicable for the SCL (TAW-HUH) project and current knowledge of explosives;
- The consequence and frequency data were subsequently combined using ERM's in-house Explosive Transport GIS Risk Assessment tool (E-TRA), which has been developed to account for three-dimensional blast effects on buildings and the effect of accidental explosions on elevated roads. It also accounts for traffic jam scenarios which could occur in some accidental scenarios as reported in the DNV (1997) study. The model is summarised in the next section and has been validated against ERM in-house proprietary software Riskplot ™. This risk assessment tool has been employed in the ERM (2009) study; and
- Finally, the results from the risk assessment were compared to the EIAO-TM Criteria. Recommendations have been made where required to ensure compliance with EIAO-TM Criteria, relevant best practice, and to reduce the overall risk levels.

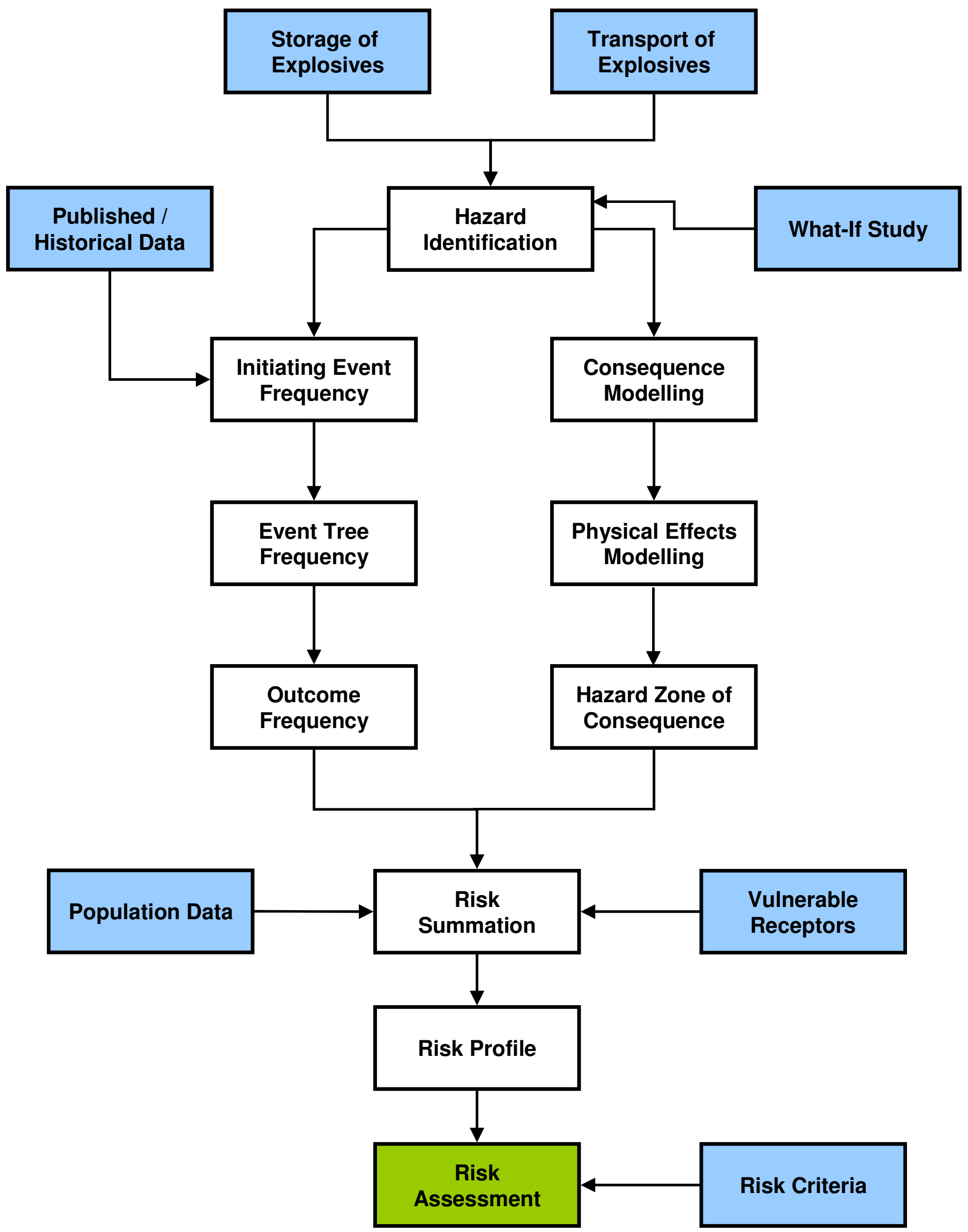
Making reference to other relevant Hong Kong QRA studies, this Hazard to Life Assessment has performed an update of the QRA parameters considered in other studies and reviewed their applicability to the transport and storage elements of the QRA as applicable for the SCL (TAW-HUH) construction. Although,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

- South Island Line (East) (SIL(E)) study (ERM, 2010a);
- Kwun Tong Line Extension (KTE) study (ERM, 2010b);
- Express Rail Link (XRL) study (ERM, 2009);
- West Island Line (WIL) study (ERM, 2008);

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

The ERM study for the Express Rail Link (ERM, 2009) is the latest QRA on the transport of explosives in Hong Kong and has formed the primary reference for the SCL (TAW-HUH) Hazard to Life Methodology.

Figure 3.2 Schematic Diagram of the QRA Process

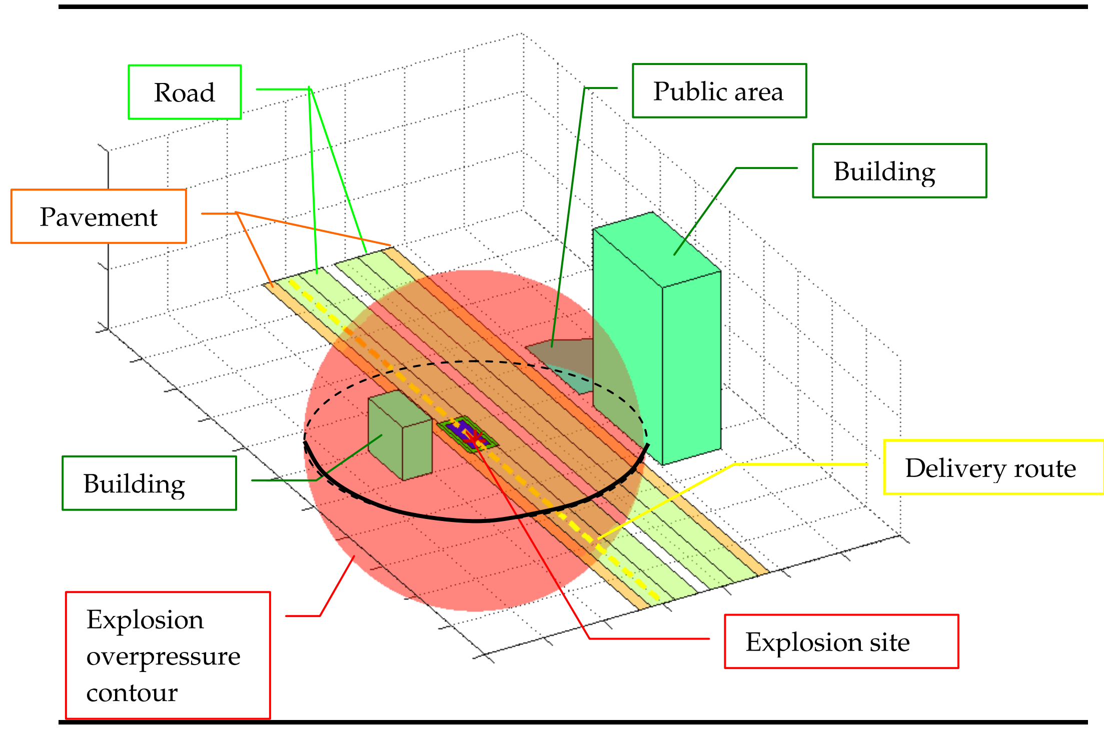


3.2. OVERVIEW OF THE EXPLOSIVE TRANSPORT RISK ASSESSMENT TOOL AND METHODOLOGY

The approach to modelling the risks for the transport of explosives is that developed for the XRL QRA (ERM, 2009) and is fully 3-dimensional and GIS based. It accounts for the potential increased risk when the explosive truck travels on elevated roads. The route from the temporary magazine to each work site is divided into sections for analysis, according to road characteristics. If initiation of the explosives on a delivery truck occurs, spherical blast waves and fragmentation may be produced which may impact on surrounding population such as other road users, buildings, as well as outdoor population on pavements and in public areas (*Figure 3.3*). The

number of fatalities from an explosion at a particular location is determined by calculating the degree of overlap between explosion overpressure contours and populated areas.

Figure 3.3 Explosion Impact on Surrounding Population



2-Dimensional Calculations

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

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

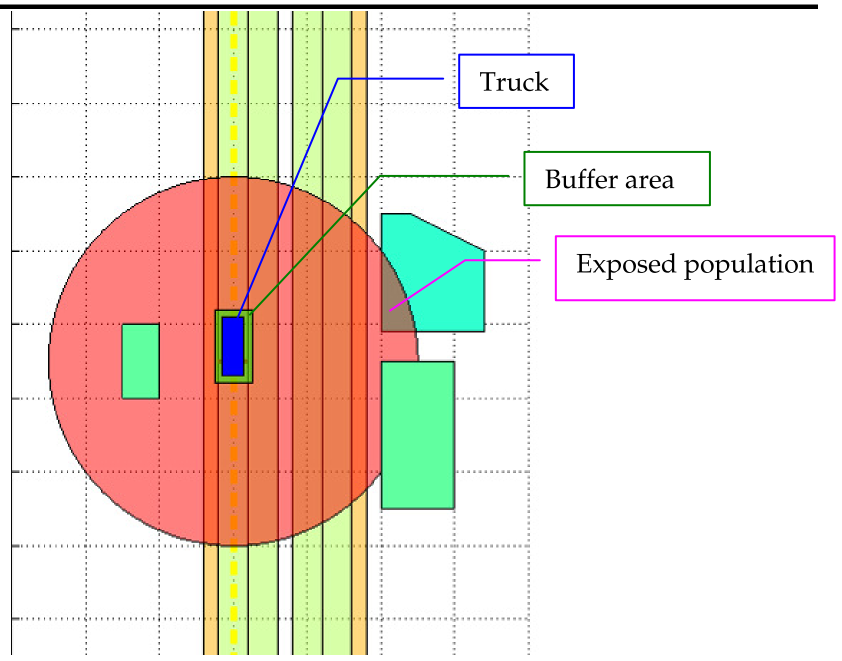
To define the population polygons, each section of a route is characterised in terms of the number of traffic lanes on the nearside and the far side, the widths of the traffic lanes, the width of the centre divide and the widths of the nearside and far side pavements. Polygons describing buildings and public areas on each side of the road were obtained from a GIS database. The building types, such as high rise residential, low rise industrial, commercial etc., are used to estimate building population and a distinction is made between population indoors and outdoors. Road population densities are estimated for two traffic conditions: flowing traffic and traffic jam. Road traffic is based on the 2011-Base District Traffic Model (BDTM) and 2007-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. This gives 100 potential explosion sites for each kilometre of the transport route.

Other assumptions made in the model include:

- The explosives trucks are assumed to be located in the slow lane of multilane roads and hence the explosion site is assumed to be centred on the slow lane;
- The explosives trucks present a hazard only during delivery of explosives from the temporary magazine to the work area. The return journey to the temporary 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 explosives trucks are expected to be a light truck e.g. a LGV pick-up truck. There will not be any member of the public located within the area occupied by the truck itself. Also, there will not be any other road vehicles within a couple of metres of the truck because of natural separation of vehicles and width of lanes. A buffer area (*Figure 3.4*) is therefore defined as 5 m × 10 m in which the population is taken to be zero. Consistent with the previously approved XRL QRA study (ERM, 2009), the explosives are assumed to be located at a position 2.5 m from the left edge and 7 m from the front edge of the buffer area. This buffer area has taken into account the area occupied by the truck and the normal separation among vehicles.

Figure 3.4 Explosion Overpressure Footprint at Ground Level



Extension to 3-Dimensional Modelling

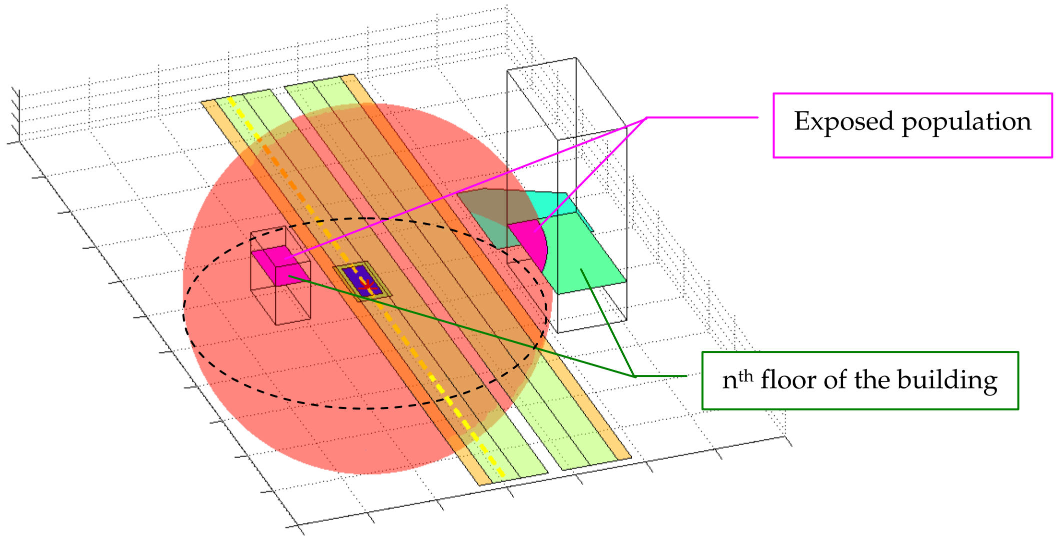
Buildings are modelled in 3-dimensions. This is achieved in essentially the same manner as the 2-D calculations, but the overlap areas between explosion overpressure contours and building polygons are calculated floor by floor (*Figure 3.5*). Since the explosion effects are spherical, the extent of the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

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

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

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

Figure 3.5 *3-Dimensional Treatment of Buildings*



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

$$PLL = \sum_i f_i N_i$$

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

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

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

4 POPULATION ESTIMATES

4.1 POPULATION ESTIMATE NEAR THE TEMPORARY EXPLOSIVE MAGAZINE

One temporary Magazine is required in order to enable efficient delivery of explosives to work areas (see *Figure 2.5*). The temporary Magazine will be located at Tseung Kwan O Area 137, and will supply explosives to work areas at Ma Chai Hang (MCH) Ventilation Building, Shansi Street and Hin Keng Portal.

The temporary Magazine site has 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.

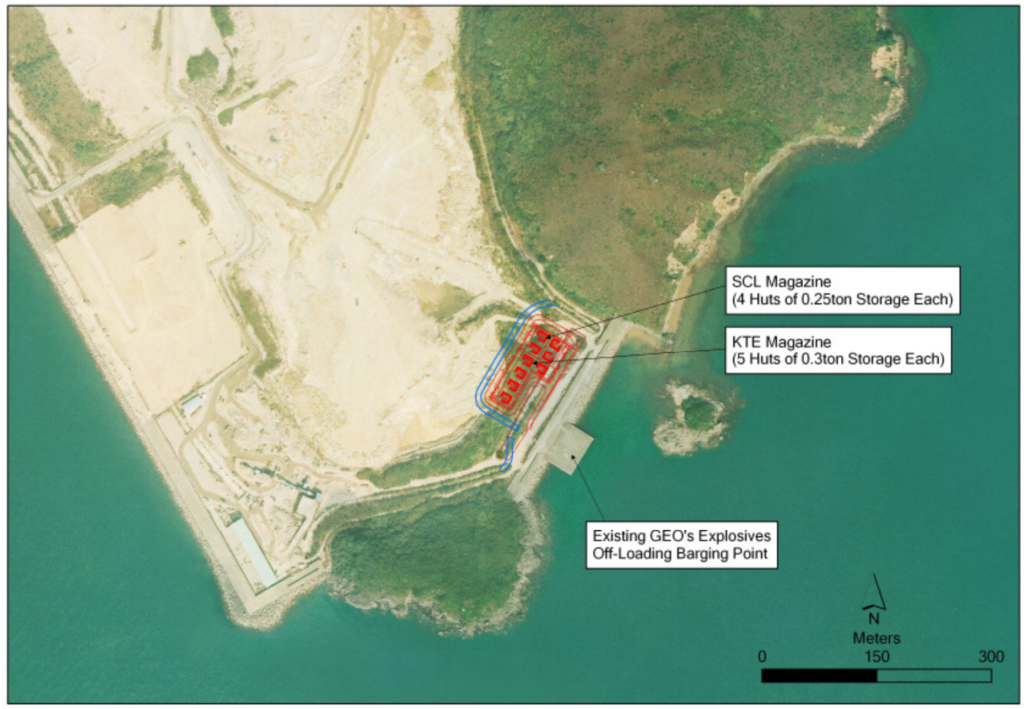
Population within the vicinity of this site is based on a survey conducted by ERM in June 2009. Additional information was gathered from GIS tools and aerial maps. From these, potential sensitive receivers in the vicinity of the site were identified and their population estimated.

The consequence analysis (*Section 7*) demonstrated that the maximum effect radius from a blast at a temporary Magazine which could produce 1% fatality is about 61m. All population within 61m radius from each site was therefore estimated.

4.1.1 *Tseung Kwan O (TKO) Area 137 Site*

The Tseung Kwan O Area 137 site is a very large area currently used as a fill bank. The site lies on level reclaimed land that is set far away from residential and public buildings (*Figure 4.1*). In addition, a jetty mooring point is currently being used by Mines Division for loading and unloading of explosives near the possible location of the temporary magazine. It is considered that there is sufficient space available at this location to allow the temporary magazine to be located at a safe distance from the explosives vessel offloading. Access to the site is also possible and is suitable for the explosives delivery vehicle. Some site formation works would be required to screen and protect the site but this is considered to be negligible. There is no known (current or future) permanent population within the impact zones of the TKO Area 137 temporary Magazine site. The nearest building is a temporary office structure over 400 metres away towards the southwest, and the proposed SENT Landfill Extension is also over 400 metres away towards the north.

Figure 4.1 Aerial Photo of the TKO Area 137 Magazine Site



Although there is no permanent population near the TKO Area 137 magazine site there is some transient population which has to be accounted for in the risk assessment in terms of presence factors if they are within the impact zone, namely occasional fishermen and deliveries to the pier by the Mines Division. This will be incorporated into the Hazard to Life Assessment.

4.2 POPULATION ALONG EXPLOSIVES DELIVERY ROUTES

Three types of population have been considered:

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

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

Table 4.1 Population Assumptions

Type of Population	Assumption	Remarks
Residential Building	3 persons / flat	Government Territorial Population and Employment Data Matrices (TPEDM) indicate current Persons Per Unit (PPU) in the transport area of slightly less than 3. A value of 3 has been adopted as a conservative assumption.
Commercial Building	9 m^2/person	Code of Practice for the Provision of Means of Escape in Case of Fire indicates 9m^2/person as a minimum requirement. For buildings considered to bear an impact on the risk results, a specific survey has been conducted.
Footpath	0.5 persons /m^2	Density figure of 0.5 persons/m^2 is defined as footpath Level Of Service (LOS) in the Highway Capacity Manual. This is considered as a reasonable conservative density for the footpaths in the study area and will be used unless specific surveys indicate lower values.
Education Institute	500 persons / hall	
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 XRL study (ERM, 2009), WIL study (ERM, 2008) and the LNG Receiving Terminal EIA (ERM, 2006), which included a detailed population survey for most parts of the explosive transportation route.

Population on the roads was estimated 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 (2009); and
- Geographic Information System (GIS) database (2008 data).

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

Accounting for the maximum licencing limit of 200kg 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 the 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 or equal to 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 on free flowing traffic. Explosive initiation following a vehicle fire (following a traffic accident or otherwise) could impact on queuing traffic conservatively assumed to occur within each lane on either side of the road in day or night conditions. Half jams are assumed in the analysis, whereby a traffic jam occurs behind the incident vehicle with a clear road in front. For such fire scenarios, traffic jam (half jam) is conservatively assumed to develop in 50% of the cases as, under low traffic conditions, such as during night time or day time at non-peak hours, road users may use alternative lanes or reverse which would not give rise to traffic jam.

In addition to road and building populations, the outdoor population on pavements was also estimated, based on a survey undertaken by ERM in July and August 2009.

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

4.2.1 *Route Sectionalisation*

The explosives delivery routes from the TKO Area 137 magazine site to the work sites (delivery points) namely Ma Chai Hang (MCH) Ventilation Building, Shansi Street Shaft and Hin Keng Portal have been broken down into sub-sections for the assessment as described in *Section 2.6.5*.

4.2.2 *Road Population*

The traffic density information used in this study is based on the latest 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 (2015) has been assumed in the analysis for delivery to various points.

A population density approach was adopted for estimating the population within vehicles on the road. Vehicle occupants were conservatively estimated as indoor with regards to consequence models (i.e. subject to glass debris impact). 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 excavation by blasting, 2015.

The BDTM data mainly represents 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 represents 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 excavation by blasting, 2015.

Road population density was calculated using the following expressions:

Annual Average Daily Traffic (AADT)

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

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

Based on average vehicle occupancy reported in the Traffic Census for the relevant transportation route, the average vehicle occupancy is around 5 persons per vehicle. This includes buses and trucks as well as taxis and private cars.

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

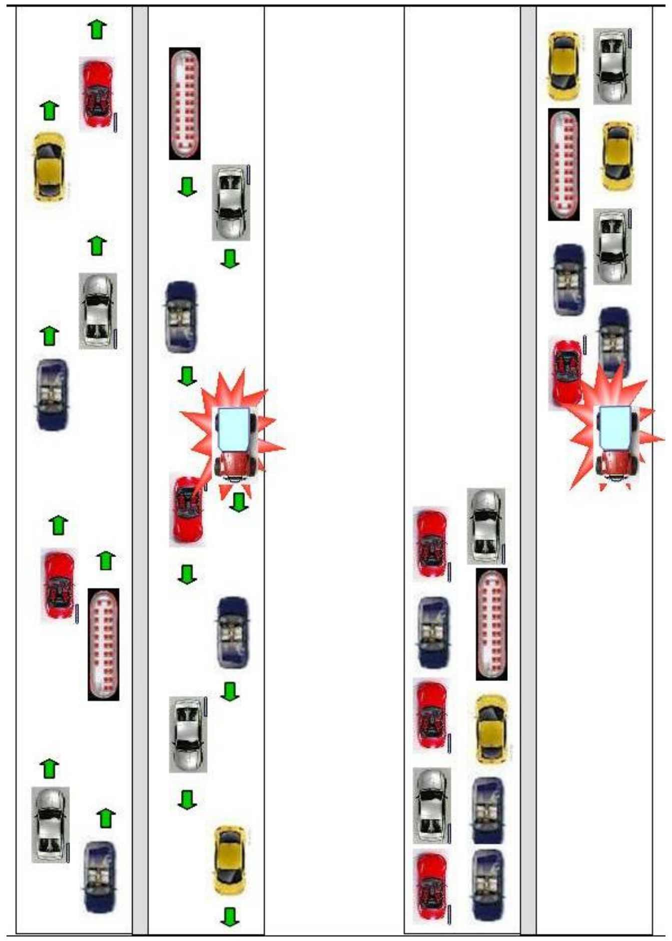
BDTM Model

Population Density (persons/m^2) = PCU / V / W /1000
where:
PCU is passenger car unit per hour
W is the road width in metre, based on actual road width 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, 2009).

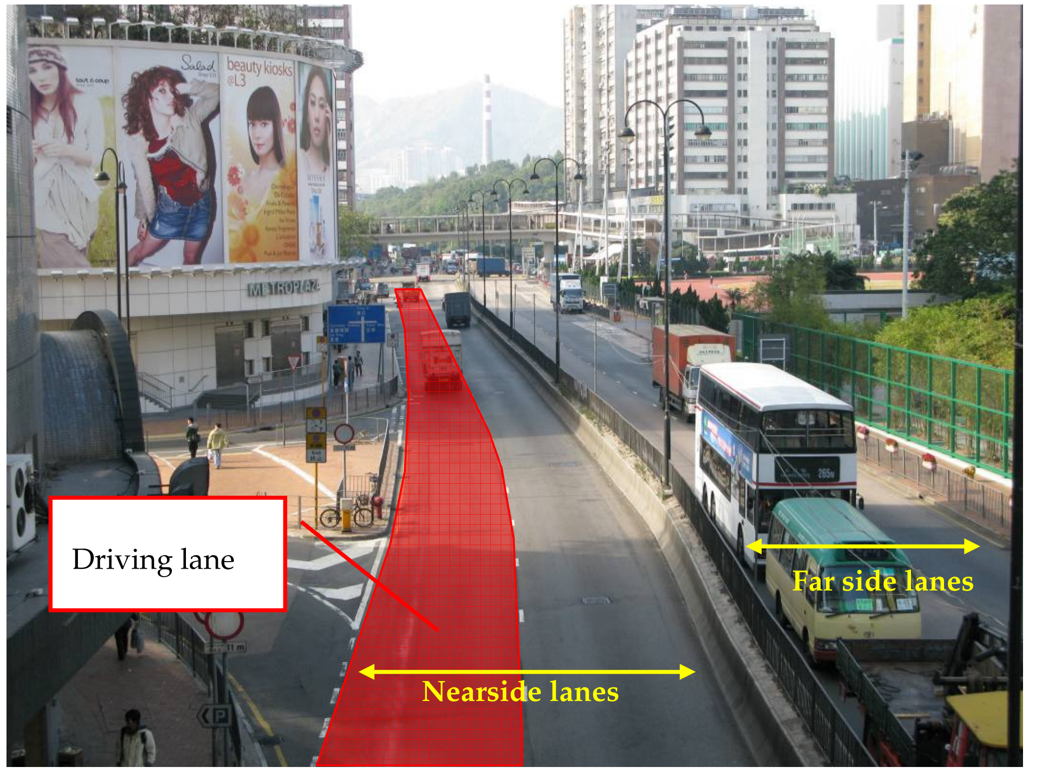
The above formulae based on AADT and BDTM provide population information for average and peak flowing traffic conditions respectively. There is a possibility of a traffic jam when explosive initiation occurs. For example, if the explosives truck catches fire either due to an accident or due to other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

Figure 4.2 Road Traffic Conditions and Scenarios Considered



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

Figure 4.3 Road Population Model



Traffic Jam Population

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

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

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

The occupancies for each type of vehicle were taken from the Annual Traffic Census (ATC) for 2007. Three core stations were selected as representative of the transport routes from the temporary Magazine site which are shown in *Table 4.2*. As a conservative measure, the peak occupancy numbers from these 3 core stations were used in the assessment.

Table 4.2 *Core Stations along the Proposed Transport Routes*

Core Station	Description	Applicable Transport Route
Stn 5017	Clear Water Bay Rd (Anderson Rd - Hiram's highway)	All routes
Stn 4217	Clear Water Bay Rd (Lung Cheung Rd - Western Junction)	All routes
Stn 3103	Ko Shan Rd (from Pak Kung St to Chi Kiang St)	Shansi St

Table 4.3 *Vehicle Occupancy for Different Types of Vehicle*

Vehicle Type	AADT Core Station			Average
	5017	4217	3103	
Motorcycle	1.2	1.2	1.5	1.30
Private car	2.0	1.7	1.8	1.83
Taxi	2.1	2.1	2.1	2.10
Public light bus	15.7	13.3	16.6	15.2
Goods vehicle	2.15	1.75	2.5	2.13
Bus	64.6	40.5	0	35.0

The traffic jam population density depends on the vehicle mix. The vehicle mix was estimated from the vehicle kilometres travelled (TD, 2007a) (VKT) by each type of vehicle in 2007 (*Table 4.4*). This approach gives the average vehicle mix for the whole territory and was used as an estimate of the vehicle mix along the transport routes. As a check on the calculation, the results were compared with the vehicle mix recorded at the 3 core stations listed in *Table 4.2* and found to match closely, however the vehicle mix average of the core stations gives a higher population density and therefore is used in order to be conservative. Combining the vehicle mix with vehicle occupancies from *Table 4.3* gives an average population density within vehicles of 0.550 persons per metre of road. For sections of the transport routes with multiple traffic lanes, a population density of 0.550 persons/m per lane was used. Road populations were further converted to a density per square metre using the lane width.

Table 4.4 *Road Population Density*

Vehicle Type	VKT in 2007 (million)	Fraction of VKT	Fraction of VKT average of Core Stations	Occupants	Length of road per vehicle (m)	Population (persons/m)
Motorcycle	319	0.0269	0.0390	1.30	5	0.010
Private car	4442	0.3749	0.3723	1.83	5	0.137
Taxi	2102	0.1774	0.2610	2.10	5	0.110
Public light bus	387	0.0327	0.1300	15.2	10	0.198
Goods vehicle	3719	0.3139	0.1533	2.13	20	0.016
Bus	878	0.0741	0.0453	35.0	20	0.079
Total	11847	1	1			0.550

4.2.3 *Pedestrian Population*

Pedestrian flow on the pavement was assessed along the explosives delivery routes by site survey carried out in July and August 2009. The site survey also aimed to collect site specific information such as the width of pavement, surrounding conditions of the roads etc. The results from the survey were

then analysed and used to calculate population densities for all the pavements along the delivery routes following the steps below:

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

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

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

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

Table 4.5 *Pavement Population Density on Roads Covered in Site Survey*

Roads	Pavement Population Density (person/m²) (1)
Delivery from TKO Area 137 Magazine Site to MCH Ventilation Building (Route 1d)	
TKO Area 137 Magazine Site Track	0
Wan Po Road (Chun Yat St- Chiu Shun Rd)	0 - 0.001
Chiu Shun Road (Wan Po Rd - Ngan O Rd)	0.004 - 0.008
Chiu Shun Road (Ngan O Rd - Po Ning Rd)	0.004 - 0.006
Hang Hau Road	0.017 - 0.034
Clear Water Bay Road (Hang Hau - Hiram's Highway)	0.018 - 0.019
Clear Water Bay Road (Hiram's Highway - Anderson Road)	0.01 - 0.034
Clear Water Bay Road (Anderson Road - New Clear Water Bay Rd Eastern Junction)	0.002 - 0
New Clear Water Bay Road (Eastern Junction - Shun Lee Street)	0 - 0
New Clear Water Bay Road (Shun Lee Street - Western Junction)	0.017 - 0.025
Clear Water Bay Road (New Clear Water Bay Rd Western Junction - Lung Cheung Rd)	0.031 - 0.038
Lung Cheung Rd (Clear Water Bay Rd - Wong Kuk Ave)	0 - 0
Lung Cheung Rd (Wong Kuk Ave - Hammer Hill Rd)	0 - 0.006
Lung Cheung Rd (Hammer Hill Rd - Po Kong Village Rd)	0 - 0.025
Po Kong Village Rd (Lung Cheung Rd - Fung Tak Rd)	0 - 0.04
Fung Tak Rd (Po Kong Village Rd - Sheung Fung St)	0.023 - 0.034
Wong Tai Sin Rd + Fung Tak Rd (Sheung Fung St - Ma Chai Hang Rd)	0.023 - 0.034
Nga Chuk St	0.034 - 0.053
Chuk Yuen Rd (Nga Chuk St - Ma Chai Hang Rd)	0.026 - 0.043
Ma Chai Hang Rd (Chuk Yuen St - Ma Chai Hang Rd Ra)	0.043 - 0.157
Delivery from TKO Area 137 Magazine Site to Shansi Street (Route 1e)	
TKO Area 137 Magazine Site Track	0
Wan Po Road (Chun Yat St- Chiu Shun Rd)	0 - 0.001

Roads	Pavement Population Density (person/m^2) [1]
Chiu Shun Road (Wan Po Rd - Ngan O Rd)	0.004 - 0.008
Chiu Shun Road (Ngan O Rd - Po Ning Rd)	0.004 - 0.006
Hang Hau Road	0.017 - 0.034
Clear Water Bay Road (Hang Hau - Hiram's Highway)	0.018 - 0.019
Clear Water Bay Road (Hiram's Hw - Anderson Road)	0.01 - 0.034
Clear Water Bay Road (Anderson Road-New Clear Water Bay Rd East Junct)	0.002 - 0
New Clear Water Bay Road (Eastern Junction - Shun Lee Street)	0
New Clear Water Bay Road (Shun Lee Street - Western Junction)	0.017 - 0.025
Clear Water Bay Road (Western Junction - Lung Cheung Rd)	0.031 - 0.038
Clear Water Bay Road (Lung Cheung Rd - Kwun Tong Rd)	0
Prince Edward Road INT (Kwun Tong Rd - Kwun Tong Bypass)	0 - 0.006
Prince Edward Road INT (Kwun Tong Bypass - Prince Edward Rd)	0.017 - 0.043
Prince Edward Road INT (Prince Edward Rd East - Choi Hung Rd)	0 - 0.029
Prince Edward Road East (Choi Hung Rd - The Nullah)	0.02 - 0.06
Prince Edward Road East & FO (The Nullah-Prince Edward Rd W)-1st Section	0.02 - 0.041
Prince Edward Road East & FO (The Nullah-Prince Edward Rd W)-2nd Section	0.02 - 0.07
Argyle Street (Prince Edward Road W - Kowloon City INT)	0.026 - 0.043
Argyle Street (Kowloon City INT - Fu Ning St)	0.029 - 0.078
Argyle Street (Fu Ning St - Lomond Rd)	0.055 - 0.06
Argyle Street (Lomond Rd - Tin Kwong Rd)	0.053 - 0.127
Tin Kwong Rd (Argyle St - Sheung Shing St)	0.029 - 0.043
Kau Pui Lung Rd	0 - 0.04
Chi Kiang St	0.025 - 0.038
Ko Shan Rd (Chi Kiang St - Pak Kung St)	0.025 - 0.04
Shansi St	0 - 0.029
Delivery from TKO Area 137 Magazine Site to Hin Keng Portal (Route 1v)	
TKO Area 137 Magazine Site Track	0
Wan Po Road (Chun Yat St- Chiu Shun Rd)	0 - 0.001
Chiu Shun Road (Wan Po Rd - Ngan O Rd)	0.004 - 0.008
Chiu Shun Road (Ngan O Rd - Po Ning Rd)	0.004 - 0.006
Hang Hau Road	0.017 - 0.034
Clear Water Bay Road (Hang Hau - Hiram's Highway)	0.018 - 0.019
Clear Water Bay Road (Hiram's Highway - Anderson Road)	0.01 - 0.034
Clear Water Bay Road (Anderson Road - New Clear Water Bay Rd Eastern Junction)	0.002 - 0
New Clear Water Bay Road (Eastern Junction - Shun Lee Street)	0
New Clear Water Bay Road (Shun Lee Street - Western Junction)	0.017 - 0.025
Clear Water Bay Road (New Clear Water Bay Rd Western Junction - Lung Cheung Rd)	0.031 - 0.038
Lung Cheung Rd (Clear Water Bay Rd - Wong Kuk Ave)	0
Lung Cheung Rd (Wong Kuk Ave - Hammer Hill Rd)	0 - 0.006
Lung Cheung Rd (Hammer Hill Rd - Po Kong Village Rd)	0 - 0.025
Lung Cheung Rd (Po Kong Village Rd - Fung Mo St)	0 - 0.061
Lung Cheung Rd (Fung Mo St - Waterloo Rd)	0.023 - 0.034
Lung Cheung Rd (Lion Rock Tunnel Rd - Nam Cheong St)	0.023 - 0.034
Lung Cheung Rd / Cornwall St (Nam Cheong St - Tai Po Rd)	0
Tai Po Rd (Lung Cheung Rd - Tai Po Rd Int)	0
Tai Po Rd (Tai Po Rd Int - Caldecott Rd)	0.021 - 0.261
Tai Po Rd - Shatin Heights (Caldecott Rd - Keng Hau Rd)	0 - 0.065
Tai Po Rd - Shatin Heights (Keng Hau Rd - Shing Ho Rd)	0 - 0.055
Mei Tin Rd (Tai Po Rd (Tai Wai) - Tsuen Nam Rd)	0.008 - 0.009
Mei Tin Rd (Tsuen Nam Rd - Che Kung Miu Rd)	0.009 - 0.019
Che Kung Miu Rd (Mei Tin Rd - Tin Sam St)	0.021 - 0.078
Che Kung Miu Rd (Tin Sam St - Hin Keng St)	0.015 - 0.021

Roads	Pavement Population Density (person/m^2) [1]
Hin Keng Estate Access Rd	0.043 - 0.208

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

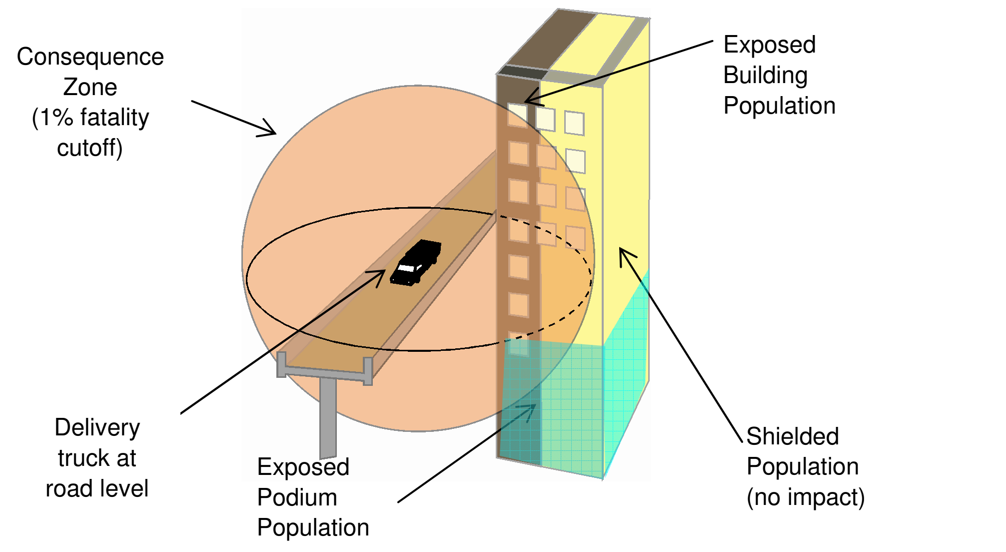
4.2.4 *Land and Building Population*

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 4500 buildings along the routes. The task of assessing population building-by-building is substantial but is necessary to accurately model the F-N pairs with high N values. Building populations are then extrapolated to Year 2015.

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

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

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



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

- Step 1: Identify existing buildings within the study area
- Step 2: Identify buildings' attributes and usage, and estimate their population
- Step 3: Project the present population to the assessment year (2015) and distribute predicted future residential population data among identified residential buildings based on a uniform population growth factor of 1% per year.
- Step 4: Adjust future population numbers of non-residential buildings

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

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

The Lands Department of the HKSAR Government maintains a Geographic Information System (GIS) database of buildings in Hong Kong. To identify buildings within the study area, ERM obtained a recent GIS map layer containing all buildings (LD, 2005). 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-categorise buildings by other attributes, such as the number of floors. Details on the building attributes and categories and associated assumptions are presented below.

Number of floors

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

Residential Buildings

Generally a population of 3 persons per unit was assumed. For most of the high-rise residential buildings, the total number of units was available from the property developers' websites. For all the remaining buildings, including the village houses and estate high-rises, the number of units per floor was estimated from the floor area, assuming 1 unit per about 65 m² (700 square feet). Based on this assumption, small structures in village setting of area less than about 30 m² were assumed to be unpopulated.

Other Buildings

While residential type buildings are well defined, less information is available for other types of buildings such as commercial, industrial etc. The approach to estimate other building population generally follows that adopted in the EIA for the Liquefied Natural Gas (LNG) Receiving Terminal (EIA 125/2006), and is based on typical Hong Kong building structure, usage, height, and typical capacity of public facilities. The details are presented in *Table 4.6.* In the application of typical values from *Table 4.6*, further refinements were made based on building height and area and taking into account the maximum density of people in most non-residential building as one person per 9 m² (the Code of Practice for the Provision of Means of Escape in Case of Fire).

Table 4.6 ***Building Population Assumptions***

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

Category	Building Height /Size[(1)]	Assumption	Total
College - Secondary School		For Form 1 – Form 5, 45 students per class, 4 classes per form. For Form 6 – Form 7, 30 students per class, 2 classes per form, Total 60 staff employed by a school	1080
School - Primary School	H	Same as College – Secondary School	
	L	30 students for each class, 2 classes per grade, 6 grades in primary school Total 30 staff employed by a school	390
Hospital		Assumed that the population for hospitals for each building height category is as follows: **Floors** – **Unit** – **People/Unit**	
	H	10 – 15 – 7	1050
	M	5 – 10 – 5	250
	L	3 – 10 – 5	150
Clinic		Assumed that the population for Clinic for each building height category is as follows: **Floors** – **Unit** – **People/Unit**	
	H	3 – 20 – 3	180
	M	2 – 10 – 2	40
	L	1 – 1 – 10	10
Temple	H	100 people for large sized temple	100
	M	50 people for medium sized temple	50
	L	10 people for small sized temple	10
MTR Station/Bus Terminus		Based on the building area	
Storage Building		Same as Car Park	
Industrial Building		**Floors** – **Units** – **People/unit**	
	H	25 – 8 – 8	1600
	M	15 – 6 – 8	720
	L	8 – 6 – 6	288
Administrative / Commercial		**Floors** – **Unit** – **People/Unit**	
	H	10 – 20 – 2	400
	M	5 – 20 – 2	200
	L	2 – 10 – 2	40
Leisure	H	200 people for large sized leisure facility	200
	M	100 people for medium sized leisure facility	100
	L	50 people for small sized leisure facility	50
	LL	10 people for very small sized leisure facility	10

Note:
(1) Legend for Building Height/Size
- H for Tall/Large,
- M for Medium,
- L for Low/Small
- LL for Very Low/Very Small

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

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

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

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

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

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

4.3 *TIME PERIODS AND OCCUPANCY*

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

Table 4.7 *Population Time Periods*

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

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

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

Type	Occupancy					
	Night (Weekdays / Saturdays / Sundays)	AM Peak (Weekdays / Saturdays / Sundays)	PM Peak (Weekdays / Saturdays / Sundays)	Weekday Daytime	Saturday Daytime*	Sunday Daytime
Administrative/ Commercial (H)	10%	10%	10%	100%	100%	100%
Administrative/ Commercial (L)	10%	10%	10%	100%	100%	100%
Administrative/ Commercial (M)	10%	10%	10%	100%	100%	100%
Car Park/Podium - residential	10%	100%	100%	70%	70%	70%
Car Park/Podium – Commercial/Industrial	0%	100%	100%	70%	45%	20%
Car Park/Podium – MTR	10%	100%	100%	70%	60%	50%
Clinic (H)	0%	10%	10%	100%	100%	100%
Clinic (L)	0%	10%	10%	100%	100%	100%
Clinic (M)	0%	10%	10%	100%	100%	100%
College	0%	10%	10%	100%	55%	10%
Fire Station/Ambulance Depot	100%	100%	100%	100%	100%	100%
Hospital (H)	80%	80%	80%	100%	90%	80%
Hospital (L)	80%	80%	80%	100%	90%	80%
Hospital (M)	80%	80%	80%	100%	90%	80%
Hotel	90%	50%	50%	20%	50%	80%
Industrial Building (H)	10%	10%	10%	100%	55%	10%
Industrial Building (L)	10%	10%	10%	100%	55%	10%
Industrial Building (M)	10%	10%	10%	100%	55%	10%
Industrial/Warehouse	0%	1%	1%	100%	51%	1%
Kindergarten	0%	10%	10%	100%	55%	10%
Leisure (H)	0%	10%	10%	70%	85%	100%
Leisure (L)	0%	10%	10%	70%	85%	100%
Leisure (LL)	0%	10%	10%	70%	85%	100%
Leisure (M)	0%	10%	10%	70%	85%	100%
MTR/bus terminus	10%	100%	100%	70%	60%	50%
Petrol Station	1%	100%	100%	50%	50%	50%
Police Station	30%	30%	30%	100%	65%	30%
Power Station	10%	10%	10%	100%	55%	10%
Residential Building (H)	100%	50%	50%	20%	50%	80%
Residential Building (L)	100%	50%	50%	20%	50%	80%
Residential Building (LL)	100%	50%	50%	20%	50%	80%
Residential Building (M)	100%	50%	50%	20%	50%	80%
School (H)	0%	10%	10%	100%	55%	10%
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/	0%	10%	10%	50%	75%	100%

Type	Occupancy					
	Night (Weekdays / Saturdays / Sundays)	AM Peak (Weekdays / Saturdays / Sundays)	PM Peak (Weekdays / Saturdays / Sundays)	Weekday Daytime	Saturday Daytime*	Sunday Daytime
Chapel (H)						
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 natural hillside areas (1, 2 and 3) were identified in the vicinity of TKO Area 137 magazine site as shown in *Table 4.9*. These have been considered in the Hazard to Life Assessment.

Table 4.9 Slopes Identified

Slopes	Site	Distance from explosive store (m)	Population
Natural Hillside Area 1	TKO Area 137 site	50	Adjacent to the temporary magazine access road
Natural Hillside Area 2	TKO Area 137 site	200	No road or population nearby
Natural Hillside Area 3	TKO Area 137 site	200	No road or population nearby

5 *HAZARD IDENTIFICATION*

5.1 *Overview*

Hazard identification consisted of a review of:

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

5.2 *Accidental Initiation due to Hazard Properties of Explosives*

5.2.1 *Explosive Type and Physical Properties*

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

Table 5.1 Explosive Types and Properties

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

* 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 temporary Magazine or stores, the likelihood of accidental initiation in situ is remote. This is because the storage environment is unlikely to experience extremes of heat, shock, impact, or vibration of sufficient intensity to initiate detonation. The most common means of accidental initiation is principally the introduction of fire. Other means of initiation include severe impact and friction.

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

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

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

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

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

5.2.2 *Hazardous Properties of Emulsion Type Explosives*

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

There are two broad categories of emulsions:

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

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

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

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

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

5.2.3 *Accidental Packaged Emulsion Initiation by Fire*

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

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

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

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

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

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

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

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

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

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

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

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

5.2.5 *Hazardous Properties of Detonating Devices*

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

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

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

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

5.3 ACCIDENTAL INITIATION ASSOCIATED WITH STORAGE AT TEMPORARY MAGAZINE

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

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

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

- Dropping of explosives during handling (for the detonators only);
- 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 TEMPORARY MAGAZINE*

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

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

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

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

than 0.5 but further refinement of this upper estimate would require additional data and more detailed analysis." (ERP, 2009).

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

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

5.5 *REVIEW OF INCIDENTS*

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

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

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

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

5.5.1 *Explosives Storage Incidents*

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

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

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

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

However, not all of these causes are applicable to the types of explosives used in the SCL (TAW-HUH) project. These are further discussed in *Section 6.1.2*.

5.5.2 *Explosives Transport Incidents*

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

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

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

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

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

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

Other pertinent statistics could be summarised below:

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

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

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

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

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

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

It is also relevant to note the experience of cartridged emulsion disposal, reported in the EIDAS database, in burning grounds in controlled burning grounds conditions (typically involving maintenance of separation distances, controlled fire, and in many cases removal of the explosives from their package), where, although the causes may have potentially included contamination i.e. mixing explosives with other materials e.g. waste copper, five events are known to have led to explosions. It is however difficult to correlate these events to transport or storage conditions under uncontrolled fire conditions with potential confinement. It is also worth noting that a number of explosive packages have been disposed by way of burning in

which no explosion occurred. However, the information is scattered and the number of such events could not be determined to estimate a probability of explosion.

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

5.6 SCENARIOS FOR HAZARD ASSESSMENT

The following hazardous scenarios were identified:

5.6.1 Temporary Proposed Magazine

A magazine site typically contains more than one explosive store. TKO Area 137, for example, will have 9 stores in total with 4 stores to be used for SCL (TAW-HUH). Within each store, explosives and detonators are stored in segregated compartments. The stores are designed with separation and enclosed walls so that initiation of the contents of one store will not affect other stores. The internal separation distances between the temporary Magazine stores meet the safety distances requirements from the UK Manufacture and Storage of Explosives Regulations 2005. Therefore, the study considers the possibility to initiate adjacent store's explosives due to escalation or domino effects to be negligible compared to the overall explosion frequency of the temporary magazine. The analysis considers the scenario to be the detonation of the full contents of each store. This, together with accidents involving the delivery trucks leads to the following scenarios that were considered in the assessment:

- Detonation of a full load of explosives on a delivery truck within the temporary magazine access road; and

- Detonation of the full quantity of explosives within a store; or a series of stores.

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

The explosives transport within the temporary magazine site has conservatively considered the maximum load and the maximum delivery frequency throughout the project as a simplification. In addition, in cases where the explosives trucks are allowed to load explosives at the same time, it was simplistically and conservatively assumed that an accidental explosion of one truck load can lead to domino effects to the other trucks resulting in a potential 3 fold increase in truck load explosion frequency for a temporary Magazine with 3 stores.

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

Table 5.3 Explosives Storage Quantities

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)
TKO Area 137	1000	2222	1204	4	301

Notes:

1 Assuming the worst case storage scenario, in which the store contains 55% detonating cord, 45% cartridged emulsion; number of detonators based on a typical pull length of 4.5m and face area of 55m² (extracted from the SCL (TAW-HUH) blasting programme)

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 temporary 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 200 g per trip to be transported in SCL (TAW-HUH), 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 SCL (TAW-HUH) project will be carried out over a 13 month period during which the explosive load requirement and delivery frequency is expected to vary (see *Section 2.5*). Risks, however, are defined on a per year basis and represent one year construction programme; the base case scenario for the Hazard to Life Assessment was therefore defined to cover different risk levels and possible construction programme deviations throughout the project period.

5.6.3 *Scenarios Considered in the Assessment*

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

Table 5.4 Scenarios Considered in the Base Case Assessment

Tag	Scenario	Explosives load (TNT eqv. kg)	No. of Trips per year	Remarks
	Storage of Explosives			
01	Detonation of full load of explosives in one store in the TKO Area 137 magazine site	301	-	Store capacity is 250kg
02	Detonation of full load of explosives in one contractor truck on the access road within TKO Area 137 magazine site boundary	194	1127	
	Transport of Explosives			
03	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 site to MCH Ventilation Building delivery point	156	513	
04	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 site to Shansi Street delivery point	193	334	
05	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 site to Hin Keng Portal delivery point	194	280	

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 TKO Area 137 magazine site	301	-	Store capacity is 250kg
02	Detonation of full load of explosives in one contractor truck on the access road within TKO Area 137 magazine site boundary	194	1353	
	Transport of Explosives			
03	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 site to MCH Ventilation Building delivery point	156	616	
04	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 site to Shansi Street delivery point	193	401	
05	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 site to Hin Keng Portal delivery point	194	336	

6 FREQUENCY ASSESSMENT

6.1 STORAGE OF EXPLOSIVES

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

The risk associated with accidental explosion during transportation within the magazine site was assessed using the same methodology as described for explosive transport, which will be discussed in detail in *Section 6.2* and is consistent with the approach considered in the XRL Study (ERM, 2009). The base frequency for accidental explosion during transport has been taken as 7.69×10^{-10}/km for normal roads, and the same frequency has been assumed while the Contractor's truck is onsite at the temporary magazine. For cases where several explosives trucks are allowed to operate within the temporary 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 temporary magazine access roads and the number of trips considered are provided in *Table 6.1*.

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

Temporary Magazine	Route length (km)	Total number of deliveries (/year)
TKO Area 137	0.42	1127

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 Temporary Magazine

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

Generic Causes

A base frequency of 1×10^{-4} /yr per temporary magazine site has been taken for generic causes of explosion during storage in the temporary magazine site based on the UK historical records (Merrifield, 1998) as detailed in the WIL Study (ERM, 2008). An analysis of the UK explosive storage experience shows

that all explosions in UK magazines (other than military stores and ordnance factories) were caused by one of the following:

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

The explosives types to be used in the SCL (TAW-HUH) 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 temporary magazine.

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

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

The installation of fire fighting measures within each temporary magazine store will reduce the probability of initiation due to fire. The proposed security system will also reduce the frequency of initiation of an explosion due to vandalism or robbery. Nevertheless, this conservative figure of 1×10^{-4} per temporary magazine site per year was retained to represent all generic causes of explosion that are common to nearly all temporary 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 temporary Magazine compared to international practice; hence risks due to manual transfer are taken to be covered in the generic failure causes.

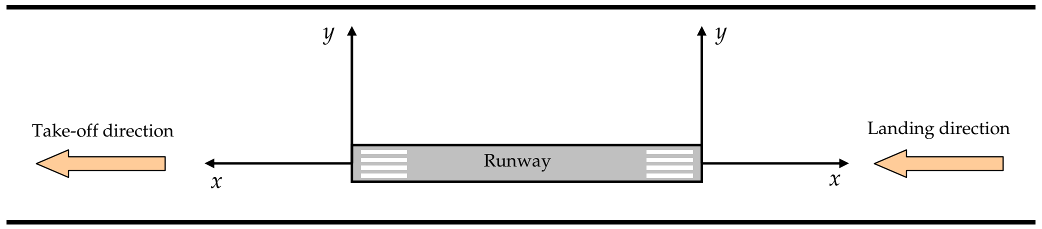
Lightning Strike

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

Fixed Wing Aircraft Crash

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

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



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

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

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

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

for $x > -3.275$ km

Take-off

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

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 temporary 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 m², suggesting a target area of 480 m² for the 4 SCL (TAW-HUH) stores at TKO Area 137 site.

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 temporary magazine sites. The risk of aircraft crash is therefore negligible compared to the risks considered in this project.

Table 6.3 Airplane Crash Frequencies

Temporary 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							
TKO Area 137	27.6	16	27.6	14.5	9.47×10^{-22}	3.63×10^{-14}	9.48×10^{-20}	7.55×10^{-15}	4.39×10^{-14}	480	2.11×10^{-17}

* 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 temporary magazine site. Recent statistics for these fires in Hong Kong country parks have been reviewed. Although the temporary Magazine is not actually located in a country park, some of the surrounding terrain and vegetation is similar to those typically found in country parks**.** According to Agriculture, Fisheries and Conservation Department (AFCD) statistics, the average number of hill fires is 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 temporary magazine design, the land within the compound will be cleared of vegetation to remove combustible materials (see *Section 2.3.2*). The temporary Magazine, referring to *Section 2.3.2*, will be constructed from fire resistance materials such as bricks, cement rendering and steel doors. The ground surface will be made of either concrete or stone to prevent fire ingress to explosive stores. Since the temporary Magazine will be protected from fire by design, together with other fire-fighting measures in place, the chance of explosive initiation due to hill fire will be much lower than the generic explosion frequency and will be at no greater risk than other temporary explosive magazines worldwide. Thus the generic explosion frequency is considered to include hill fire scenarios.

Earthquake

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

Escalation

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

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

Ground vibration distances R can be assessed using the formula

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

where

A is the vibration threshold (mm/s)
Q is the mass of explosive detonated.
$K = 1200$, $d = 0.5$, $b = 1.22$.

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

Applying the above equation and the ground coupling correlation of the WIL study (ERM, 2008), the maximum ground vibration generated from detonating of 301 kg TNT equivalent explosive is calculated at 140 mm/s for a separation of 16 m which is less than 229mm/s . Hence, this study considers the possibility to initiate adjacent store’s explosives due to escalation or domino effect to be negligible compared to the overall explosion frequency.

Conclusion on Accidental Initiation in Temporary Magazine

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

6.1.3 *Impact on Air Traffic near the TKO Area 137 Site*

The proposed TKO Area 137 magazine site will be located about 3 km, 1.5 km, 19 km and 48 km away respectively from the regular arrival paths 25L/25R, departure paths 07L/07R (North), 07L/07R (South) and 25L/25R at Hong Kong International Airport (*Figure 6.2* and *Figure 6.3*). These distances are far beyond the maximum impact area of fragments generated in an explosion.

The downwind leg of the approach to 25L/25R passes over the temporary magazine site (*Figure 6.2*). An aircraft flying along this leg might be stuck by the explosion fragments. The maximum fragment range for an explosion from a temporary Magazine is reported to be less than 600m (Moreton, 2002). Thus, the maximum height that the fragments can reach is less than 600 m considering gravity force in the vertical direction. From an air safety point of view, U.S. National Transport Safety Board recommends a minimum flight altitude of 2000 ft (~ 610 m) above terrain and obstacles in mountainous areas according to Federal Aviation Regulations (FAR) Part 95 (NTSB, 1998). The Civil Aviation Department of Hong Kong adopts a flight altitude of 3000 ft (~ 910 m) above hilly terrains based on the obstacle clearance criteria. (LegCo, 1998a and LegCo, 1998b). The actual flight height at the temporary magazine site could be much higher than 3000 ft considering that the site resides at the initial section of arrival paths 07L/07R. A similar site, Sai Kung, a mountainous area located at the initial section of arrival paths 25L/25R, has a flight altitude of approximately 5000 ft (~ 1520 m) (LegCo, 1998a and LegCo, 1998b). Therefore, aircrafts passing the temporary Magazine site are at safe distances from the Magazine.

Figure 6.2 Arrival Flight Paths of Hong Kong International Airport

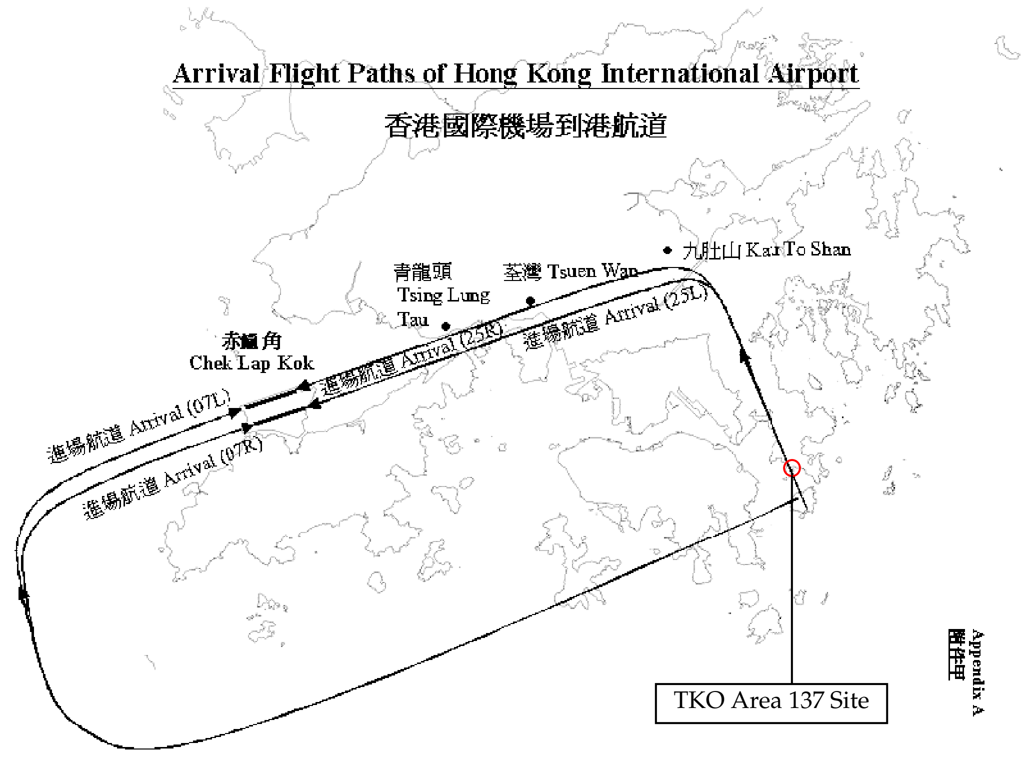


Figure 6.3 Departure Flight Paths of Hong Kong International Airport

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 temporary Magazine 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 study (DNV, 1997) and to a great extent on the ACDS study (ACDS, 1995) and its associated frequency assessment reported by Moreton (Moreton, 1993).

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

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

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

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

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

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

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

above, a significant crash impact leading to the loss of integrity of the load compartment and/or a significant mechanical energy affecting the explosive load.

6.2.1 *Explosive initiation frequency during transport as used in previous Hong Kong studies*

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

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

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

- Light Goods Vehicle (LGV) pick-up type truck for explosive delivery;
- Recent Hong Kong Transport Department statistics;
- Hong Kong specific vehicle fire data;
- Specific Hong Kong explosive delivery truck design feature;
- Specific Hong Kong explosive delivery truck operation; and
- Revised knowledge of explosives properties.

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

Initiation Probability on Significant Impact

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

Probability of Explosive Response to Fire

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

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

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

Vehicle Involvement Rate

In previous studies undertaken in Hong Kong including the WIL EIA (ERM, 2008), Ocean Park Develop (Maunsell, 2006) and DNV QRA (DNV, 1997) studies, they adopted the frequencies derived for the M/HGV to account for Hong Kong situation based on the relevant HK HGV to UK HGV reportable

vehicle collision involvement. Since specific LGV pick-up type trucks will be used in the project, a review of the Hong Kong accident data and vehicle involvement rate for LGVs was carried out based on the data published by the Transport Department between 2003 and 2007.

Explosive Initiation Frequency for Different Types of Road

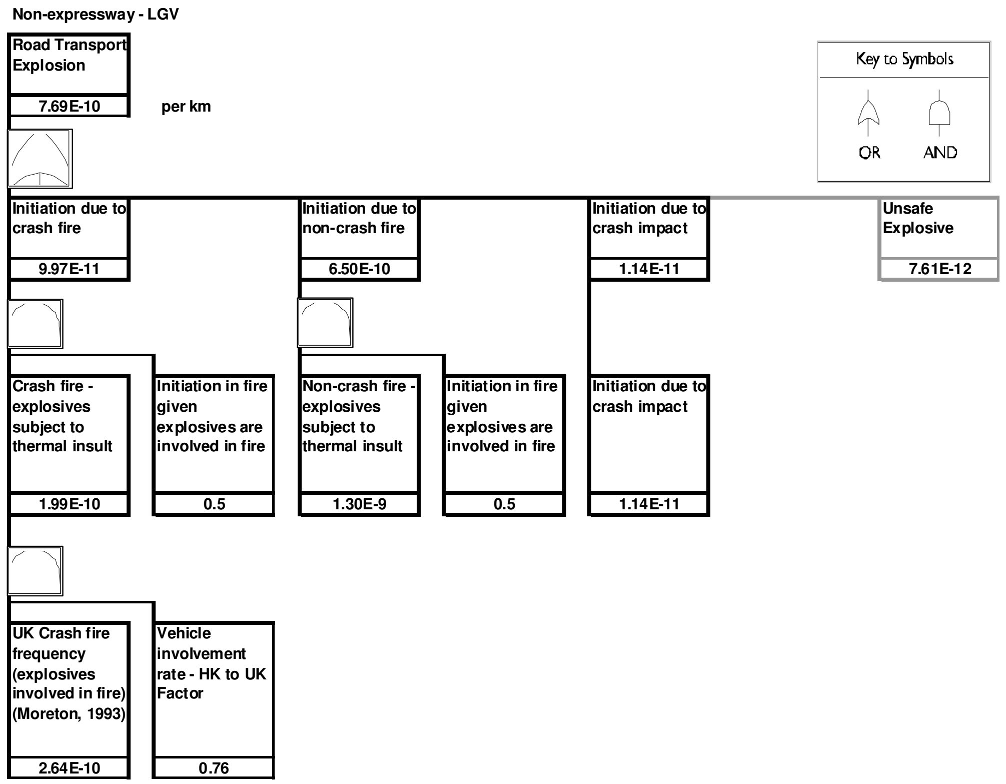
Since the vehicle impact speed and the accident involvement rate on highway/ major roads and non-highway are significantly different, different sets of explosive initiation frequencies for Expressway and Non-expressway have been derived during explosive transport to reflect the road conditions along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

The components of the explosive initiation fault tree adopted in the XRL QRA (ERM, 2009) as well as their individual probabilities are shown in *Table 6.5* and the fault tree models for the road transport explosion are shown in *Figure 6.4* and *Figure 6.5*. The frequencies of explosives initiation during road transport were therefore estimated at 6.87×10^{-10}/km on expressway and 7.69×10^{-10}/km on other road sections considering an additional 1% increase for "unsafe explosives" (i.e. a factor of 1.01), as justified in the WIL QRA (ERM, 2008).

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

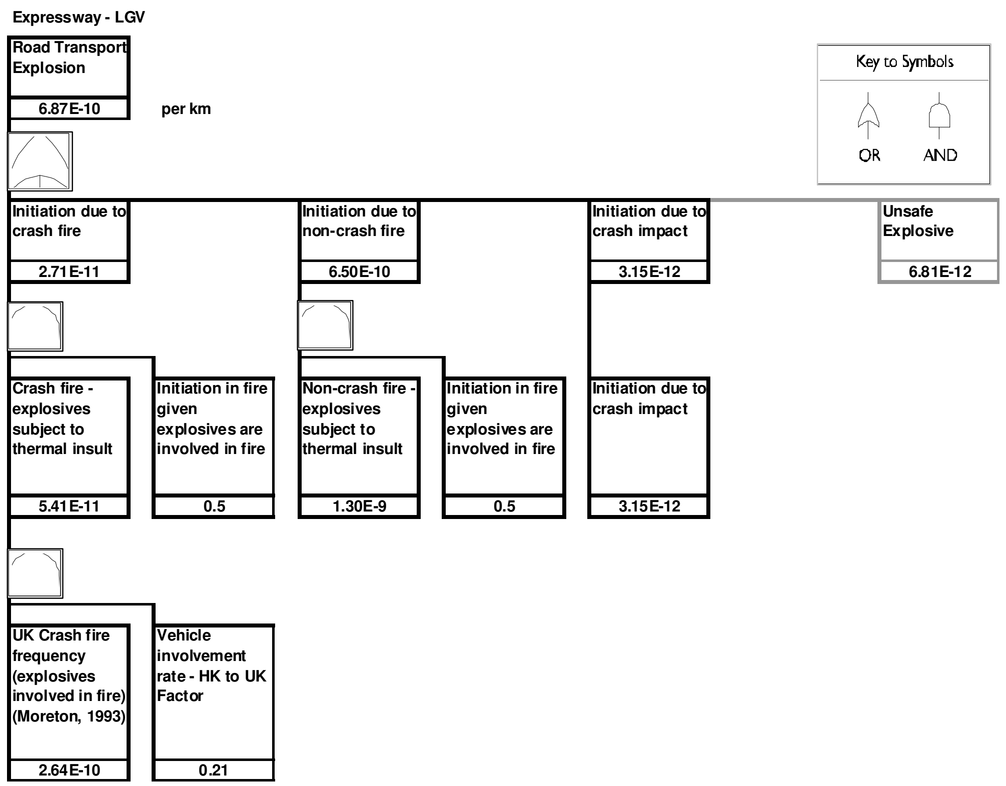
Event	Event type	Value
Vehicle crash (on expressway)	Frequency	1.27×10^{-7} /km
Vehicle crash (on non-expressway)	Frequency	4.68×10^{-7} /km
Crash fire (on expressway)	Frequency	5.41×10^{-11} /km
Crash fire (on non-expressway)	Frequency	1.99×10^{-10} /km
Non-crash fire	Frequency	1.30×10^{-9} /km
Explosives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

Figure 6.4 ***Explosives Initiation Fault Tree for Non-Expressway – Road Transport Events from the XRL QRA (ERM, 2009)***



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

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



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

6.2.2 *Transport Explosion Frequency for SCL (TAW-HUH)*

The Hazard to Life Assessment study for SCL (TAW-HUH) has been performed based on the explosive initiation frequencies derived in the XRL study (ERM, 2009) for the transport of explosives and the specific explosive transport vehicle design and operation to be used as part of the SCL (TAW-HUH) project. This approach is consistent with previous studies. The explosives initiation fault tree models for the road transport events for non-expressway and expressway are presented in *Figure 6.4* and *Figure 6.5* respectively, although the fault tree for expressways is not needed in this study since there are no expressways along the transport routes.

7 CONSEQUENCE ASSESSMENT

7.1 GENERAL

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

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

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

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

- Primary;
- Secondary; and
- Tertiary effects.

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

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

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

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

7.2 PHYSICAL EFFECT MODELLING

7.2.1 Blast and Pressure Wave for Explosion

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

People Indoors

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

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

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

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

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

People Outdoors

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

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

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

7.2.2 Flying fragments or missiles

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

7.2.3 Thermal Radiation

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

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

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

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

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

For the largest explosive mass of 301 kg (initiation of an entire store contents), a fireball radius of 11.7 m is predicted with a duration of 2.0 seconds.

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

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

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

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

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

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

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

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

Where X is the distance measured along the ground from the object to a point directly below the centre of the fireball. This distance must be greater than the radius of the fireball, because actual development of the fireball often involves an initial hemispherical shape, which would engulf nearby receptors.

Additionally, as the fireball lifts off the ground, the distance to near field receptors changes significantly. This means that the radiation estimates in the near field are of questionable accuracy.

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

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

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

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

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/m^2), t is the exposure duration and Pr is the probit that is related to probability of fatality.

The thermal dose units corresponding to 1%, 50%, and 90% fatality levels are 956, 2377, and 3920 s.(kW/m^2)$^{4/3}$ respectively. These broadly match with the 1000, 1800 and 3200 TDU levels reported by the UK HSE Safety Report Assessment Guides (HSE HFLs) for the same fatality levels. Applying the HSE thermal dose criteria limits for a fireball of duration 2.0 s, indicates that the incident radiation fluxes to cause these fatality levels are estimated as 105, 164, and 252 kW/m^2.

Comparing these with the fireball surface emissive power of 141 kW/m^2, shows that these levels of thermal flux will only be realised when in very close proximity to the fireball. Therefore, it can be concluded that a fireball from the initiation of cartridged emulsion within the temporary 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 301 kg TNT Equivalence of Explosive

Consequence	Receiver's location	Effect radius (m)
Shockwave and debris - ESTC model	Indoor	61.1
	Outdoor	21.5
Ground shock – Object falling threshold (PPV = 100mm/s)	Indoor / outdoor close by a structure	19.2

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

The effect radius of 90mm/s was calculated as 21.0 m for detonation of 301 kg TNT equivalence of explosives, which correspond to the maximum quantity of explosive (TNT equivalent) to be stored in each temporary magazine store. From *Table 4.9,* all the slopes are too far away to be affected. Therefore, the hazards from a ground shock are not considered further in this assessment.

The management of the Fill Bank at TKO Area 137 plan to construct a fill slope near the temporary magazine site which will have a relatively gentle incline (about 11°). The fill slope will be completed before the temporary Magazine is built and put into use. Based on the critical peak particle velocity (PPVc) of 49 mm/s for the fill slope and the calculated PPV of 233m/s for a 0.01% chance of slope failure (which would occur at 10.5 m away from the store in the event of a detonation), the fill slope at more than 20 m away is too far to be affected by the ground vibration due to a store detonation.

The fill slope could fail due to washout during heavy rain and the runoff may have the potential to cause damage to the temporary Magazine site. Suitable engineering measures are to be implemented to prevent washout impacting the stores and this is given in the recommendations section of this report.

7.3 RESULTS OF CONSEQUENCE ASSESSMENT

The consequence results for each transport and storage scenario are summarised in *Table 7.2* and *Table 7.3.* Consequence distances for the storage scenarios (no. 1 -2) may be compared to the separation distances specified in the temporary Magazine designs, as follows: public footpaths must be at least 54 m away (vehicle routes must be further); buildings must be at least 180 m 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)
	<u>*Storage of Explosives*</u>				
01	Detonation of full load of explosives in one store in TKO Area 137 site	301	90%	20.6	16.5
			50%	23.9	17.2
			10%	35.4	19.0
			3%	47.3	20.4
			1%	61.1	21.5
02	Detonation of full load of explosives in one contractor truck on the access road within the TKO Area 137 magazine site boundary	194	90%	17.9	14.3
			50%	20.7	14.9
			10%	30.6	16.5
			3%	40.9	17.6
			1%	52.7	18.7
	<u>*Transport of Explosives*</u>				
03	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 to Ma Chai Hang delivery point	156	90%	16.6	13.3
			50%	19.2	13.9
			10%	28.5	15.3
			3%	38.1	16.4
			1%	49.5	17.4

No.	Scenario	TNT eqv. kg	Fatality Prob.	*Indoor* Impact distance (m)	*Outdoor* Impact distance (m)
04	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 site to Shansi Street delivery point	193	90%	17.8	14.3
			50%	20.6	14.9
			10%	30.6	16.4
			3%	40.8	17.6
			1%	52.6	18.6
05	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 site to Hin Keng Portal delivery point	194	90%	17.9	14.3
			50%	20.7	14.9
			10%	30.6	16.5
			3%	40.9	17.6
			1%	52.7	18.7

Table 7.3 *Summary of Results for Worst Case Consequence Scenarios*

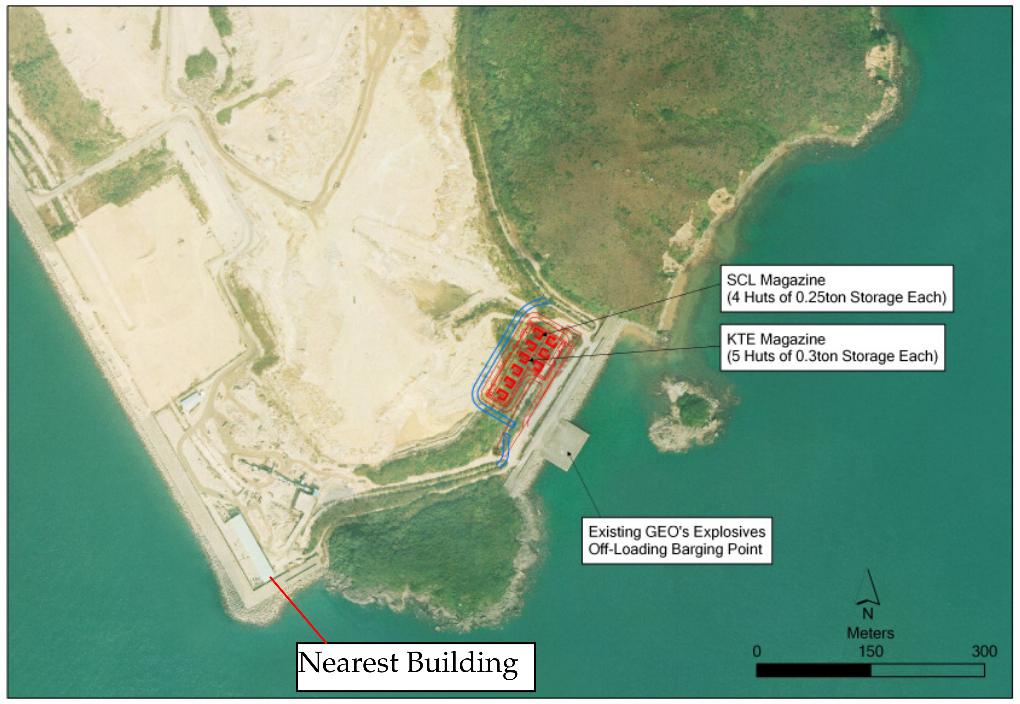
No.	Scenario	TNT eqv. kg)	Fatality Prob.	*Indoor* Impact distance (m)	*Outdoor* Impact distance (m)
	<u>*Storage of Explosives*</u>				
01	Detonation of full load of explosives in one store of TKO Area 137 site	301	90%	20.6	16.5
			50%	23.9	17.2
			10%	35.4	19.0
			3%	47.3	20.4
			1%	61.1	21.5
02	Detonation of full load of explosives in one contractor truck on the access road within the TKO Area 137 magazine site boundary	194	90%	17.9	14.3
			50%	20.7	14.9
			10%	30.6	16.5
			3%	40.9	17.6
			1%	52.7	18.7
	<u>*Transport of Explosives*</u>				
03	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 to Ma Chai Hang delivery point	156	90%	16.6	13.3
			50%	19.2	13.9
			10%	28.5	15.3
			3%	38.1	16.4
			1%	49.5	17.4
04	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 site to Shansi Street delivery point	193	90%	17.8	14.3
			50%	20.6	14.9
			10%	30.6	16.4
			3%	40.8	17.6
			1%	52.6	18.6
05	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 site to Hin Keng Portal delivery point	194	90%	17.9	14.3
			50%	20.7	14.9
			10%	30.6	16.5
			3%	40.9	17.6
			1%	52.7	18.7

7.4 SECONDARY HAZARDS

7.4.1 *Property Damage*

The nearest building to the TKO Area 137 magazine is approximately 400 m away, which is well outside of the 204 m specified in the requirements. The 400 m also substantially exceeds the 1% fatality distance. Moreover the storage is not within the Consultation Zone of any PHIs and is not close to any other vulnerable risk receptors.

Figure 7.1 *Location of TKO Area 137 Magazine in Relation to Nearest Building*



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 Wan Po Road and Clear Water Bay Road. There is a possibility that an explosion on a road vehicle may trigger a landslide or a boulder fall. This is regarded as a secondary hazard. The impact of this hazard in terms of potential consequences was evaluated using the approach adopted in the XRL study (ERM, 2009). It was found that any landslide and boulder fall event will impact the same area along the road that is already affected by the primary explosion consequences. Hence, no significant additional fatality will occur.

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

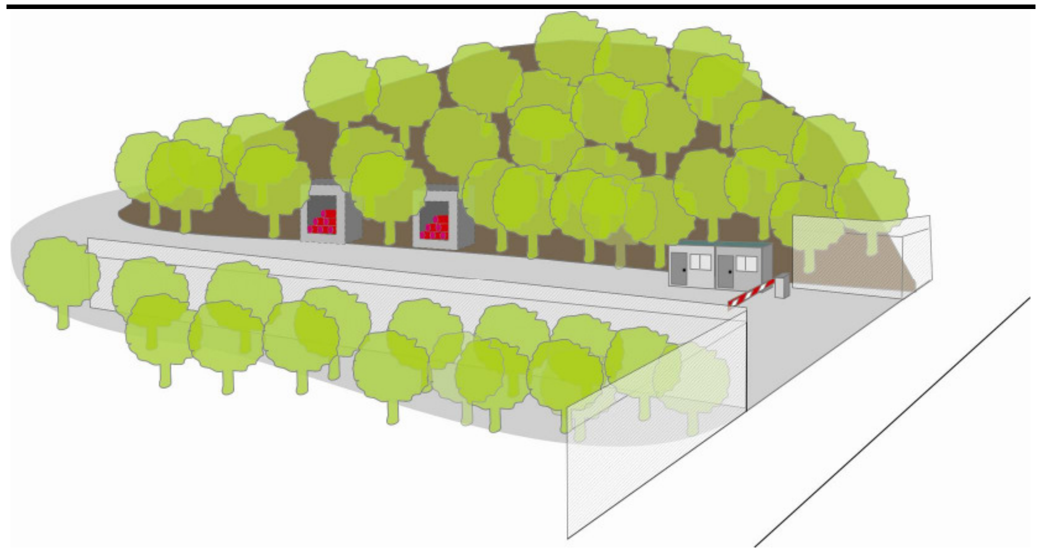
A number of sensitive facilities, namely the Kowloon Government Explosives Depot, SD Shek Lei Piu Water Treatment Works, WSD Pak Kong Water Treatment Works and WSD Ma On Shan Water Treatment Works, are situated along the explosives delivery route from TKO Area 137 to Hing Keng Portal via either Po Lam Road or Sai Sha Road (Sai Kung). The potential impacts to these facilities are discussed in the following subsections.

Kowloon Government Explosives Depot (Base Case: TKO Area 137 to Hing Keng Portal via Po Lam Road)

From TKO Area 137 to the Hin Keng Portal delivery point the base case route is via Tai Po Road, a section of which adjoins the Kowloon Government Explosives Depot.

Although the explosives depot is within the impact radius of the explosives vehicle, it is largely shielded by the natural hillside and the surrounding vegetation. As well as this characteristic terrain, the explosives depot is specially designed to minimise any impacts from external activities– reinforced concrete bunkers built into the natural hillside; store entrances facing away from Tai Po Road; and strategically placed concrete walls to protect the stores. It is believed that the safety of the depot will not be compromised leading to a store explosion in the event of truck explosion from the road. *Figure 7.2* depicts the topography and design of the explosives depot.

Figure 7.2 ***Topography and Design of the Explosive Depot***



The scenario can also be dismissed due to its remote possibility. An order of magnitude analysis is given here to qualify the possibility of the explosives depot being impacted by an explosion on the road.

Lees suggests an overpressure of 2.3 psi as the lower limit of serious structural damage and an overpressure of 2 -3 psi could shatter concrete (not reinforced) or cinder block walls (Lees, 1996). It is therefore deemed appropriate to assume an overpressure of below 2 psi would not impact on explosives inside a store.

If we consider the frequencies of explosives initiation during road transport of 7.69 x10^{-10}/km for non-expressways, with 336 trips in the worst case, considering a distance of 128.4 m (38.4 m for the length of explosives depot

alongside Tai Po Road plus 45 m for additional route each side of the depot which impact 2psi on the stores). The event frequency of explosives initiation is 3.32 x 10^{-8} per year along that particular stretch of road. This is considered negligible, about 4 orders of magnitude lower, when compared to the generic explosion frequency of an explosive storage, i.e. 10^{-4} per year. The impact frequency will diminish further if the protections offered by the topography and the depot design are to be considered.

Therefore, it can be concluded that explosives vehicle travelling alongside Tai Po Road poses negligible risk to the magazine.

SD Shek Lei Piu Water Treatment Works (Base Case: TKO Area 137 to Hing Keng Portal via Po Lam Road)

The base case route via Tai Po Road passes more than 600 m away from the SD Shek Lei Piu Treatment Works. This is well outside the 100 m impact zone of the explosives truck and hence not considered further.

WSD Pak Kong Water Treatment Works and WSD Ma On Shan Water Treatment Works (ALARP Case: TKO Area 137 to Hin Keng Portal via Sai Sha Road)

The transport route via Sai Sha Road passes more than 300 m away from either site. Again this is well outside the 100 m impact zone of the explosives truck and therefore not considered further.

8 RISK SUMMATION

8.1 OVERVIEW

The Consultants' in-house software has been used for risk calculation and summation. This integrates the risks associated with the temporary 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 risk results for this worst case scenario are also shown for comparison purposes.

8.2 RISK MEASURES

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

8.2.1 Societal Risk

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

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

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

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

8.2.2 Individual Risk

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

8.3 SOCIETAL RISK

8.3.1 Potential Loss of Life

Table 8.1 and *Table 8.2* below show the PLL values for the storage of explosives at the temporary Magazine site and the transport of explosives to the blasting sites. As expected, the Worst Case (PLL = 6.23×10^{-4}/year) imposes a higher risk than the Base Case (PLL = 4.77×10^{-4}/year).

The temporary proposed Magazine storage site (TKO Area 137) has negligible contribution to the overall risks since it is located in a remote area with no permanent population nearby.

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

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

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

Table 8.1 PLL for Base Case

Case: Base Case	PLL (per year)	Contribution (%)
Storage of Explosives		
TKO Area 137	9.17E-07	0.20%
Transport of Explosives		
TKO Area 137 to Ma Chai Hang Ventilation Building	1.80E-04	37.7%
TKO Area 137 to Shansi Street Shaft	1.34E-04	28.1%
TKO Area 137 to Hin Keng Portal	1.62E-04	34.0%
Total	4.77E-04	100.0%

Table 8.2 *PLL for Worst Case*

Case: Worst Case	PLL (per year)	Contribution (%)
Storage of Explosives		
TKO Area 137	9.17E-07	0.15%
Transport of Explosives		
TKO Area 137 to Ma Chai Hang Ventilation Building	2.32E-04	37.2%
TKO Area 137 to Shansi Street Shaft	1.74E-04	28.0%
TKO Area 137 to Hin Keng Portal	2.16E-04	34.7%
Total	6.23E-04	100.0%

8.3.2 *F-N Curves*

Figure 8.1 shows the overall F-N curves for explosives storage and transport combined. These include the TKO Area 137 magazine site and the associated transport routes to the 3 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 for the three worksites. It can be seen that for both cases the risks lie in the ALARP region.

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

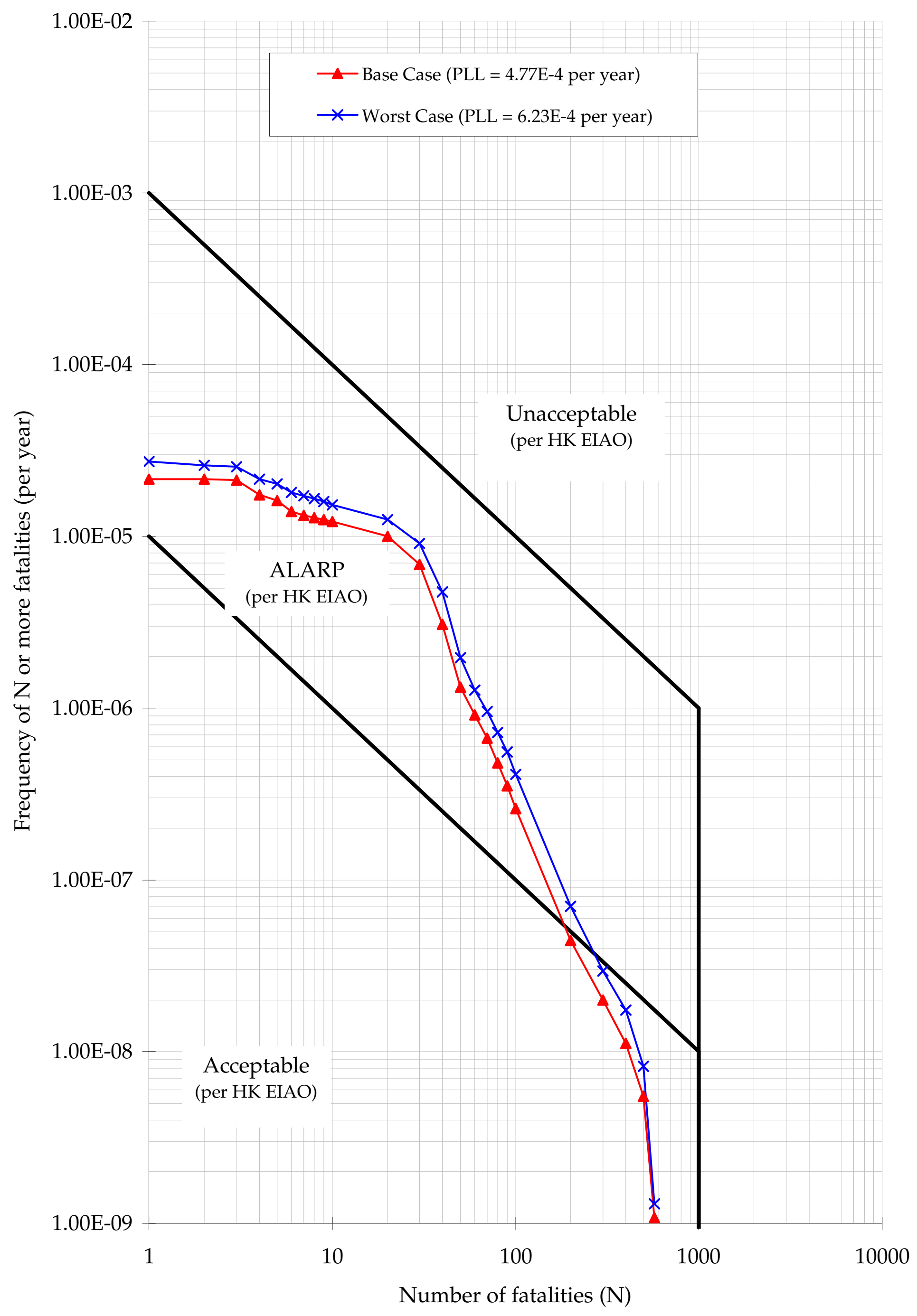


Figure 8.2 shows the F-N curve for the Base Case with a breakdown by storage and transport. It can be seen that risks from the temporary Magazine are negligible compared to transport risks. This is consistent with the comments made in relation to the PLL. Population in the vicinity of the temporary Magazine site is very low and hence the societal risks are small.

Figure 8.3 provides a breakdown by population type for the Base Case scenario. 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. 79% of the PLL (3.78×10^{-4} per year compared to the total of 4.77×10^{-4} per year) is related to population in vehicles. Scenarios involving high numbers of fatalities are related to fatalities in buildings close to the road. This is particularly noticeable towards the end of the delivery route to Shansi Street the route passes through single carriageway roads close to residential buildings with high population densities.

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

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

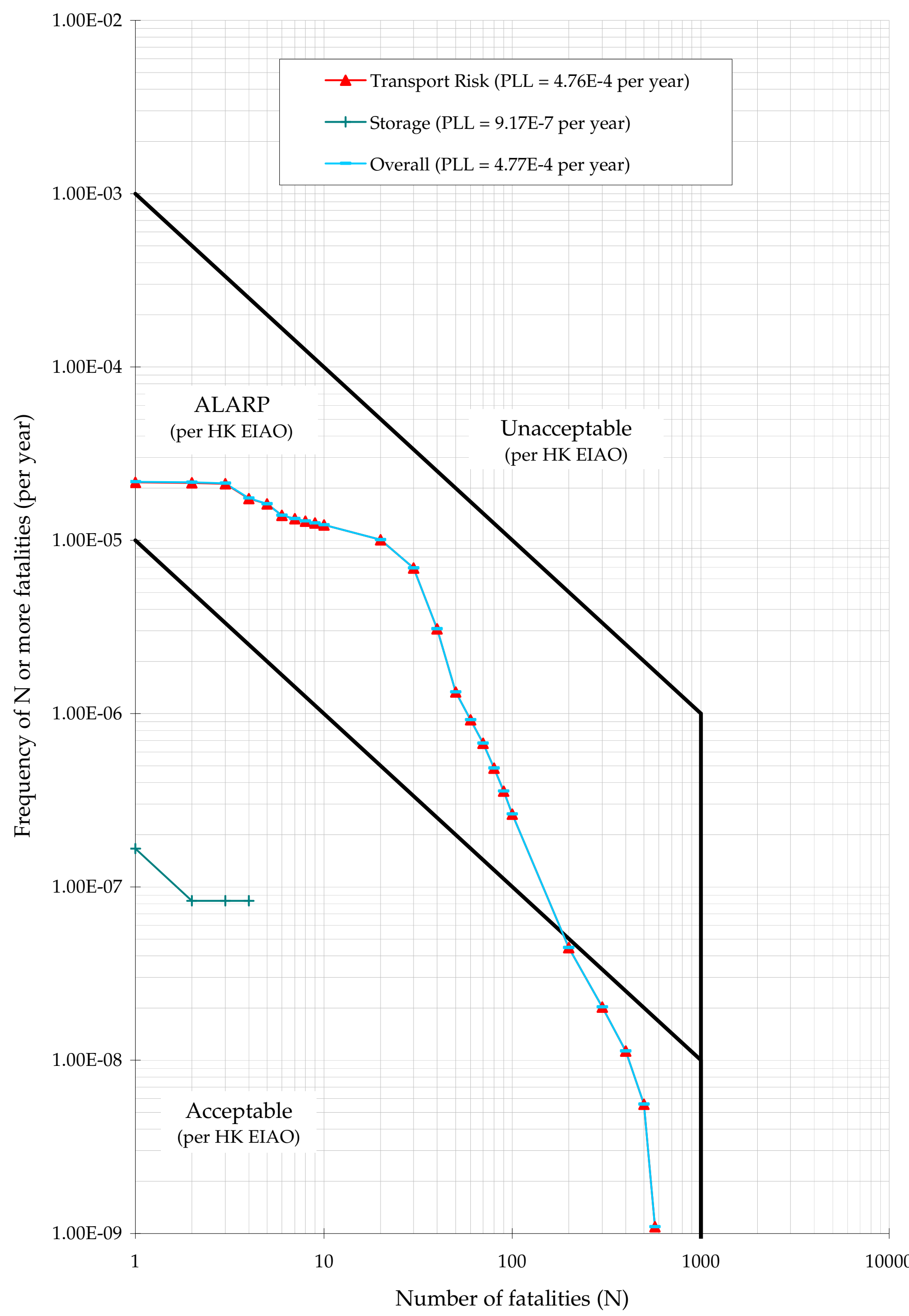
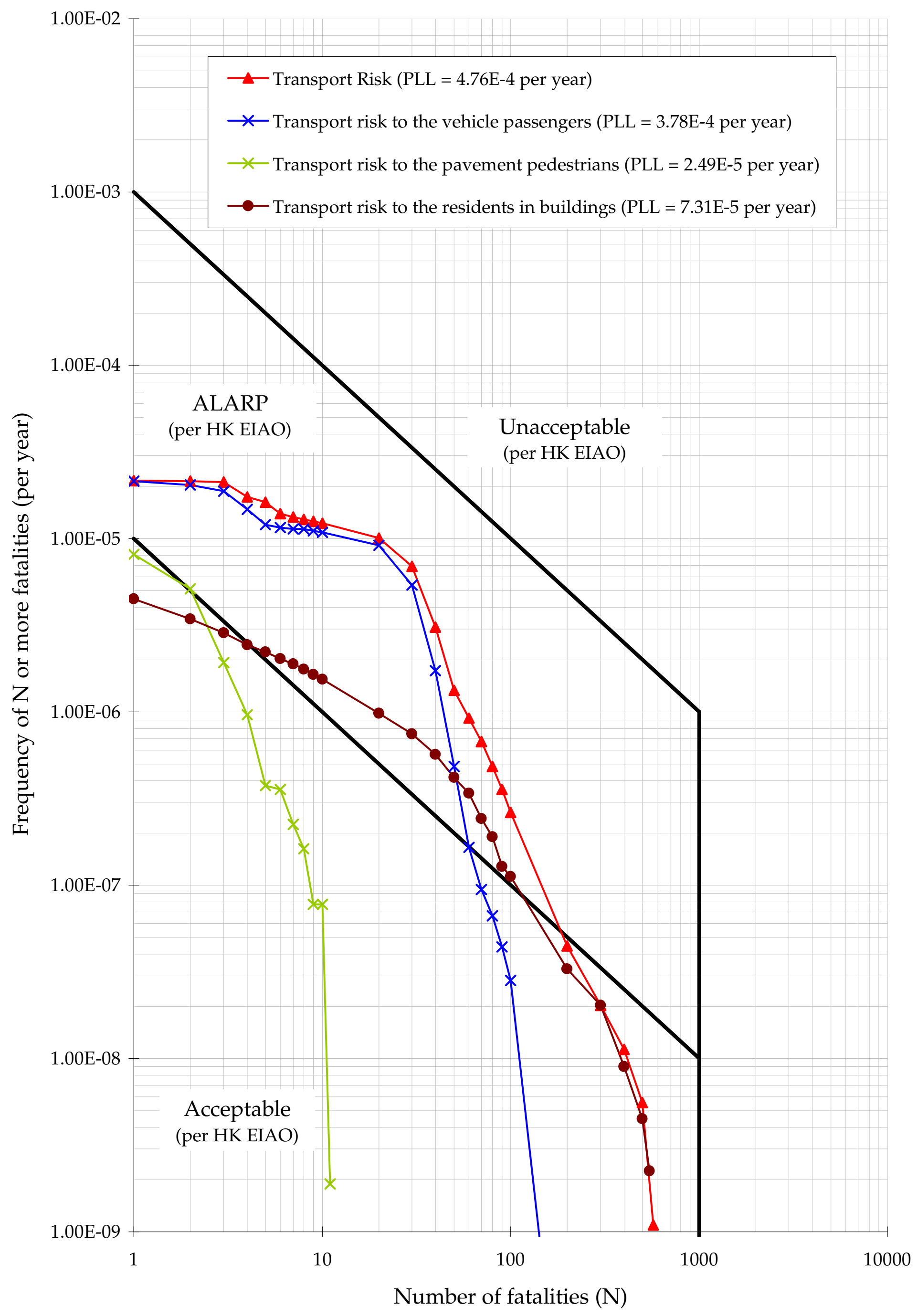


Figure 8.3 *F-N Curve for the Base Case with Breakdown by Population Type*



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 the public on the roads but not the explosives truck crew.

8.4 *INDIVIDUAL RISK*

The individual risk (IR) for each section of the transport route is listed in *Table 8.3*. The same data is shown graphically in *Figure 8.4*. The IR summation takes into account that some road sections are common to several transport routes; the IR is roughly proportional to the frequency of explosives trucks travelling

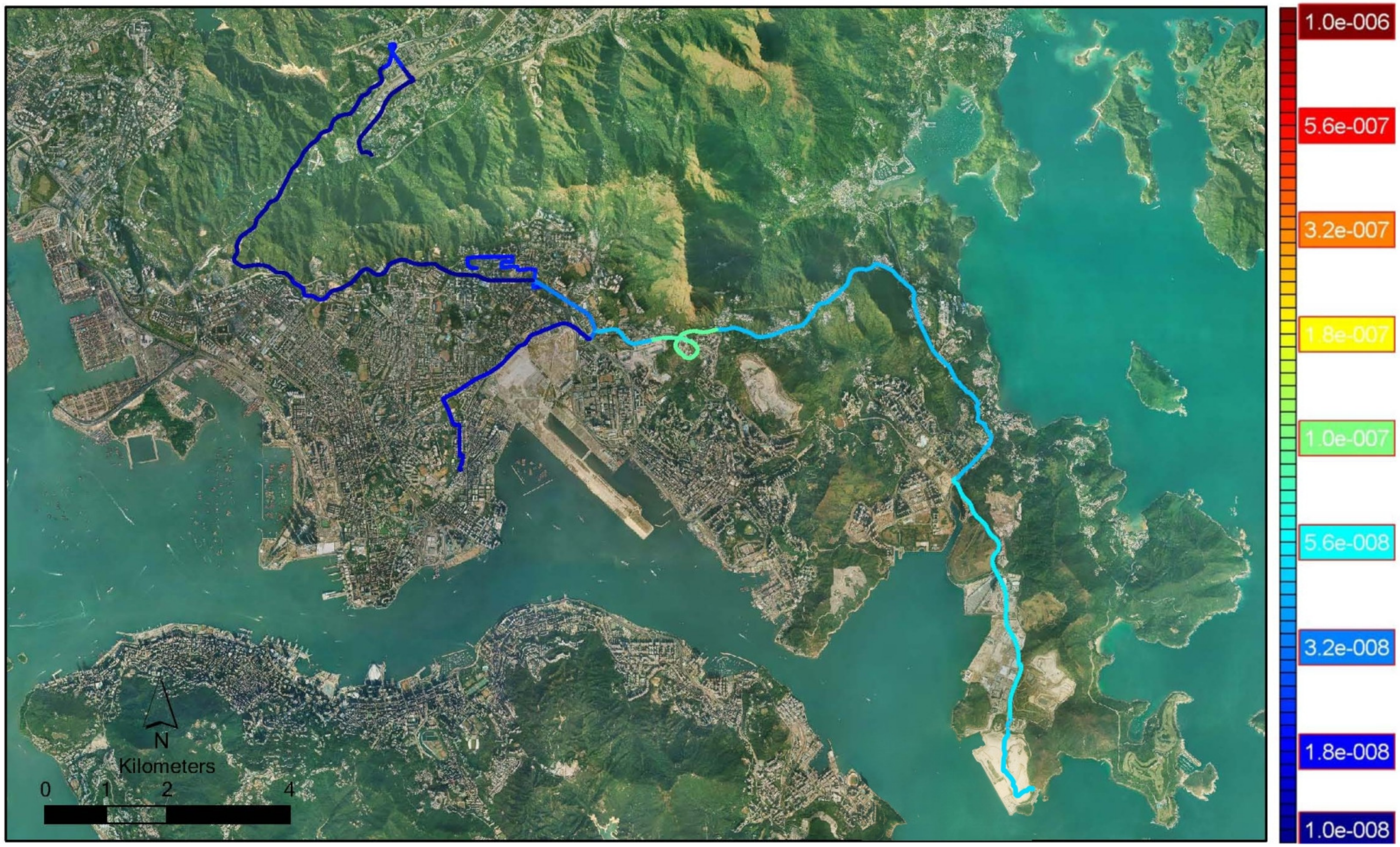
along the road. The IR results presented below represent the maximum individual risk occurring on the road in the same lane as the explosives delivery truck. It can be seen that the maximum IR is about 8×10^{-8} per year. This is a low risk when compared to Hong Kong Risk Guidelines which require the 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 TKO Area 137 Magazine (Base Case)*

Section ID	Description	Maximum IR (per year)
Route 1d (TKO Area 137 Magazine – Ma Chai Hang Ventilation Building)		
road 1d1	TKO Area 137 Magazine Site Track	4.35E-08
road 1d2	Wan Po Road (Chun Yat St- Chiu Shun Rd)	4.68E-08
road 1d3a	Wan Po Road (Chun Yat St- Chiu Shun Rd)	3.99E-08
road 1d3b	Chiu Shun Road (Wan Po Rd - Ngan O Rd)	3.99E-08
road 1d4	Chiu Shun Road (Ngan O Rd - Po Ning Rd)	4.00E-08
road 1d5	Hang Hau Road	4.03E-08
road 1d6a	Clear Water Bay Road (Hang Hau - Hiram's Highway)	3.97E-08
road 1d6b	Clear Water Bay Road (Hiram's Highway - Anderson Road)	7.76E-08
road 1d7	Clear Water Bay Road (Anderson Road - New Clear Water Bay Rd Eastern Junction)	7.32E-08
road 1d8	New Clear Water Bay Road (Eastern Junction - Shun Lee Street)	3.92E-08
road 1d9	New Clear Water Bay Road (Shun Lee Street - Western Junction)	3.93E-08
road 1d10a	Clear Water Bay Road (New Clear Water Bay Rd Western Junction - Lung Cheung Rd)	2.7E-08
road 1d10b	Lung Cheung Rd (Clear Water Bay Rd - Wong Kuk Ave)	2.7E-08
road 1d10c	Lung Cheung Rd (Wong Kuk Ave - Hammer Hill Rd)	2.72E-08
road 1d11	Lung Cheung Rd (Hammer Hill Rd - Po Kong Village Rd)	2.58E-08
road 1d12	Po Kong Village Rd (Lung Cheung Rd - Fung Tak Rd)	1.83E-08
road 1d13	Fung Tak Rd (Po Kong Village Rd - Sheung Fung St)	2.01E-08
road 1d14	Wong Tai Sin Rd + Fung Tak Rd (Sheung Fung St - Ma Chai Hang Rd)	1.91E-08
road 1d15	Nga Chuk St	1.81E-08
road 1d16	Chuk Yuen Rd (Nga Chuk St - Ma Chai Hang Rd)	1.79E-08
Route 1e (TKO Area 137 Magazine – Shansi Street Shaft)		
road 1e1	TKO Area 137 Magazine Site Track	4.35E-08
road 1e2	Wan Po Road (Chun Yat St- Chiu Shun Rd)	4.68E-08
road 1e3a	Chiu Shun Road (Wan Po Rd - Ngan O Rd)	3.95E-08
road 1e3b	Chiu Shun Road (Ngan O Rd - Po Ning Rd)	3.95E-08
road 1e4	Hang Hau Road	4E-08
road 1e5	Clear Water Bay Road (Hang Hau - Hiram's Highway)	4.03E-08
road 1e6a	Clear Water Bay Road (Hiram's Hw - Anderson Road)	3.97E-08
road 1e6b	Clear Water Bay Road (Anderson Road-New Clear Water Bay Rd East Junct)	7.76E-08
road 1e7	New Clear Water Bay Road (Eastern Junction - Shun Lee Street)	7.32E-08
road 1e8	New Clear Water Bay Road (Shun Lee Street - Western Junction)	3.92E-08
road 1e9	Clear Water Bay Road (Western Junction - Lung Cheung Rd)	3.93E-08
road 1e10	Clear Water Bay Road (Lung Cheung Rd - Kwun Tong Rd)	3.53E-08
road 1e11a	Prince Edward Road INT (Kwun Tong Rd - Kwun Tong Bypass)	1.23E-08

Section ID	Description	Maximum IR (per year)
road 1e11b	Prince Edward Road INT (Kwun Tong Bypass - Prince Edward Rd)	1.22E-08
road 1e11c	Prince Edward Road INT (Prince Edward Rd East - Choi Hung Rd)	1.22E-08
road 1e11d	Prince Edward Road East (Choi Hung Rd - The Nullah)	1.25E-08
road 1e11e	Prince Edward Road East & FO (The Nullah-Prince Edward Rd W)-1st Section	1.23E-08
road 1e11f	Prince Edward Road East & FO (The Nullah-Prince Edward Rd W)-2nd Section	1.16E-08
road 1e12a	Argyle Street (Prince Edward Road W - Kowloon City INT)	1.2E-08
road 1e12b	Argyle Street (Kowloon City INT - Fu Ning St)	1.22E-08
road 1e12c	Argyle Street (Fu Ning St - Lomond Rd)	1.22E-08
road 1e12d	Argyle Street (Lomond Rd - Tin Kwong Rd)	1.45E-08
road 1e13	Tin Kwong Rd (Argyle St - Sheung Shing St)	1.46E-08
road 1e14	Kau Pui Lung Rd	1.32E-08
road 1e15	Chi Kiang St	1.37E-08
road 1e16	Ko Shan Rd (Chi Kiang St - Pak Kung St)	1.38E-08
road 1e17	Shansi St	1.27E-08
Route 1v (TKO Area 137 Magazine – Hin Keng Portal)		
road 1v1	TKO Area 137 Magazine Site Track	4.35E-08
road 1v2	Wan Po Road (Chun Yat St- Chiu Shun Rd)	4.68E-08
road 1v3a	Chiu Shun Road (Wan Po Rd - Ngan O Rd)	3.95E-08
road 1v3b	Chiu Shun Road (Ngan O Rd - Po Ning Rd)	3.95E-08
road 1v4	Hang Hau Road	4E-08
road 1v5	Clear Water Bay Road (Hang Hau - Hiram's Highway)	4.03E-08
road 1v6a	Clear Water Bay Road (Hiram's Highway - Anderson Road)	3.97E-08
road 1v6b	Clear Water Bay Road (Anderson Road - New Clear Water Bay Rd Eastern Junction)	7.76E-08
road 1v7	New Clear Water Bay Road (Eastern Junction - Shun Lee Street)	7.32E-08
road 1v8	New Clear Water Bay Road (Shun Lee Street - Western Junction)	3.92E-08
road 1v9	Clear Water Bay Road (New Clear Water Bay Rd Western Junction - Lung Cheung Rd)	3.93E-08
road 1v10a	Lung Cheung Rd (Clear Water Bay Rd - Wong Kuk Ave)	2.7E-08
road 1v10b	Lung Cheung Rd (Wong Kuk Ave - Hammer Hill Rd)	2.7E-08
road 1v10c	Lung Cheung Rd (Hammer Hill Rd - Po Kong Village Rd)	2.7E-08
road 1v11a	Lung Cheung Rd (Po Kong Village Rd - Fung Mo St)	1.69E-08
road 1v11b	Lung Cheung Rd (Fung Mo St - Waterloo Rd)	1.03E-08
road 1v11c	Lung Cheung Rd (Lion Rock Tunnel Rd - Nam Cheong St)	1.05E-08
road 1v11d	Lung Cheung Rd / Cornwall St (Nam Cheong St - Tai Po Rd)	1.46E-08
road 1v12a	Tai Po Rd (Lung Cheung Rd - Tai Po Rd Int)	1E-08
road 1v12b	Tai Po Rd (Tai Po Rd Int - Caldecott Rd)	1.05E-08
road 1v12c	Tai Po Rd - Shatin Heights (Caldecott Rd - Keng Hau Rd)	1.06E-08
road 1v12d	Tai Po Rd - Shatin Heights (Keng Hau Rd - Shing Ho Rd)	1.92E-08
road 1v13a	Mei Tin Rd (Tai Po Rd (Tai Wai) - Tsuen Nam Rd)	1.99E-08
road 1v13b	Mei Tin Rd (Tsuen Nam Rd - Che Kung Miu Rd)	1.05E-08
road 1v14a	Che Kung Miu Rd (Mei Tin Rd - Tin Sam St)	1.02E-08
road 1v14b	Che Kung Miu Rd (Tin Sam St - Hin Keng St)	1.02E-08
road 1v15	Hin Keng Estate Access Rd	1.03E-08

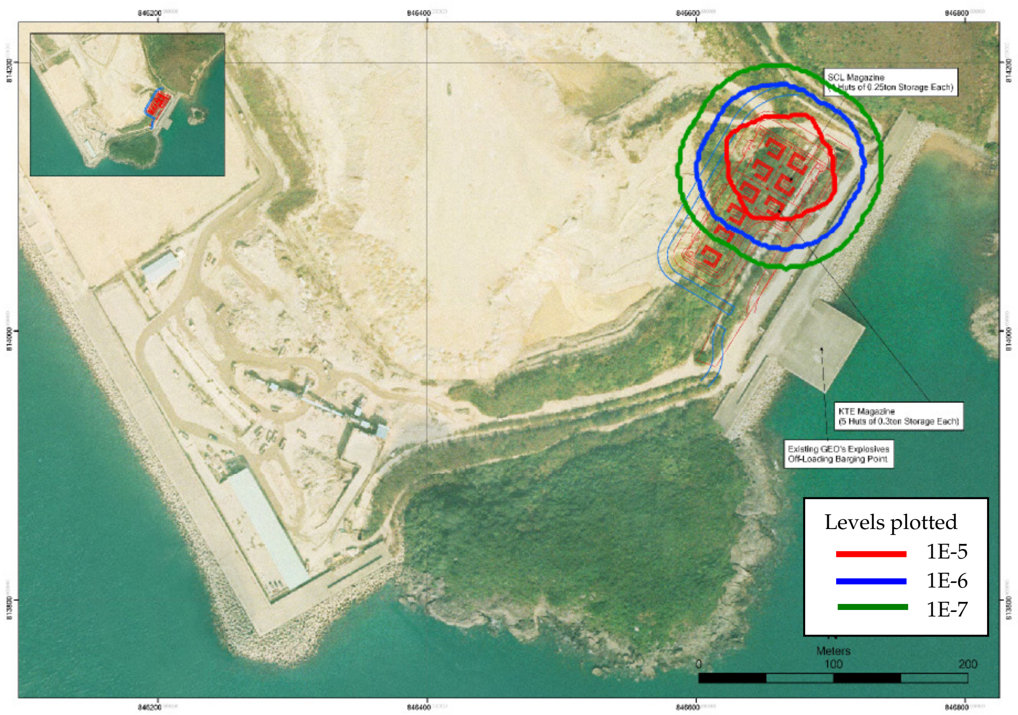
Figure 8.4 Maximum IR for the Delivery Routes from TKO Area 137 Magazine (Base Case)



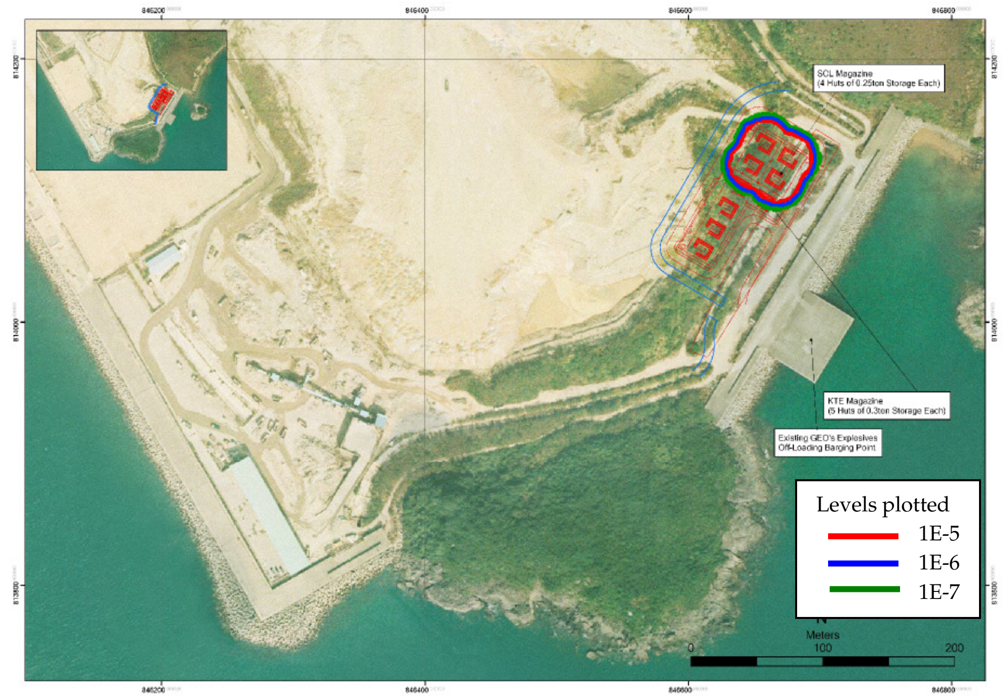
For the temporary storage Magazine, individual risk contours have been plotted and overlaid on plot layouts for TKO Area 137 site (*Figure 8.5*). IR contours (assuming a risk exposure factor of 100%) have been presented for both outdoor and indoor populations, with the 10^{-5} per year contour extending offsite in both cases. Persons indoors experience higher risks due to breaking windows and risk of building collapse. However, there are no buildings or structures nearby that lie within these contours and hence the outdoor contours are more appropriate. The maximum IR is about 1×10^{-4} per year considering the base frequency used in the analysis for explosion. This however, neglects to take into account presence factors. The temporary Magazine site is in a remote area and the 10^{-5} per year contours impact only on woodland areas where there is no continuous presence of people. The presence of people in these areas will be rare, with the nearest building being the Construction & Demolition material sorting facilities located about 400 m to the west of the temporary Magazine site. A presence factor of 2 hours/day (about 8%) has been given to an outside person being present in the area within 100 metres of the temporary Magazine. The most exposed population group will be Mines Delivery personnel who will be making/ receiving deliveries at the jetty. Such persons are not expected to be present more than 8% of the time (up to 4 personnel in 2 trucks, 2 hours per day, 6 days per week). 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 8.5 ***IR of the TKO Area 137***

Indoor



Outdoor



8.5 *UNCERTAINTY ANALYSIS AND SENSITIVITY TESTS*

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

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

Explosion Consequence Model

The employed ESTC model, or any other established TNT explosion model, tends to overpredict the number of fatalities (or, probability of fatality for an individual) when compared to the actual fatalities in past incidents related to explosives. It can be seen that no recorded incident involving road transport had resulted in more than 12 fatalities even in urban locations, while from the assessment, the maximum fatalities due to road transport is estimated as about 600. There is some conservatism in the model although it is acknowledged that given the dense urban environment in Hong Kong, the fatalities estimated during transport of explosives may not be too conservative.

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

Intervention of the Explosive Truck Crew

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

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

Intervention of the Fire Service Department

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

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

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

Escape and Evacuation

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

Explosive Initiation under Thermal Stimulus

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

9 ALARP ASSESSMENT

9.1 RISK RESULTS AND APPROACH TO ALARP

The Hazard to Life Assessment of the SCL (TAW-HUH) project has assessed the risks arising from the proposed temporary Magazine site in TKO Area 137 as well as the risks associated with the road transport from this site to the work areas. From *Section 8*, the risks posed by the storage and transport of explosives, for both base case and worst case, are 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, estimated at 6.23×10^{-4} 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 risk arising from explosive transport is much more significant than that of explosives storage; hence, the following assessment focuses on the transportation aspect of the explosives.

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

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

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

9.2 APPROACH TO ALARP ASSESSMENT

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

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

The safety benefits are evaluated as follows:

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

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

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

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

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

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

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

9.3 *MAXIMUM JUSTIFIABLE EXPENDITURE*

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

Maximum Justifiable Expenditure

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

Maximum Justifiable Expenditure = HK$ 33M x 20 x 6.23E-4 x 1.5
= HK$ 0.62M

The design life of a mitigation measure is assumed as 1.5 years based on the construction phase of the SCL (TAW-HUH) 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 to the following broad categories:

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

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

9.4.1 *Need for a Tunnel and Proposed Alignment*

According to the SCL Tai Wai to Hung Hom Section Preliminary Design Draft Final Report (MTR 1), the final alignment is the result of a considerable amount of investigation and review of numerous routes undertaken throughout the preliminary design stage. The different options were examined considering accessibility to users, capital cost, operation and maintenance costs, buildability, construction safety, durability and programme, interfaces with other parties. Also taken into account were constraints such as the orientation of the existing MTR lines, buildings and other major structures along the alignment.

Opting for any alternative alignment option will cost significantly more than the Maximum Justifiable Expenditure.

9.4.2 *Temporary Magazine Requirement and Selection Process*

Temporary Magazine Requirement

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

Temporary Magazine Selection Process

The temporary Magazine site selection process is documented in the SCL & KTE Location Study for Explosives Magazine report (MTR 4). 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 requires that the minimum separation distances to sensitive receivers stipulated in the UK Manufacture and Storage of Explosives Regulations 2005 are met. For the SCL (TAW-HUH) 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 - 54 m;
- Class B Receivers: Minor Road, Railway Line - 81 m;
- Class C Receivers: Major road, place of public resort - 161 m;
- Class D Receivers: Buildings- 180 m;
- Class E Receivers: Vulnerable Building- 161 m.

A number of the temporary magazine site options have been ruled out on the basis that they failed to meet the minimum separation distance requirements.

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 explosives carrying vehicles;
- Site constraints such as existing conditions;
- Land availability; and
- Environment and heritage impact.

Site Selection

The temporary magazine site selection has considered a total of 42 candidate sites and they are depicted in *Figure 9.1*. This selection process takes into account the following aspects:

- external separation distances,
- distance from mines delivery pier to temporary magazine site,
- average distance from temporary magazine to SCL (TAW-HUH) work sites,
- environmental and heritage impact,
- land availability, site constraints, and
- access of Mines explosives carrying vehicles

On this basis, the majority of the sites were found to have some constraints which made them impracticable for the project. The key constraints for each candidate site are summarised in *Table 9.1*.

Figure 9.1 Candidate Temporary Magazine Sites for the SCL (TAW-HUH) Project

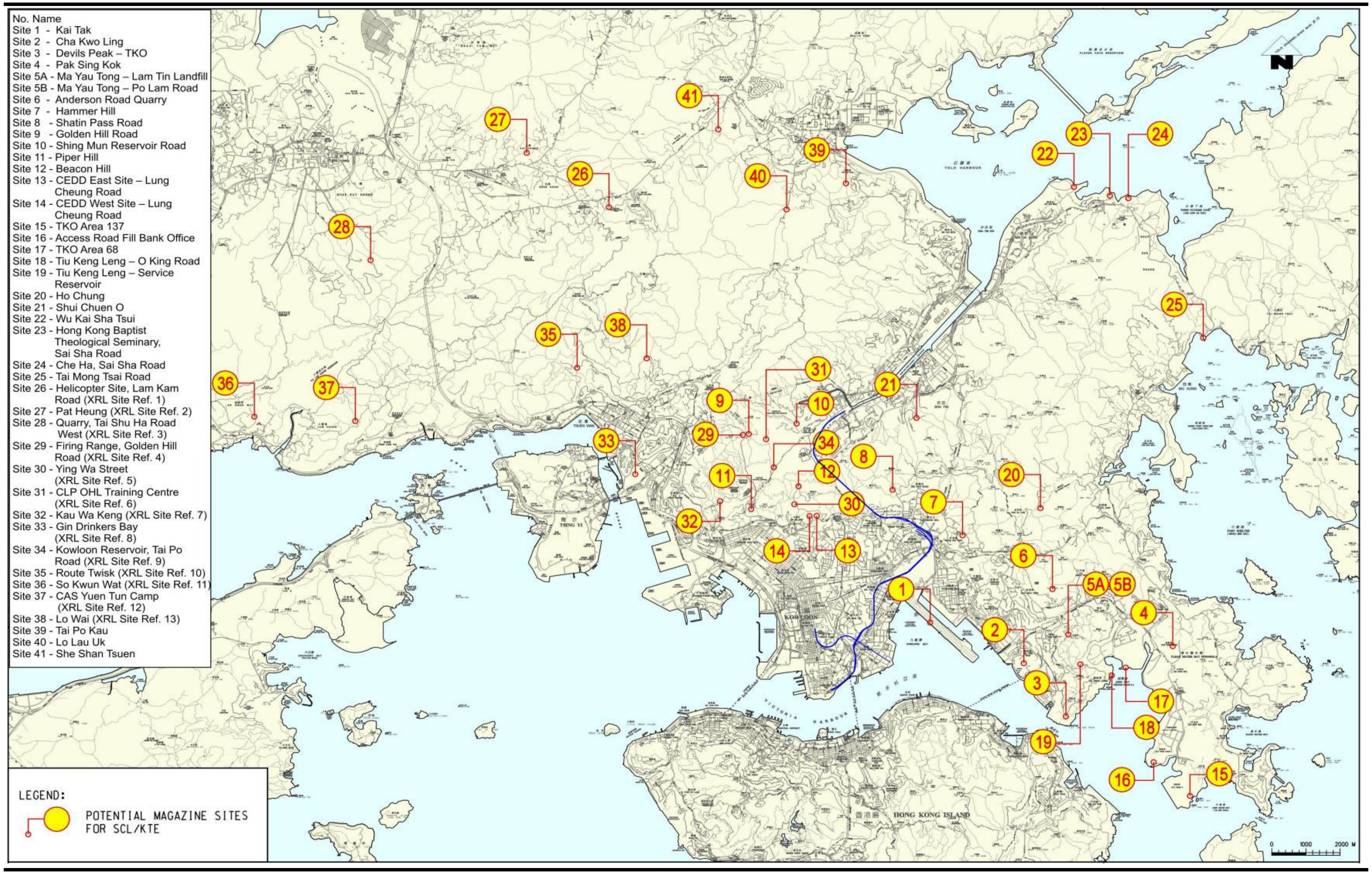


Table 9.1 Summary of Issues for Each Candidate Site

Site Ref	Site Name	Summary of Key Issues
1	Kai Tak	▪ The Kai Tak Development started in 2009 and work is ongoing in three phases ▪ Any potential magazine site being considered has to take into account the different phases of the Development. ▪ Minimal site formation required. ▪ Direct transport of explosives by Mines DG vessel constrained (no pier or landing point) ▪ Access road layout covers large parts of the site and the construction programme is ongoing from 2009 ▪ During the preliminary design stage, three sites were considered as possible vacant area between 2011 and 2013 for KTE/ SCL (TAW-HUH) explosives storage namely Kai Tak 1, Kai Tak 2 and Kai Tak 3. ▪ Kai Tak 1 is located at the northeast portion of the ex-airport runway and adjacent to the To Kwa Wan Typhoon Shelter, the barging points and site access roads. Due to the vicinity of these facilities, the mandatory external separation distance requirement for Kai Tak 1 cannot be satisfied. ▪ Two other sites, namely Kai Tak 2 (located in south apron area of ex-airport) and Kai Tak 3 (located in southeast portion of ex-airport runway), were also considered. However, with reference to the latest development plan, both sites would be in conflict to the Kai Tak development stage 1 roads works and Kai Tak 3 is in close vicinity to the cruise terminal. Therefore, the mandotory external separation distance requirement for both sites could not be satisfied.
2	Cha Kwo Ling	▪ Adjacent to the Cha Kwo Ling Tsuen, FEHD Depot and Sai Tso Wan Recreation Ground ▪ Government land, with a gun emplacement present. ▪ Site formation works and access road required. ▪ Mandatory external separation distance requirement cannot be met.
3	Devil's Peak	▪ No vehicular access road to the site ▪ Government land. ▪ Close to major access road for the TKO Chinese Permanent Cemetery and the villages along the coast to the south. ▪ Mandatory external separation distance requirement not met.
4	Pak Shing Kok	▪ Reserved for the residential development confirmed by Lands Department. ▪ Good access and minimal work required ▪ Mandatory external separation distance requirement cannot be met
5a	Ma Yau Tong (Site A)	▪ Situated at the EPD restored landfill area with a landfill gas extraction station along the access road ▪ Gas leaks from the landfill may be a risk to the magazine store and explosives transport vehicles ▪ Adjacent to the Lam Tin Park ▪ Mandatory external separation distance requirement cannot be met

Site Ref	Site Name	Summary of Key Issues
5b	Ma Yau Tong (Site B)	▪ Situated on the Government land current occupied by WSD Contract 13/WSD/07 which is planned for completion in Jan 2011 ▪ Existing access road very steep and narrow - requires substantial formation works. ▪ A few private lots with steel workshops, storage areas etc. nearby as well as a number of existing graves. ▪ Mandatory external separation distance requirement cannot be met.
6	Anderson Road Quarry	▪ Site is occupied by a quarry operator under operation until year 2013 and is not available for explosive storage ▪ Mandatory external separation distance requirement not met
7	Hammer Hill	▪ Government land with adequate space and good access. ▪ Adjacent to Discipline Service Quarter Blocks and Kingsford Terrace ▪ Mandatory external separation distance requirement cannot be met.
8	Shatin Pass Road	▪ Government land. ▪ Site formation required, including work on the access road (which has been subject to recent landslides). ▪ Fat Chong Temple, building platforms and numerous overhead power lines in the area. ▪ Mandatory external separation distance requirement cannot be met
9	Golden Hill	▪ Site lies within Kam Shan Country Park so potential for significant environmental impact. ▪ Good access but significant site formation required. ▪ Close to existing Police shooting range and a portion of the Maclehose Trail. ▪ Mandatory external separation distance requirement cannot be met
10	Shing Mun Reservoir Road	▪ Government land requiring clearance of trees. ▪ Access road steep with tight bends. ▪ Nearby residential buildings (LakeView Garden) and public road. ▪ Mandatory external separation distance requirement cannot be met
11	Piper Hill	▪ Government land. ▪ Access road steep with tight bends. Also insufficient area to turn vehicles. ▪ Close to a power cable pylon at the north, Maclehose Trail at the north east and Tai Po Road at both south and west sides ▪ Mandatory external separation distance requirement cannot be met
12	Beacon Hill	▪ Site lies within the Lion Rock Country Park; potential for significant environmental impact. ▪ Close to a part of Maclehose Trail at the south side ▪ Steep terrain, including narrow steep access road in poor condition. ▪ Mandatory external separation distance requirement cannot be met.

Site Ref	Site Name	Summary of Key Issues
13	CEDD East Site	▪ Site currently occupied by HyD works ▪ Adequate level platforms present, however access road narrow and steep. ▪ Next to Lung Cheung Road and close to residential block Phoenix House and WSD M&E Workshop ▪ Mandatory external separation distance requirement cannot be met.
14	CEDD West Site	▪ Government land- occupied by CEDD ▪ Large level platforms present and satisfactory access. ▪ Site is next to Lung Cheung Road and close to residential block Beacon Heights ▪ Mandatory external separation distance requirement cannot be met.
15	TKO Area 137	▪ Currently managed by CEDD. ▪ A remote area with no public access nearby ▪ Very good clearance from properties and nearby facilities with no existing buildings or other sensitive receivers within the extent of the mandatory external separation distance zone ▪ Easy delivery from Mines Division Pier (close to an existing CEDD off-loading point) ▪ Adequate access road currently in use by Mines Division vehicles. ▪ Minor site formation required (preparation of a level platform, access road and surface system for the magazine complex). ▪ Mandatory external separation distance requirement met.
16	Access Road, Fill Bank Office	▪ Currently occupied by CEDD. ▪ Adequate space and paved access road. ▪ Existing site office and fill bank loading jetties nearby. ▪ Mandatory external separation distance requirement cannot be met.
17	TKO Area 68	▪ Within the CEDD works site for TKO further Development – Infrastructure Works at Town Centre South and Tiu Keng Leng. The CEDD works to be completed in 2012 ▪ Close to the new public roads formed under the CEDD contract ▪ Site subject top storm damage from rough seas in bad weather. The seawall is in bad condition with settlement and typhoon damage ▪ Mandatory external separation distance requirement cannot be met.
18	Tiu Keng Leng, O King Road	▪ Government land. ▪ Limited level area adjacent to sea wall ▪ Paved access road. ▪ Situated next to O King Road and Ocean Shores residential block ▪ Mandatory external separation distance requirement cannot be met.

Site Ref	Site Name	Summary of Key Issues
19	Tiu Keng Leng Service Reservoir	▪ Government land. ▪ Inadequate level areas present. ▪ Narrow paved access road. ▪ Close to WSD service reservoir and O King public road. ▪ Mandatory external separation distance requirement cannot be met.
20	Ho Chung	▪ Government land. ▪ Inadequate level areas present. ▪ Narrow paved access road may need upgrading. ▪ Within Ma On Shan Country Park, next to the Wilson Trial. ▪ Mandatory external separation distance requirement cannot be met.
21	Shui Chuen O	▪ Government land but scheduled for development by the Housing Department (HD) ▪ Existing level areas present, minimum site formation required. ▪ Easy access and flat ground. ▪ Area rezoned and is now part of the proposed development. ▪ Mandatory external separation distance requirement cannot be met.
22	Wu Kai Sha Tsui	▪ Government land, requires clearance of trees. ▪ Inadequate level areas present, significant site formation required. ▪ Paved access road. ▪ Whitehead Club and Golf Driving Range nearby ▪ Mandatory external separation distance requirement cannot be met.
23	Hong Kong Baptist Theological Seminary, Sai Sha Road	▪ Government land, currently used as car parking area, limited in size. ▪ Some site formation required. ▪ Unpaved access road. ▪ To the of north of Hong Kong Baptist Theological Seminary is Sai O Pigging Station ▪ Mandatory external separation distance requirement cannot be met.
24	Che Ha, Sai Sha Road	▪ Government land requires significant tree felling. ▪ No suitable site identified. ▪ Unpaved village access road. ▪ Che Ha Village and private tree nursery nearby. ▪ Mandatory external separation distance requirement cannot be met.
25	Tai Mong Tsai Road	▪ Government land. ▪ Site formation required.

Site Ref	Site Name	Summary of Key Issues
		▪ No vehicle access to the site. ▪ Nearby a roundabout of Tai Mong Tsai Road/ Sai Sha Road and public BBQ area of country park. ▪ Mandatory external separation distance requirement cannot be met.
26	Helicopter Site, Lam Kam Road (XRL Site Ref. 1)	▪ Government owned, currently used by Plan D for storage of confiscated goods. ▪ Next to Heliservice office compound and Lam Kam Road (Major Road). ▪ Mandatory external separation distance requirement cannot be met.
27	Pat Heung (XRL Site Ref. 2)	▪ Private agricultural land. ▪ No public access to the road. ▪ The narrowed village access road with tight bends and constricted crossing over open nullah is the only access road to the site. ▪ Mandatory external separation distance requirement cannot be met.
28	Qarry, Tai Shu Ha Road West (XRL site ref. 3)	▪ Government owned, area of disused borrow pits. ▪ Relatively flat area, low level vegetation. ▪ Fully surfaced wide public roads to the site from Yuen Long ▪ Currently used by XRL and is not available.
29	Firing Range, Golden Hill Road (XRL Site Ref. 3)	▪ Government owned, currently used by existing firing range area. ▪ Minimal site formation required. ▪ Mandatory external separation distance requirement cannot be met.
30	Ying Wa Street	▪ Government owned. ▪ Steeply sloping site. ▪ Significant formation /slope works required. ▪ Mandatory external separation distance requirement cannot be met.
31	CLP OHL Training Centre	▪ Currently used by CLP as OHL training school. ▪ Road very narrow, steep and twisty. ▪ Mandatory external separation distance requirement cannot be met.
32	Kau Wa Keng	▪ Government owned, granted to WSD. ▪ Road very narrow, steep and twisty. ▪ Mandatory external separation distance requirement cannot be met.

Site Ref	Site Name	Summary of Key Issues
33	Gin Drinkers Bay	▪ Government owned. ▪ Former landfill site still producing large volumes of explosive methane gas. ▪ Mandatory external separation distance requirement cannot be met.
34	Kowloon Reservoir, Tai Po Road	▪ Government owned. ▪ Close to Tai Po road, Kowloon Reservoir and some existing buildings ▪ Mandatory external separation distance requirement cannot be met.
35	Route Twisk	▪ Government owned. ▪ Road very narrow, steep and twisty ▪ Mandatory external separation distance requirement cannot be met.
36	So Kwun Wat	▪ Currently used by XRL and is not available.
37	CAS Yuen Tun Camp	▪ Currently used for outdoor training and activities ▪ Access road is steep and narrow in paces and poorly maintained. ▪ Close to building structures of Camp site and several footpaths. ▪ Mandatory external separation distance requirement cannot be met.
38	Lo Wai	▪ Private land and is not available. ▪ Close to building structures of Camp site and several footpaths. ▪ Mandatory external separation distance requirement cannot be met.
39	Tai Po Kau	▪ Private agricultural land and is not available. ▪ Minor site formation works required. ▪ Mandatory external separation distance requirement cannot be met.
40	Lo Lau Uk	▪ Partly government owned and partly private land. ▪ Site is liable to flooding due to runoff from adjacent river. ▪ Mandatory external separation distance requirement cannot be met.
41	She Shan Tsuen	▪ Private agricultural land and is not available. ▪ Minor site formation works required. ▪ Mandatory external separation distance requirement cannot be met.

Note:
(1) For details, refer to SCL / KTE Location Study for Explosives Magazine report (Ref MTR 4)
(2) Mandatory external separation distance requirements referred to 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*".

The magazine site selection process has been taken forward to this ALARP assessment. Those candidate sites that are in non-compliance with the Commissioner of Mines' mandatory external separation requirements can be translated into 'impracticable' and therefore ruled out of contention. The remaining site, namely the TKO Area 137 site has been selected for further site evaluation.

9.4.3 *Use of Magazines Closer to the Construction Sites*

Amongst the initially proposed list of magazine sites, only 1 site was retained as practicable; which is TKO Area 137.

TKO Area 137: This site is in a remote area with no public access nearby. It would be required to supply all blasting sites within the Kowloon area, and by dividing the temporary magazine site into several buildings with adequate internal separation distances, this site can provide sufficient storage capacity. The site is also convenient for the Mines Delivery with a pier nearby for deliveries. It is generally remote from the blasting sites, but as there are many different blasting locations within Kowloon, any temporary magazine site would require a certain amount of overland transport to the blasting locations.

The only practicable location for the temporary Magazine site is therefore TKO Area 137. This site has been used as the basis for this hazard to life assessment.

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 sectors renders the option not practicable since it could lead to several months of project delay.

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

9.4.5 *Use of Alternative Routes*

The shortest route has generally been selected for explosive deliveries to sites. Selecting an alternative route has negligible costs and therefore presents a

viable option. Based on a review of the possible transport routes for this project, Po Lam Road or Anderson Road have been presented as alternative routes to Ma Chai Hang Ventilation Building and Shansi Street Shaft, and Sai Sha Road (via Sai Kung) as an alternative route to Hing Keng Portal. The alternative routes to be explored in the context of risk are depicted in *Figures 9.2, 9.3 and 9.4*.

This option has been selected for further analysis.

9.4.6 *Use of Different Explosive Types*

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

The detonating cord in this project uses a PETN core with a melting point of around 140 degC. Different detonating cord technologies are available such as those using a RDX or HMX core with a slightly higher melting point (210 degC and 276 degC). This may offer more time before an explosion occurs following a fire event. The time gained and risk reduction achieved by implementing these technologies would however be negligible for the purpose of this assessment. This option is therefore not considered further.

9.4.7 *Use of Combined Road/Marine Transport Option*

The combined Road/Marine transport option from the temporary magazine site to the SCL (TAW-HUH) construction sites was also considered, based on the SCL/KTE Magazine Site Selection Report (MTR 4), but ruled out due to the following impracticalities:

- DG (Shipping) Regs Cap 295 prohibits overnight (sunset to sunrise) transport of explosives through the harbour. Therefore, road transport from the Magazine to the SCL (TAW-HUH) construction sites will be required for all the early morning and late evening blasts. Given the cycle times of blast timing and the preference to generally avoid blast times between say, 10pm and 6am in shallow depth tunnels within the residential areas, these early morning / late night blasts will represent the vast majority of SCL (TAW-HUH) blasts.

- Public piers were studied to examine the option of delivering explosives by sea. For this option, the pier would have to satisfy the general requirements provided by Mines Division (CEDD 5) which include separation distance requirements. The key requirements by Mines Division include, amongst others:

    - Separation distance requirements, as used by the Port Authority of Queensland, with such area required to be cleared of non-essential persons. For the load to be transported in this project, the minimum separation distance requirement is 44m;

    - Suitable berthing facilities;

- Suitable water depth; and
- Firefighting facilities.

It should be noted that explosives delivery vessels are not permitted to enter typhoon shelters.

Following this survey, it was concluded that, there is no public pier available for transporting explosives for the SCL (TAW-HUH) project.

- For the construction of a pier (including a new Dangerous Goods pier), approval is necessary under the Foreshore and Sea-bed (Reclamation) Ordinance (FSRO). This involves application to the District Lands Office, internally circulation amongst Government departments, clearance from the Department of Justice to publish a draft gazette, a 60 day period for public response and then final approval. The process may take up to 18 months if an environmental permit is also required, either through a direct application or through an Environmental Impact Assessment. Construction would take 9 additional months. The project programme will be subject to significant delay and therefore this option is not practicable. Additionally, within the harbour area, the conditions of the Protection of the Harbour Ordinance cannot be satisfied as reclamation and marine piling in the harbour would be required for the construction of a pier.

- The option of transporting explosives from the temporary Magazine site to a vertical seawall near the construction site was also considered. Seawalls do not generally meet the general requirements from Mines Division described above. Suitable berthing and tie-in facilities would need to be provided to meet the general requirements provided by Mines Division (CEDD 5). The construction requirements for such facilities will involve modifications to the seabed thereby requiring gazettal under Foreshore and Sea-bed (Reclamation) Ordinance and will violate the Protection of the Harbour Ordinance.

- This option also poses additional constraints such that the construction will be dependent on sea conditions: tide, waves, etc.

This option is therefore not considered practicable.

9.4.8 *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' (or mini 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$ 500,000 higher (for 75%/25% PETN – TNT cast boosters) than the cost of 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 cartridged emulsion. There are also some limitations in the availability of 'cast boosters' since the number of suppliers who can provide this material is limited.

This option has been selected for further analysis.

9.4.9 *Safer Explosives Truck Design*

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

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

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

9.4.10 *Lower Frequency of Explosives Transport*

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

9.4.11 *Reduction of Accident Involvement Frequency*

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

9.4.12 Reduction of Fire Involvement Frequency

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

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

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

9.4.13 Summary

In summary, the following options have been considered for further safety benefit evaluation and cost-benefit analysis.

Option 1: Use of Alternative Routes – Po Lam Road, Anderson Road, Sai Kung

Option 2: Use of Smaller Quantities of Explosives

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

9.5 OPTION CASE 1 - USE OF ALTERNATIVE ROUTES: PO LAM ROAD, ANDERSON ROAD AND SAI SHA ROAD (VIA SAI KUNG)

9.5.1 Population along the alternative transport routes

For the delivery points at Ma Chai Hang Ventilation Building and Shansi Street Shaft there are two possible alternative routes that can be assessed. For the delivery point at Hin Keng Portal there is one alternative route that can be assessed.

Details of the two alternative routes from TKO Area 137 magazine site to Ma Chai Hang Ventilation Building and Shansi Street Shaft are provided in *Table 9.2* and *Table 9.3* and shown in *Figure 9.2* and *Figure 9.3*. The population estimation methodology along the transport routes is the same as the base case described in *Section 4.*

The Po Lam Road and Anderson Road alternative options are valid for the delivery points in the Kowloon area (namely Ma Chai Hang Ventilation Building and Shansi Street Shaft). For the Hin Keng Portal there is a third alternative delivery route using Sai Sha Road (via Sai Kung). This is shown in Figure 9.4 and described in *Table 9.4* below.

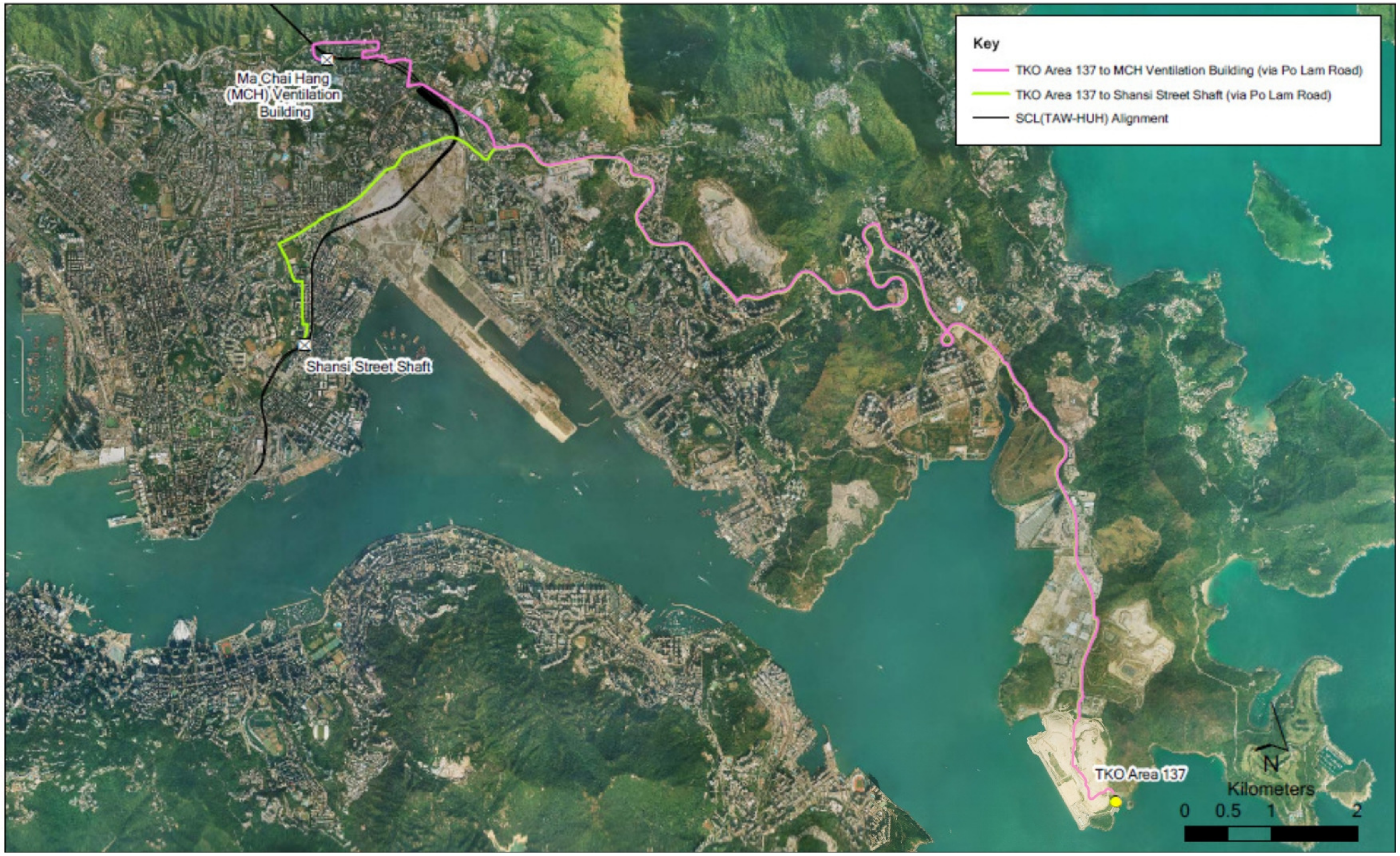
Table 9.5 provides a comparison of transport distances to each work site between Clear Water Bay Road and Po Lam Road.

Table 9.2 Alternative Delivery Routes for the Ma Chai Hang Ventilation Building and Shansi Street Shaft via Po Lam Road

Tag	Description
Route 4d (TKO Area 137 –Ma Chai Hang Ventilation Building)	
Road 4d1	TKO Area 137 Magazine Site Track
Road 4d2	Wan Po Road (Chun Yat St- Chiu Shun Rd)
Road 4d3	Wan Po Road (Chiu Shun Rd - Po Shun Rd)
Road 4d4a	Po Hong Road (Wan Po Rd - Wan Lung Rd)
Road 4d4b	Po Hong Road (Wan Lung Rd - Wan Hang Rd)
Road 4d4c	Po Hong Road (Wan Hang Rd - Po Fung Rd)
Road 4d4d	Po Hong Road (Po Fung Rd - Po Lam Rd N)
Road 4d5a	Po Lam Road N (Po Hong Rd - Tsui Lam Rd)
Road 4d5b	Po Lam Road N (Tsui Lam Rd E Jun - W Jun)
Road 4d6a	Po Lam Road (Tsui Lam Rd - Anderson Rd)
Road 4d6b	Po Lam Road (Anderson Rd - Sau Mau Ping Rd)
Road 4d7a	Sau Mau Ping Road (Po Lam Rd - Sau Mau Path)
Road 4d7b	Sau Mau Ping Road (Sau Mau Path - Sau Ming Rd)
Road 4d7c	Sau Mau Ping Road (Sau Ming Rd - Hip Wo St)
Road 4d8a	Shun Lee Tsuen Road (Hip Wo St - Shun King St)
Road 4d8b	Shun Lee Tsuen Road (Shun King St - Clear Water Bay Rd)
Road 4d9	New Clear Water Bay Road (Eastern Junction - Shun Lee Street)**
Road 4d10	New Clear Water Bay Road (Shun Lee Street - Western Junction)
Road 4d11	Clear Water Bay Road (New Clear Water Bay Rd Western Junction - Lung Cheung Rd)
Road 4d12a	Lung Cheung Rd (Clear Water Bay Rd - Wong Kuk Ave)**
Road 4d12b	Lung Cheung Rd (Wong Kuk Ave - Hammer Hill Rd)**
Road 4d12c	Lung Cheung Rd (Hammer Hill Rd - Po Kong Village Rd)**
Road 4d13	Po Kong Village Rd (Lung Cheung Rd - Fung Tak Rd)

Tag	Description
Road 4d14	Fung Tak Rd (Po Kong Village Rd - Sheung Fung St)**
Road 4d15	Wong Tai Sin Rd + Fung Tak Rd (Sheung Fung St - Ma Chai Hang Rd)**
Road 4d16	Nga Chuk St
Road 4d17	Chuk Yuen Rd (Nga Chuk St - Ma Chai Hang Rd)**
Road 4d18	Ma Chai Hang Rd (Chuk Yuen St - Ma Chai Hang Rd Ra)**
Route 4e (TKO Area 137 – Shansi Street)	
Road 4e1	TKO Area 137 Magazine Site Track
Road 4e2	Wan Po Road (Chun Yat St- Chiu Shun Rd)
Road 4e3	Wan Po Road (Chiu Shun Rd - Po Shun Rd)
Road 4e4a	Po Hong Road (Wan Po Rd - Wan Lung Rd)
Road 4e4b	Po Hong Road (Wan Lung Rd - Wan Hang Rd)
Road 4e4c	Po Hong Road (Wan Hang Rd - Po Fung Rd)
Road 4e4d	Po Hong Road (Po Fung Rd - Po Lam Rd N)
Road 4e5a	Po Lam Road N (Po Hong Rd - Tsui Lam Rd)
Road 4e5b	Po Lam Road N (Tsui Lam Rd E Jun - W Jun)
Road 4e6a	Po Lam Road (Tsui Lam Rd - Anderson Rd)
Road 4e6b	Po Lam Road (Anderson Rd - Sau Mau Ping Rd)
Road 4e7a	Sau Mau Ping Road (Po Lam Rd - Sau Mau Path)
Road 4e7b	Sau Mau Ping Road (Sau Mau Path - Sau Ming Rd)
Road 4e7c	Sau Mau Ping Road (Sau Ming Rd - Hip Wo St)
Road 4e8a	Shun Lee Tsuen Road (Hip Wo St - Shun King St)
Road 4e8b	Shun Lee Tsuen Road (Shun King St - Clear Water Bay Rd)
Road 4e9	New Clear Water Bay Road (Eastern Junction - Shun Lee Street)**
Road 4e10	New Clear Water Bay Road (Shun Lee Street - Western Junction)
Road 4e11	Clear Water Bay Road (New Clear Water Bay Rd Western Junction - Lung Cheung Rd)
Road 4e12	Clear Water Bay Road (Lung Ccheung Rd - Kwun Tong Rd)
Road 4e13a	Prince Edward Road INT (Kwun Tong Rd - Kwun Tong Bypass)
Road 4e13b	Prince Edward Road INT (Kwun Tong Bypass - Prince Edward Rd)
Road 4e13c	Prince Edward Road INT (Prince Edward Rd East - Choi Hung Rd)
Road 4e13d	Prince Edward Road East (Choi Hung Rd - The Nullah)
Road 4e13e	Prince Edward Road East & FO (The Nullah - Prince Edward Rd W) -1st Section
Road 4e13f	Prince Edward Road East & FO (The Nullah - Prince Edward Rd W) - 2nd Section
Road 4e14a	Argyle Street (Prince Edward Road W - Kowloon City Int)
Road 4e14b	Argyle Street (Kowloon City Int - Fu Ning St)
Road 4e14c	Argyle Street (Fu Ning St - Lomond Rd)
Road 4e14d	Argyle Street (Lomond Rd - Tin Kwong Rd)
Road 4e15	Tin Kwong Rd (Argyle St - Sheung Shing St)
Road 4e16	Kau Pui Lung Rd
Road 4e17	Chi Kiang St
Road 4e18	Ko Shan Rd (Chi Kiang St - Pak Kung St)**
Road 4e19	Shansi St

Figure 9.2 Alternative routes (Po Lam Road) to MCH Ventilation Building and Shansi Street Shaft



As well as the Po Lam Road alternative route for the Ma Chai Hang and Shansi Street delivery points as shown in *Figure 9.2* and described in *Table 9.4* there is a second alternative: Anderson Road although longer will also be evaluated. This is shown in *Figure 9.3* and described in *Table 9.5* below.

Table 9.3 ***Alternative Delivery Routes for the Ma Chai Hang Ventilation Building and Shansi Street Shaft via Anderson Road***

Tag	Description
Route 5d (TKO Area 137 –Ma Chai Hang Ventilation Building)	
Road 5d1	TKO Area 137 Magazine Site Track
Road 5d2	Wan Po Road (Chun Yat St- Chiu Shun Rd)
Road 5d3	Wan Po Road (Chiu Shun Rd - Po Shun Rd)
Road 5d4a	Po Hong Road (Wan Po Rd - Wan Lung Rd)
Road 5d4b	Po Hong Road (Wan Lung Rd - Wan Hang Rd)
Road 5d4c	Po Hong Road (Wan Hang Rd - Po Fung Rd)
Road 5d4d	Po Hong Road (Po Fung Rd - Po Lam Rd N)
Road 5d5a	Po Lam Road N (Po Hong Rd - Tsui Lam Rd)
Road 5d5b	Po Lam Road N (Tsui Lam Rd E Jun - W Jun)
Road 5d6a	Po Lam Road (Tsui Lam Rd - Anderson Rd)
Road 5d6b	Po Lam Road (Anderson Rd - Sau Mau Ping Rd)
Road 5d7a	Anderson Road (Clear Water Bay Road - Po Lam Rd) - 1st Section
Road 5d7b	Anderson Road (Clear Water Bay Road - Po Lam Rd) - 2nd Section
Road 5d8	Clear Water Bay Road (Anderson Road - New Clear Water Bay Rd Eastern Junction)**
Road 5d9	New Clear Water Bay Road (Eastern Junction - Shun Lee Street)**
Road 5d10	New Clear Water Bay Road (Shun Lee Street - Western Junction)
Road 5d11	Clear Water Bay Road (New Clear Water Bay Rd Western Junction - Lung Cheung Rd)
Road 5d12a	Lung Cheung Rd (Clear Water Bay Rd - Wong Kuk Ave)**
Road 5d12b	Lung Cheung Rd (Wong Kuk Ave - Hammer Hill Rd)**
Road 5d12c	Lung Cheung Rd (Hammer Hill Rd - Po Kong Village Rd)**
Road 5d13	Po Kong Village Rd (Lung Cheung Rd - Fung Tak Rd)
Road 5d14	Fung Tak Rd (Po Kong Village Rd - Sheung Fung St)**
Road 5d15	Wong Tai Sin Rd + Fung Tak Rd (Sheung Fung St - Ma Chai Hang Rd)**
Road 5d16	Nga Chuk St
Road 5d17	Chuk Yuen Rd (Nga Chuk St - Ma Chai Hang Rd)**
Road 5d18	Ma Chai Hang Rd (Chuk Yuen St - Ma Chai Hang Rd Ra)**
Route 5e (TKO Area 137 – Shansi Street)	
Road 5e1	TKO Area 137 Magazine Site Track
Road 5e2	Wan Po Road (Chun Yat St- Chiu Shun Rd)
Road 5e3	Wan Po Road (Chiu Shun Rd - Po Shun Rd)
Road 5e4a	Po Hong Road (Wan Po Rd - Wan Lung Rd)
Road 5e4b	Po Hong Road (Wan Lung Rd - Wan Hang Rd)
Road 5e4c	Po Hong Road (Wan Hang Rd - Po Fung Rd)
Road 5e4d	Po Hong Road (Po Fung Rd - Po Lam Rd N)
Road 5e5a	Po Lam Road N (Po Hong Rd - Tsui Lam Rd)
Road 5e5b	Po Lam Road N (Tsui Lam Rd E Jun - W Jun)
Road 5e6a	Po Lam Road (Tsui Lam Rd - Anderson Rd)
Road 5e6b	Po Lam Road (Anderson Rd - Sau Mau Ping Rd)
Road 5e7a	Anderson Road (Clear Water Bay Road - Po Lam Rd) - 1st Section
Road 5e7b	Anderson Road (Clear Water Bay Road - Po Lam Rd) - 2nd Section Section
Road 5e8	Clear Water Bay Road (Anderson Road - New Clear Water Bay Rd Eastern Junction)**
Road 5e9	New Clear Water Bay Road (Eastern Junction - Shun Lee Street)**
Road 5e10	New Clear Water Bay Road (Shun Lee Street - Western Junction)

Tag	Description
Road 5e11	Clear Water Bay Road (New Clear Water Bay Rd Western Junction - Lung Cheung Rd)
Road 5e12	Clear Water Bay Road (Lung Cheung Rd - Kwun Tong Rd)
Road 5e13a	Prince Edward Road INT (Kwun Tong Rd - Kwun Tong Bypass)
Road 5e13b	Prince Edward Road INT (Kwun Tong Bypass - Prince Edward Rd)
Road 5e13c	Prince Edward Road INT (Prince Edward Rd East - Choi Hung Rd)
Road 5e13d	Prince Edward Road East (Choi Hung Rd - The Nullah)
Road 5e13e	Prince Edward Road East & FO (The Nullah - Prince Edward Rd W) -1st Section
Road 5e13f	Prince Edward Road East & FO (The Nullah - Prince Edward Rd W) - 2nd Section
Road 5e14a	Argyle Street (Prince Edward Road W - Kowloon City Int)
Road 5e14b	Argyle Street (Kowloon City Int - Fu Ning St)
Road 5e14c	Argyle Street (Fu Ning St - Lomond Rd)
Road 5e14d	Argyle Street (Lomond Rd - Tin Kwong Rd)
Road 5e15	Tin Kwong Rd (Argyle St - Sheung Shing St)
Road 5e16	Kau Pui Lung Rd
Road 5e17	Chi Kiang St
Road 5e18	Ko Shan Rd (Chi Kiang St - Pak Kung St)**
Road 5e19	Shansi St

Figure 9.3 Alternative routes (Anderson Road) to MCH Ventilation Building and Shansi Street Shaft

The Po Lam Road and Anderson Road alternative options are valid for the delivery points in the Kowloon area (namely Ma Chai Hang Shaft and Shansi Street Shaft). For the Hin Keng Portal there is a third alternative delivery route using Sai Sha Road (via Sai Kung). This is shown in *Figure 9.4* and described in *Table 9.4* below.

Table 9.4 Alternative Delivery Route for the Hin Keng Portal via Sai Kung (Sai Sha Road)

Tag	Description
Route 1w (TKO Area 137 –Hin Keng Portal)	
Road 1w1	TKO Area 137 Magazine Site Track
Road 1w2	Wan Po Road (Chun Yat St- Chiu Shun Rd) **
Road 1w3a	Chiu Shun Road (Wan Po Rd - Ngan O Rd)**
Road 1w3b	Chiu Shun Road (Ngan O Rd - Po Ning Rd)**
Road 1w4	Hang Hau Road
Road 1w5	Clear Water Bay Road (Hang Hau - Hiram's Highway)
Road 1w6	Hiram's Highway (Clear Water Bay Rd - Po Tung Rd)
Road 1w7	Po Tung Rd & Tai Ming Tsai Rd (Hiram's Highway - Yan Yee Rd)
Road 1w8a	Sai Sha Rd (Tai Mong Tsai Rd - Po Tung Rd)
Road 1w8b	Sai Sha Rd (Nai Chung - Ma On Shan Rd)
Road 1w9a	Ma On Shan Rd (Hang Hong St Ra-Hang Shun St)
Road 1w9b	Ma On Shan Rd (Hang Shun Street - Slip Rd To & From Tate's Cairn Highway)
Road 1w10	Tate's Cairn Highway Slip Rd (Ma On Shan Rd Nr Hang Shun St - Tate's Cairn Highway)
Road 1w11	She Lek Highway (Tate's Cairn Highway INT - Slip Rd From Sha Tin Wai Rd)
Road 1w12a	Sha Tin Wai Rd (Ngan Shing St - Sha Tin Rd)
Road 1w12b	Sha Tin Rd (Sha Tin Wai Rd - Lion Rock Tunnel Road)
Road 1w13	Sha Kok St (Sha Tin Wai Rd - Tai Chung Kiu Rd)
Road 1w14	Tai Chung Kiu Rd (Sha Kok Rd - Lion Rock Tunnel Rd)
Road 1w15a	Che Kung Miu Rd (Lion Rock Tunnel Rd - Sha Tin Tau Rd)
Road 1w15b	Che Kung Miu Rd (Sha Tin Tau - Mei Tin Rd)
Road 1w15c	Che Kung Miu Rd (Mei Tin Rd - Tin Sam Rd)
Road 1w15d	Che Kung Miu Rd (Tin Sam St - Hin Keng St)
Road 1w16	Hin Keng Estate Access Rd

Figure 9.4 Alternative route (Sai Sha Road) for Hin Keng Portal

Table 9.5 **_Transport Distance to each work site via Clear Water Bay Road, Po Lam Road, Anderson Road and Sai Kung_**

Work site	Transport Distance (km)			
	Via Clear Water Bay Road	Via Po Lam Road (alternative route)	Via Anderson Road (alternative route)	Via Sai Kung (Sai Sha Road - alternative route)
Ma Chai Hang	20.71	17.77	19.27	-
Shansi Street	21.55	18.61	22.75	-
Hin Keng Portal	31.42	-	-	35.15

9.5.2 *Scenarios Considered*

The scenarios considered (as shown in *Table 9.6*) are identical to the Worst Case Scenario although the routes are different.

Table 9.6 *Scenarios Considered in Option Case 1 Assessment*

Tag	Scenario	Explosives load (TNT eqv. kg)
Storage of Explosives		
01	Detonation of full load of explosives in one store in TKO Area 137 site	301
02	Detonation of full load of explosives in one contractor truck on the access road within the TKO Area 137 magazine site boundary	194*
Transport of Explosives		
03	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 site to Ma Chai Hang delivery point	156*
04	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 to Shansi Street delivery point	193*
05	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 to Hin Keng Portal delivery point	194*

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

As the number of trips and explosives loads are the same as in the worst case scenario, and only the transport routes are different, the extent of consequences (impact distances) based on the explosive loads are also the same as in the worst case scenario, as shown 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 TKO Area 137 site	301	90% 50% 10% 3% 1%	20.6 23.9 35.4 47.3 61.1	90% 50% 10% 3% 1%	16.5 17.2 19.0 20.4 21.5
02	Detonation of full load of explosives in one contractor truck on the access road within the TKO Area 137 magazine site boundary	194*	90% 50% 10% 3% 1%	17.9 20.7 30.6 40.9 52.7	90% 50% 10% 3% 1%	14.3 14.9 16.5 17.6 18.7
Transport of Explosives						
03	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 site to Ma Chai Hang delivery point	156*	90% 50% 10% 3% 1%	16.6 19.2 28.5 38.1 49.5	90% 50% 10% 3% 1%	13.3 13.9 15.3 16.4 17.4
04	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 to Shansi Street delivery point	193*	90% 50% 10% 3% 1%	17.8 20.6 30.6 40.8 52.6	90% 50% 10% 3% 1%	14.3 14.9 16.4 17.6 18.6
05	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 to Hin Keng Portal delivery point	194*	90% 50% 10% 3% 1%	17.9 20.7 30.6 40.9 52.7	90% 50% 10% 3% 1%	14.3 14.9 16.5 17.6 18.7

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

The resulting F-N curves for the alternative route options are shown in *Figure 9.5* and *Figure 9.6*. Since the Po Lam Road and Anderson Road options are to the same delivery points they are shown together for comparison purposes with the original delivery route using Clear Water Bay Road in *Figure 9.5*.

The risk comparison between the original transport route from TKO Area 137 along Clear Water Bay Road and Tai Po Road to Hin Keng Portal and the alternative route via Sai Kung to Hin Keng Portal is shown separately in *Figure 9.6*.

Figure 9.5 F-N Curve for Alternative Routes to Ma Chai Hang Ventilation Building and Shansi Street Shaft: Po Lam Road and Anderson Road options

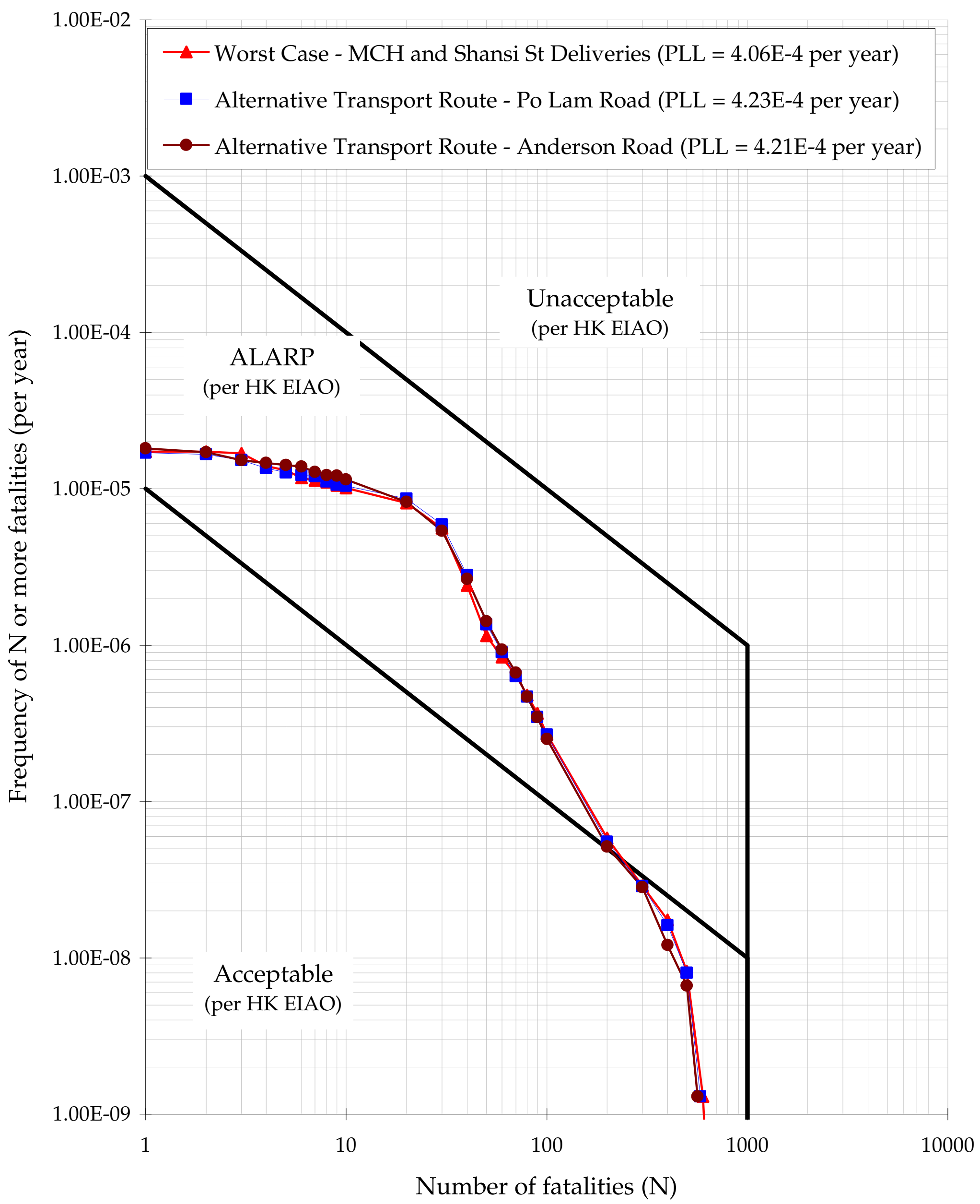
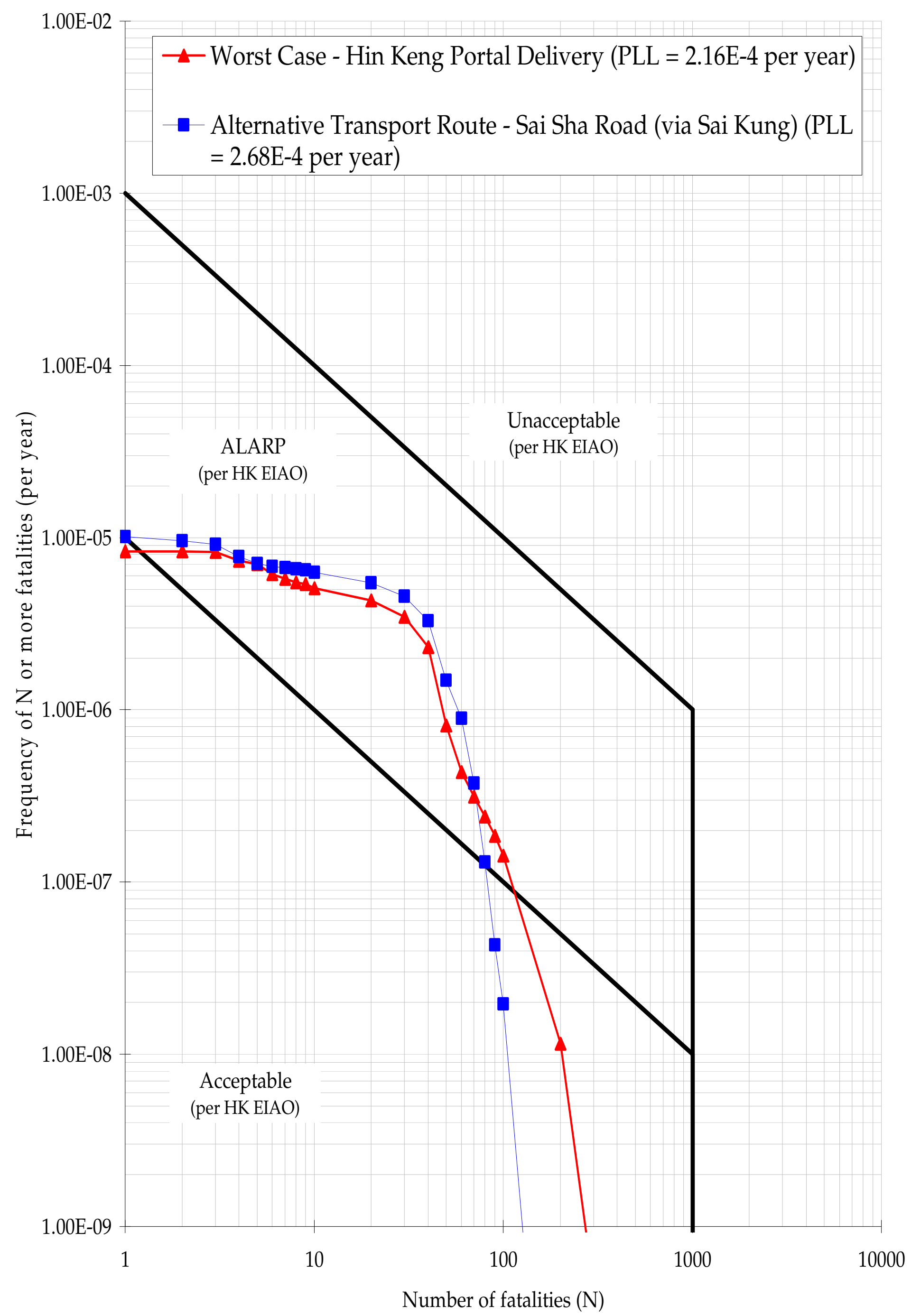


Figure 9.6 F-N Curve for Alternative Route to Hin Keng Portal: Sai Sha Road (via Sai Kung) option



9.5.3 *Risk Analysis for Option Case 1*

For the alternative Po Lam Road or Anderson Road options there is a slight increase in risk of 1.4x 10^{-5} and 1.2x 10^{-5} per year respectively. Although the travel distances are similar the population distribution is different along all three routes. The results show that there is little difference between the Clear Water Bay Road option and the Po Lam Road and Anderson Road options.

Anderson Road is not recommended by Mines Division due to specific problems with that route option. Construction works, including blasting, involving the Development at Anderson Road (DAR) and the Rehabilitation of Anderson Road Quarry (ARQ), are ongoing along both sides of Anderson Road. Temporary closure of Anderson Road is sometimes required at the time of blasting, and it is a relatively narrow road with heavy vehicular traffic due to DAR and ARQ operations. The road conditions based on surveys for the Clear Water Bay Road and Po Lam Road options are similar, however Po Lam Road has a greater number of curves, slopes and cross-road intersections compared to Clear Water Bay Road which generally has slip roads for entry/exit. With reference to the XRL study where the derivation of the accident frequency is described (ERM, 2009) the number and severity of accidents occurring at cross-roads is far greater than at slip roads. However due to limited data available specifically for these road sections it is not possible to derive specific accident rates with sufficient confidence in statistical terms.

The population distribution for the two options is also quite different. The Po Lam Road option passes through areas of greater urban development leading to more pavement sections and a higher number of high-rise residential buildings (along Po Hong Road, Po Lam Road, Sau Mau Ping Road and Shun Lee Tsuen Road) which provide a greater pavement and building population potentially at risk compared to the Clear Water Bay Road option.

For the alternative Sai Sha Road (via Sai Kung) option to Hin Keng Portal delivery point there is also a slight increase in risk of 5.2 x 10^{-5} per year. In this case the longer travel distance has the greatest influence on the increase in risk, although the population distribution and accident involvement frequency are different. There is nevertheless a notable risk reduction related to scenarios causing more than 100 fatalities.

The risk for the alternative Po Lam Road or Anderson Road options for Ma Chai Hang Ventilation Building and Shansi Street Shaft and for the alternative Sai Kung option for the Hin Keng Portal is higher than for the base case Clear Water Bay Road option due mainly to the population distribution along the routes. The base case Clear Water Bay Road option is therefore preferred.

9.6 OPTION CASE 2 – USE OF SMALLER QUANTITIES OF EXPLOSIVES

9.6.1 *Explosives Quantities Required for Blasting*

The risk has been calculated based on the use of cartridged emulsion as the blasting explosive or as a primer for bulk emulsion. It is possible to use smaller explosive charges such as cast boosters or mini cast boosters instead of cartridged emulsion as primers for bulk emulsion. This option reduces the quantity of explosives required for transportation for the sections where bulk emulsion will be used. However the main explosive component of cast boosters being PETN means that they have a higher TNT equivalency compared to cartridged emulsion.

9.6.2 *Scenarios Considered*

The scenarios considered are similar to the Worst Case Scenario although the quantity of explosives delivered is different for the sections where bulk emulsion is used for blasting. The Worst Case Scenario where cartridged emulsion is used remains the same as in *Table 5.5.* The Worst Case Scenario for when bulk emulsion is used with cast boosters has a different Equivalent TNT load as shown in *Table 9.8*.

Table 9.8 Scenarios Considered in Option Case 2 Assessment

Tag	Scenario	Cartridge Blasting (TNT eqv. Kg)	No of Trips per year	Bulk Blasting (TNT eqv. Kg)	No. of Trips per year
Storage of Explosives					
01	Detonation of full load of explosives in one store within TKO Area 137 site	301		301	-
02	Detonation of full load of explosives in one contractor truck on the access road within TKO Area 137 magazine site boundary	194*	353	25	774
Transport of Explosives					
03	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 site to Ma Chai Hang delivery point	156*	30	21	483
04	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 to Shansi Street delivery point	193*	165	25	169
05	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 to Hin Keng Portal delivery point	194*	158	21	122

Note:
* The explosives loads considered here are identical to the loads applied in the Worst Case Scenario
- Where bulk emulsion is used for blasting the cartridged emulsion primer has been replaced by cast boosters

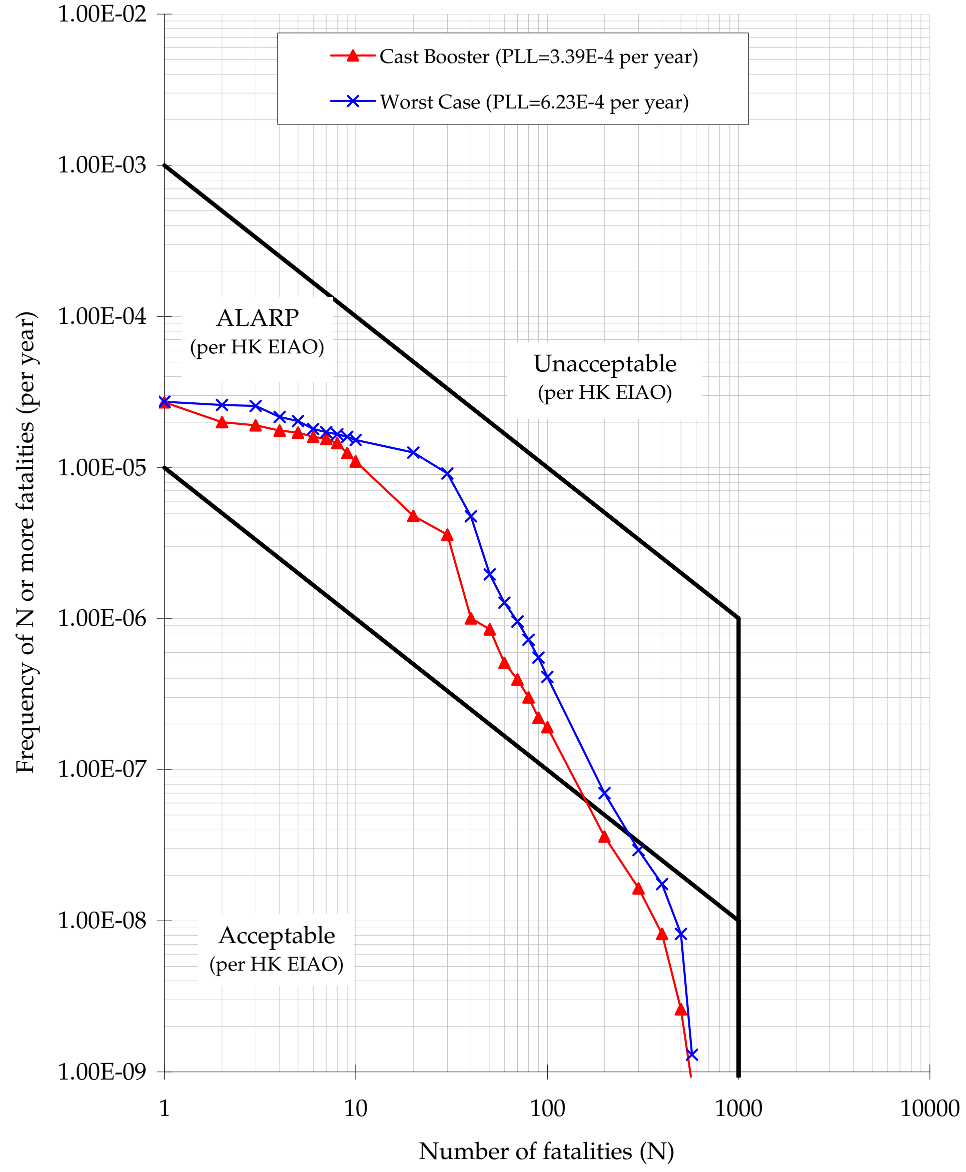
- Total number of trips (cartridge and bulk blasting combined) is the same as the total in the Worst Case Scenario

The consequence results for the blasting using cartridged emulsion is the same as shown previously in *Table 7.3*, the consequence results for the blasting using bulk emulsion with cast boosters as primers is shown in *Table 9.9* below.

Table 9.9 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 TKO Area 137 site	301	90%	20.6	90%	16.5
			50%	23.9	50%	17.2
			10%	35.4	10%	19.0
			3%	47.3	3%	20.4
			1%	61.1	1%	21.5
02	Detonation of full load of explosives in one contractor truck on the access road within TKO Area 137 magazine site boundary	25	90%	9.1	90%	7.3
			50%	10.5	50%	7.6
			10%	15.6	10%	8.4
			3%	20.8	3%	9.0
			1%	27.0	1%	9.6
Transport of Explosives						
03	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 site to Ma Chai Hang delivery point	21	90%	8.6	90%	6.9
			50%	9.9	50%	7.2
			10%	14.7	10%	7.9
			3%	19.6	3%	8.5
			1%	25.7	1%	9.0
04	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 to Shansi Street delivery point	25	90%	9.1	90%	7.3
			50%	10.5	50%	7.6
			10%	15.6	10%	8.4
			3%	20.8	3%	9.0
			1%	27.0	1%	9.6
05	Detonation of full load of explosives in one contractor truck on public roads – from TKO Area 137 to Hin Keng Portal delivery point	21	90%	8.6	90%	6.9
			50%	9.9	50%	7.2
			10%	14.7	10%	7.9
			3%	19.6	3%	8.5
			1%	25.7	1%	9.0

Figure 9.7 F-N Curve for the use of Cast Boosters as Primers for Bulk Blasting in place of Cartridged Emulsion



9.6.3 *Risk Analysis for Option Case 2*

The PLL obtained from implementing this option is estimated to be 3.39×10^{-4} per year, which is around 46% reduction in risk compared to the PLL of 6.23×10^{-4} per year for the Worst Case Scenario.

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

= HK$ 33M x 20x 2.84×10^{-4} x 1.5

= HK$ 0.28M

Strictly according to the execution of "Cost Benefit Analysis" the use of cast boosters is not justifiable. The cost of using cast boosters (>0.5M HKD) is higher than the safety benefits (0.28M HKD) achieved over the construction period.

Although this option fails the Cost Benefit Analysis it is marginal. There is uncertainty on the relative pricing of cast boosters versus cartridged emulsion which may change based on market demand and supply.

Use of cartridged emulsion satisfies the requirements of the TM, however MTR endeavours to follow best practice wherever possible, which includes selecting explosives with minimal impact on public safety. Currently there are some constraints on the availability and supply of cast boosters hence any recommendation to use only cast boosters could have an impact on the project schedule. However due to the risk reduction achieved the use of cast boosters is to be maximised, which is to be encouraged. MTR is to review, on an ongoing basis during the detailed design, tender and construction phases, and implement the use of cast boosters during construction to the maximum extent possible.

It should be noted that cartridged emulsion cannot be completely eliminated from the construction activity. Cast boosters can only be used as a replacement for cartridged emulsion in its role as a primer for bulk emulsion explosives, therefore cartridged emulsion will still be required for those sections that require cartridge-only blasting due to the proximity of sensitive receivers resulting in a low MIC. Also unforeseen ground conditions and fault zones dictate the use of cartridge-only blasting and hence it is essential to retain the flexibility of using cartridged emulsion for blasting if and when required.

The use of cast boosters for those sections where bulk explosives are used has been considered in the above calculations for risk reduction as well as for cost estimates.

9.7 *ALARP ASSESSMENT RESULTS*

The evaluation of each option considered is summarised in *Table 9.10*.

Table 9.10 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$ 0.62M	Neither practicable nor justified.
Use of Magazines Closer to the Construction Sites	Not Practicable	-	-	Closest practicable magazine site to the construction sites has been selected
Use of different explosive types (different types of detonating cord)	Pose some limitations	HK$ 1M	No safety benefit	Not justified
Alternative Routes (Option Case 1)	Practicable	-	Negative	Clear Water Bay Road preferred
Use of Smaller Explosives Quantities (Option Case 2)	Practicable	> HK$ 0.50M	HK$ 0.28M	Use of cast boosters is not cost effective. The cast booster option will be explored further in line with the use of best practice in explosives selection. [1]
Safer explosive truck (reduced fire load)	Practicable	-	-	Based on low implementation costs, this option has been directly incorporated in recommendations
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

Note: [1] Please refer to Hazard to Life Assessment Final Report, Section 9.6.3, 5th paragraph.

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 SCL (TAW-HUH) 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 11.2.1*). In additional some general recommendations have been made to minimise the risks further and in accordance with best practices (see *Section 11.2.2*).

10.2 RECOMMENDATIONS

10.2.1 *Recommendations for Meeting the ALARP Requirements*

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

- The truck design should comply with the Requirements for Approval of an Explosives Delivery Vehicle (CEDD 2) and limit the amount of combustibles in the cabin. The fuel carried in the fuel tank should also be minimised to reduce the duration of any fire;
- The explosive truck accident frequency should be minimised by implementing a dedicated training programme for both the driver and his attendants, including regular briefing sessions and implementation of a defensive driving attitude. In addition, drivers should be selected based on good safety records and medical checks;
- The Contractor should as far as practicable combine the explosive deliveries for a given work area;
- Only the required quantity of explosives for a particular blast should be transported to avoid the return of unused explosives to the temporary Magazine;
- Whenever practicable, a minimum headway between two consecutive truck convoys of 10 min is recommended;

- The explosive truck fire involvement frequency should be minimised by ensuring the implementation of a robust emergency response and training to make sure the adequate fire extinguishers are used correctly and attempts are made to evacuate the area of the incident or securing the explosive load if possible. All explosive vehicles should be equipped with the required amount and type of fire extinguishers and shall be agreed with Mines Division;
- The Contractor should as far as practicable use the preferred transport route; and
- The Contractor should coordinate explosives deliveries with the delivery of chlorine to Shatin Water Treatment Works in order to avoid overlapping.

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

1. The security plan should address different alert security levels to reduce opportunity for arson / deliberate initiation of explosives. The corresponding security procedure should be implemented with respect to prevailing security alert status announced by the Government.
2. Emergency plans (i.e. magazine operational manual) should be developed to address uncontrolled fire in the temporary Magazine area and for transport. The case of fire near an explosives truck in jammed traffic should also be covered. Drills of the emergency plans should be carried out at regular intervals.
3. Adverse weather working guideline should be developed to clearly define procedures for explosives transport during thunderstorms.
4. The Magazine storage quantities need to be reported on a monthly basis to ensure that the two day storage capacity is not exceeded.

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

10.2.3 Storage of Explosives in Temporary Magazine Store

The temporary 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 temporary Magazine are properly controlled.

2. There should be good house-keeping within the temporary Magazine to ensure that combustible materials are not allowed to accumulate.
3. The temporary 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 temporary 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 temporary Magazine store area.
7. Good housekeeping outside the temporary Magazine stores to be followed to ensure combustibles (including vegetation) are removed.
8. A speed limit within the temporary Magazine area should be enforced to reduce the risk of a vehicle impact or incident within the temporary Magazine area.
9. Traffic Management should be implemented within the temporary Magazine site, to ensure that no more than 1 vehicle will be loaded at any time, in order to avoid accidents involving multiple vehicles within the site boundary. Based on the construction programme, considering that 6 trucks could be loaded over a peak 2 hour period, this is considered feasible.
10. The design of the fill slope close to the temporary Magazine site should consider potential washout failures and incorporate engineering measures to prevent a washout causing damage to the temporary Magazine stores.
11. The Magazine storage quantities need to be reported on a monthly basis to ensure that the two day storage capacity is not exceeded.

10.2.4 Transport of Explosives

General Recommendations:

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

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

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

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

4. 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 records.

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

Contractors Licenced Vehicle Recommended Safety Requirements:

- Battery isolation switch;
- Front mounted exhaust with spark arrestor;
- Fuel level should be kept as far as possible to the minimum level required for the transport of explosives;
- Minimum 1 x 9 kg water based AFFF fire extinguisher to be provided;
- Minimum 1 x 9 kg dry chemical powder fire extinguisher to be provided;
- Horizontal fire screen on cargo deck and vertical fire screen mounted at least 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 tires and vehicle integrity;
- Regular monthly vehicle inspections;
  - Fuel system
  - Exhaust system
  - Brakes
  - Electrics
  - Battery
  - Cooling system
  - Engine oil leaks
- Vehicle log book in which monthly inspections and maintenance requirements are recorded; and
- Mobile telephone equipped.

Recommended Requirements for the Driver of the Explosives Vehicle:

The driver shall:

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

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

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

- the laws and Regulations relating to the transport of explosives;
- security and safe handling during the transport of explosives;
- training courses provided by the explosives manufacturer or distributor, covering the following:

- explosives identification;
- explosion hazards; and
- explosives sensitivity;

- the dangers which could be caused by the types of explosives;
- the packaging, labeling and characteristics of the types of explosives;
- the use of fire extinguishers and fire fighting procedures; and
- emergency response procedures in case of accidents.

The driver should additionally be responsible for the following:

- The driver shall have a full set of Material Safety Data Sheets (MSDS) for each individual explosive onboard the vehicle for the particular journey;
- The MSDS and Removal Permit (where applicable) shall be produced to any officer of the Mines Division of CEDD upon request;
- A card detailing emergency procedures shall be kept on board and displayed in a prominent place on the drivers door;
- Before leaving the temporary 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 temporary magazine;
  - Be competent to operate all equipment onboard the vehicle including fire extinguishers and the vehicle emergency cut-off switches;
  - Prohibit smoking when the vehicle is loaded with explosives;
  - When explosives are loaded, ensure the vehicle is not left unattended;

  - Be conversant with emergency response procedures.

Specific Recommended Requirements for the Explosives Vehicle Attendants:

- When the vehicle is loaded with explosives, it shall be attended by the driver and at least one (1) other person authorized by the Commissioner of Mines. The vehicle attendant shall:
  - Be the assistant to the driver in normal working conditions and in case of any emergency
  - Be conversant with the emergency response procedures
  - 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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Annex A

HATS2A - Transport of Explosives

APPENDIX 13A - ANNEX A - CONTENTS

1 INTRODUCTION

1.1 OVERVIEW

The Harbour Area Treatment Stage 2A (HATS2A) project has been identified as one of the potential concurrent projects with SCL (TAW-HUH) project in terms of geographical location and time period for the transport of explosives. In order to conduct the cumulative risk assessment for the SCL (TAW-HUH) project, the frequency and consequence analysis specifically for HATS2A Contractor's transport of explosives trucks were considered. The risk assessment specifically conducted for HATS2A transport of explosives is presented in the following sections.

1.2 DELIVERY ROUTES OF HATS2A TRANSPORT OF EXPLOSIVES

Based on the transport of explosives programme provided by Drainage Services Department (DSD), explosives will be delivered by HATS2A Contractor's trucks from the Kowloon Explosives Depot (KED) to two delivery points: Kwun Tong Pier and Stonecutters Island.

This risk assessment for the transport of explosives considers the HATS2A delivery routes that specifically overlap with the SCL (TAW-HUH) project. *Table 1.1* lists the delivery routes to both delivery points of HATS2A that overlaps with SCL (TAW-HUH) routes.

Table 1.1 ***Delivery routes of HATS2A Contractor's truck overlapping with SCL (TAW-HUH) project***

Section ID	Description
Route 1H (Kowloon Explosives Depot – Kwun Tong Pier)	
Road 1Ha	Lung Cheung Rd (Clear Water bay Rd - Wong Kuk Ave)
Road 1Hb	Lung Cheung Rd (Wong Kuk Ave - Hammer Hill Rd)
Road 1Hc	Lung Cheung Rd (Hammer Hill Rd - Po Kong Village Rd)
Road 1Hd	Lung Cheung Rd (Po Kong Village Rd - Fung Mo St)
Road 1He	Lung Cheung Rd (Fung Mo St - Waterloo Rd)
Road 1Hf	Lung Cheung Rd (Lion Rock Tunnel Rd - Nam Cheong St)
Road 1Hg	Lung Cheung Rd / Cornwall St (Nam Cheong St - Tai Po Rd)
Road 1Hh	Tai Po Rd (Lung Cheung Rd - Tai Po Rd INT)
Road 1Hi	Tai Po Rd (Tai Po Rd INT - Caldecott Rd)
Road 1Hj	Tai Po Rd - Shatin Heights (Caldecott Rd - KED)
Route 2H (Kowloon Explosives Depot – Stonecutters Island)	
Road 2Ha	Tai Po Rd (Lung Cheung Rd - Tai Po Rd INT)
Road 2Hb	Tai Po Rd (Tai Po Rd INT - Caldecott Rd)
Road 2Hc	Tai Po Rd - Shatin Heights (Caldecott Rd - KED)

2 HAZARD TO LIFE ASSESSMENT METHODOLOGY

2.1 METHODOLOGY FOR HATS2A TRANSPORT OF EXPLOSIVES

The risk assessment for the HATS2A transport of explosives follows the same methodology as presented in Appendix 13A and has considered the following:

- The collection and review of relevant data for HATS2A transport of explosives from the Kowloon Explosives Depot (KED), as well as population and vulnerable receptors, such as slopes, retaining walls etc., in the vicinity of the proposed transport routes which overlap with SCL(TAW-HUH);

- 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 risk assessment;

- Frequency estimation. A specific frequency assessment has been conducted to account for specific characteristics of HATS2A Contractor's trucks;

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

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

- The same frequency model was adopted in this study as that of ERM (2009) study, which has been derived to reflect the current Transport Department statistics, Fire Services Department statistics, specific design features applicable for HATS2A Contractor's trucks, and current knowledge of explosives;

- The consequence and frequency data were subsequently combined using ERM's in-house Explosive Transport GIS Risk Assessment tool (E-TRA), which has been developed to account for three-dimensional blast effects on buildings and the effect of accidental explosions on elevated roads. It also accounts for traffic jam scenarios which could occur in some accidental scenarios as reported in the DNV (1997) study. This risk assessment tool is employed consistently with the SCL (TAW-HUH) assessment in Appendix 13A.

2.2 POPULATION ALONG EXPLOSIVES DELIVERY ROUTES

The same population estimates as utilised for SCL (TAW-HUH) presented in Appendix 13A has been adopted for the HATS2A transport of explosives. The following three types of population have been considered and have been presented in detail in Appendix 13A:

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

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

Population on the roads was estimated 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 (2009); and
- Geographic Information System (GIS) database (2008 data).

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

3 HAZARD IDENTIFICATION

3.1 OVERVIEW

Hazard identification follows the same approach as presented in detail in Appendix 13A for SCL (TAW-HUH) transport of explosives which consisted of a review of:

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

3.2 SCENARIOS FOR HATS2A TRANSPORT OF EXPLOSIVES HAZARD ASSESSMENT

Hazardous scenarios considered for the HATS2A transport of explosives are:

- Accidents involving explosives delivered and transferred from the Kowloon Explosives Depot (KED) to each delivery point for only the routes that overlap with SCL project.
- One HATS2A Contractor's truck transports a total of 500kg TNT eqv. load with detonators (assumed to be stored in a separate compartment) estimated at 5kg of the total load. Therefore, the HATS2A Contractor's truck is considered to carry a mixed load of explosives and detonators.

The HATS2A project is estimated to overlap with the SCL (TAW-HUH) project for the beginning two months of the SCL project programme. Risks, however, are defined on a per year basis and represent conservatively a one year overlap period. The scenario for the Hazard to Life Assessment was therefore defined to cover different risk levels and possible construction programme deviations throughout the project period.

The number of deliveries was derived from the delivery schedule provided by DSD of which, in the morning, three HATS2A Contractor's trucks deliver explosives from Kowloon Explosives Depot (KED) to Kwun Tong Pier and one HATS2A Contractor's trucks delivers explosives to Stonecutters Island. The delivery schedule is similarly repeated in the evening. The total amount of deliveries in one day is then six HATS2A Contractor's trucks to Kwun Tong Pier and two HATS2A Contractor's trucks to Stonecutters Island. As with SCL (TAW-HUH) transport of explosives, deliveries are assumed for six days a week.

The following hazardous scenarios were identified for the HATS2A transport of explosives which overlap with the SCL (TAW-HUH) project:

Table 3.1 Scenarios considered in the HATS2A transport of explosives assessment

Tag	Scenario	Explosives load (TNT eqv. kg)	No. of Trips per year
Transport of Explosives			
01	Detonation of full load of explosives in one HATS2A Contractor's truck on public roads – from Kowloon Explosives Depot to Kwun Tong Pier delivery point (overlap route section with SCL only)	500	1872
02	Detonation of full load of explosives in one HATS2A Contractor's truck on public roads – from Kowloon Explosives Depot to Stonecutters Island delivery point (overlap route section with SCL only)	500	624

4 FREQUENCY ASSESSMENT

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

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

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

The basic event frequencies for the transport of explosives for SCL (TAW-HUH) Contractor trucks has been derived following a detailed frequency assessment as part of the XRL study (ERM, 2009). The assessment considered the following:

- Light Goods Vehicle (LGV) pick-up type truck for explosive delivery;
- Recent Hong Kong Transport Department statistics;
- Hong Kong specific vehicle fire data;
- Specific Hong Kong explosive delivery truck design feature;
- Specific Hong Kong explosive delivery truck operation; and
- Revised knowledge of explosives properties.

The SCL Contractor's trucks had specific design features while complying with Mines Division guidelines on requirements for approval of an explosives delivery vehicle (CEDD 2). Based on data provided by Drainage Services Department (DSD), the HATS2A Contractor's truck has been designed according to the Mines Division guidelines (CEDD 2). The HATS2A Contractor truck has the following specific characteristics which differ from the SCL (TAW-HUH) Contractor's trucks:

- Carrying a mixed load of explosives and detonators within the same truck, but stored in separate compartments;
- MGV transporting a total load of 500kg (with 5kg of detonators out of the total load); and
- Fire protection requirement complying with Mines Division guidelines (CEDD 2).

4.1 *TRANSPORT OF EXPLOSIVES*

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

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

- **Non-crash fire**:
  This cause category includes any explosion instance where the explosive load has been subject to thermal stimulus which was not the result of a vehicle collision. Events in this category, not only include instances where the explosive load is directly engulfed in the fire but also events where thermal stimulus occurs by ways of heat conduction and convection;
- **Crash fire**:
  This cause category is similar to the non-crash fire category but only concerns fires resulting from a vehicle collision;
- **Crash impact**:
  This cause category includes all instances of vehicle collisions with a sufficient energy to significantly affect the stability of the explosive and which could have the potential to cause an accidental explosion; and
- **Spontaneous explosion ('unsafe explosive'):**
  The term 'unsafe explosive' originates from the ACDS study (ACDS, 1995).

  It includes explosions, during conditions of normal transport, resulting from breach of regulations caused by badly packaged, manufactured, and/or 'out-of-specification' explosives.

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

Based on the Hazard Identification section of Appendix 13A, 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.

In the case of a HATS2A Contractor's truck which carries a mixed load and a crash occurs, the likelihood of detonators being initiated by the impact is estimated to be higher than for the main explosive load, but the possibility of detonator initiation causing the main explosive load to subsequently initiate in the separate compartment of the HATS2A Contractor's truck is considered unlikely as presented in the DNV study (DNV, 1997). However, there is a possibility that a fire due to detonator initiation may spread to the main explosive load compartment and initiate the main explosive load. This possibility has been specifically modeled in the frequency assessment following the methodology described in the DNV study (DNV, 1997).

Other scenarios in this annex 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 frequency components for HATS2A transport of explosives is largely based upon the assessment from the XRL study (ERM, 2009) given the current knowledge on the explosives' properties, vehicle incident frequencies provided by the Transport Department and Fire Services Department and specific design features applicable for the SCL (TAW-HUH) project such as:

- HATS2A Contractor's truck characteristics for an LGV have been taken considering the more conservative overall frequency values of LGV's over MGV's, and to maintain a consistent and conservative approach with the frequency assessment performed for the SCL project contractors' delivery trucks;
- Recent Hong Kong Transport Department statistics;
- Hong Kong specific vehicle fire data;
- Specific Hong Kong explosive delivery truck design feature;

- Specific Hong Kong explosive delivery truck operation; and
- Revised knowledge of explosives properties.

4.2 *Explosive Initiation Frequency during Transport Used for HATS2A*

Where not specifically detailed in this Annex, the historical background for the derivation of each frequency component is presented in the XRL study (ERM, 2009) report. In the case of HATS2A Contractor's truck, the main differences in assumptions to that of the SCL Contractors' trucks are:

- Conservatively, no credit has been given for any fire protection;
- HATS2A Contractor's truck carries a mixed load of both explosives and detonators; and
- MGV as compared to LGV.

The frequency parameters used for HATS2A transport of explosives are summarised in the following sections.

Initiation Probability on Significant Impact for the Main Explosive Load

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

Initiation Probability on Significant Impact for Mixed Loads

HATS2A Contractor's trucks carry mixed loads (i.e. detonators and explosives within the same vehicle). The detonators and explosives are stored in separate compartments with specific measures to prevent fire propagation from the detonator compartment to the main explosives compartment as per Mines Guidelines (CEDD 2). The DNV Study (DNV, 1997) has assessed the probability that a fire resulting from detonator initiation may escalate and initiate the main explosive load as follows. The probability of detonator initiation as a result of a vehicle collision has been taken as 0.01 making reference to the ACDS report (ACDS, 1995). The probability of a fire in the detonator compartment spreading to the main load was estimated as 0.1. The probability of 0.5 for the initiation given fire involvement has been taken, resulting in the overall probability of initiation by this scenario to be 0.0005.

Probability of Explosive Response to Fire

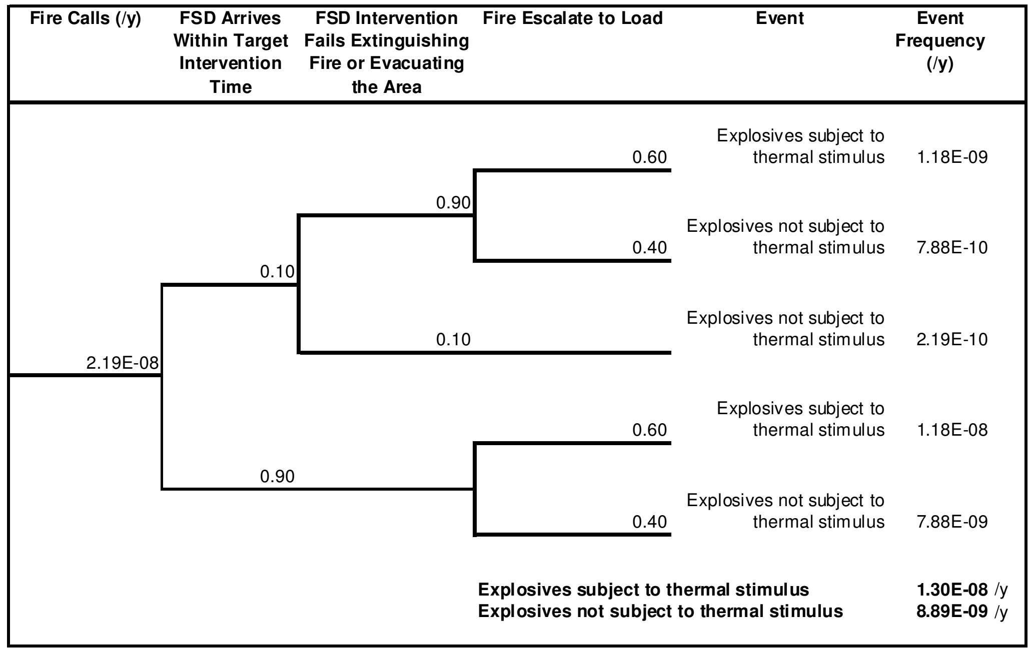
The initiation of explosives in the DNV study (DNV, 1997) was assessed as 0.1 for any fire involvement. This value was based on the ACDS study (ACDS, 1995), which was derived from an expert judgement for heat insensitive

explosive group which included a variety of explosives. In the XRL study (ERM, 2009), the proportion of detonating cord and cartridged emulsion differs from the previous projects. The sensitivity of the explosive load to fire and impact has therefore been reviewed. Based on the experts' knowledge (ERP, 2009) and experience on PETN and sensitised emulsion, the probability that the explosive melts and detonates once the fire impacts on the load is more likely than what was initially assumed in the ACDS study (ACDS, 1995) given the recent transport accident experience and the known properties of mixed explosives used. In the absence of further test data on transported explosives, a probability of 0.5 has been taken in the XRL study (ERM, 2009) to more appropriately represent the mix of explosive loads as applicable in the study. The same probability of 0.5 is used for HATS2A transport of explosives.

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

Referring to the expert panel review (ERP, 2009) a thermal stimulus is sufficient to cause an explosion of the explosive load based on updated knowledge on explosive properties. HATS2A Contractor's trucks are based on Mines Guidelines (CEDD 2), and conservatively, no credit was given to the truck crew intervention and fire screen combination as a conservative approach, thus negating the 0.1 risk reduction factor as credited to Contractor's delivery trucks for SCL project. The non-crash fire frequency of 1.30 x 10^{-8} /km was then derived specifically as shown in the form of an event tree in *Figure 2.1* for Hong Kong conditions based on goods vehicle data provided by the Transport Department in 2007 and Fire Services Department data on causes of fire call incidents in Hong Kong between 2004 and 2008.

Figure 4.1 Event tree for non-crash fire scenario for HATS2A



In the DNV Study, it was assumed that the detonators response to a heat stimulus will result in 100% chances of initiation of the detonators resulting in a fire which may further propagate to the explosive load. The main difference between mixed loads explosive and non-mixed load in a non-crash fire situation is the speed of which the fire propagates. Hence, the probability of initiation of the explosive load due to non-crash fire remains at 0.5.

Frequency of 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 2.64×10^{-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.

In the case for mixed loads, it was assumed that under a crash fire situation, there is a possibility that explosives may mix with detonators due to the loss of compartment integrity and resulting in initiation of the main explosives load due to fire from detonators. In absence of detailed information on the compartment behaviour in a vehicle collision, this probability has been assumed to be unity. This is considered in the frequency model for the crash fire fault tree branch and the probability was taken conservatively as 1 for the initiation of the main explosives load in a crash fire situation.

Vehicle Involvement Rate

In previous studies undertaken in Hong Kong including the WIL EIA (ERM, 2008), Ocean Park Develop (Maunsell, 2006) and DNV QRA (DNV, 1997) studies, they adopted the frequencies derived for the M/HGV to account for Hong Kong situation based on the relevant HK HGV to UK HGV reportable vehicle collision involvement. Since the vehicle involvement rate for LGV's based on Hong Kong accident data and vehicle involvement rate published by the Transport Department between 2003 and 2007 are higher for both non-expressway and expressway than compared to M/HGV's, the frequency for LGV's were applied to HATS2A Contractor's trucks as a conservative approach.

Explosive Initiation Frequency for Different Types of Road

Since the vehicle impact speed and the accident involvement rate on highway/ major roads and non-highway are significantly different, different sets of explosive initiation frequencies for expressway and non-expressway

have been derived during explosive transport to reflect the road conditions along the transport routes.

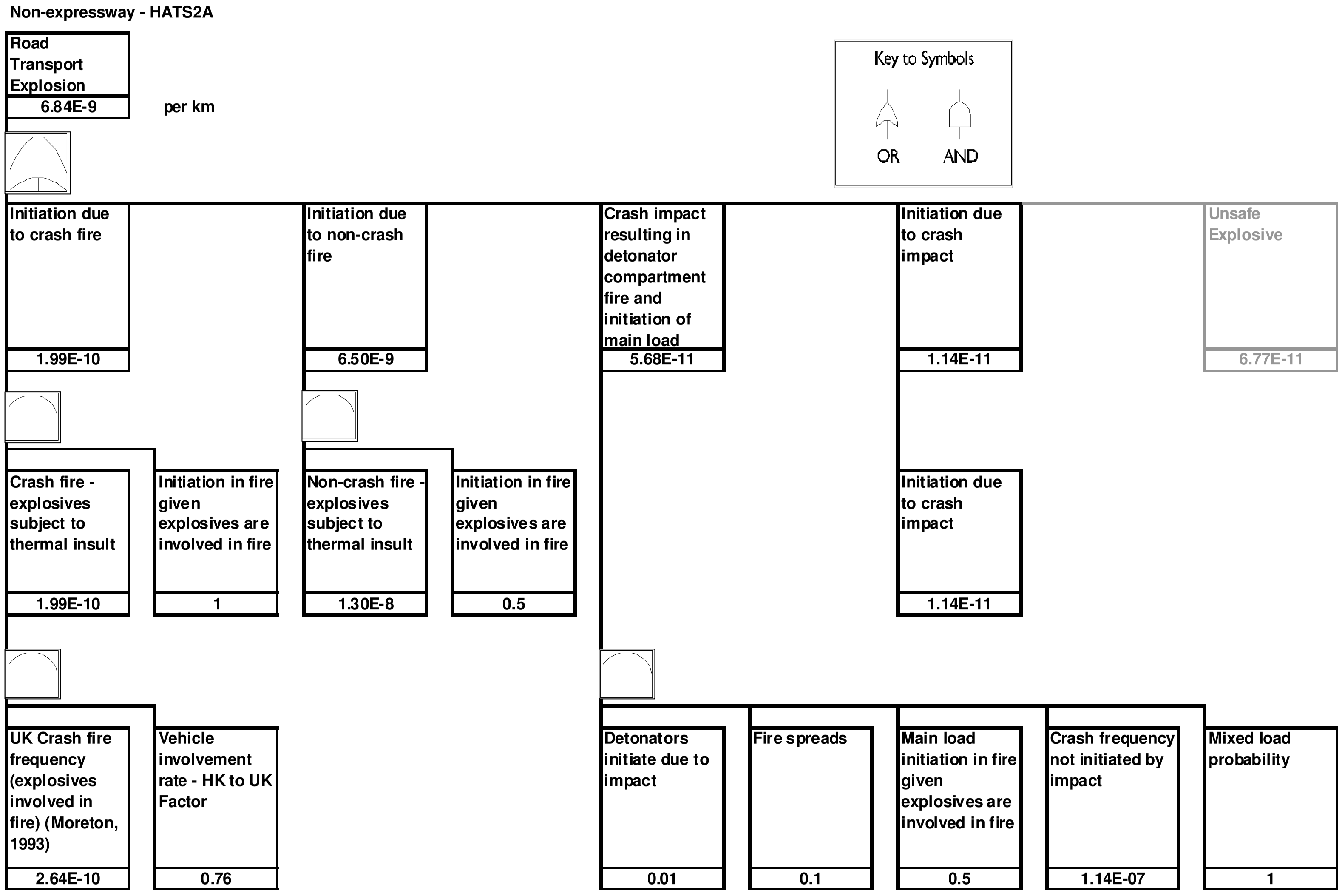
4.2.1 *Transport Explosion Frequency for HATS2A*

The components of the explosive initiation fault tree used for HATS2A transport of explosives are shown in *Table 4.1* and the fault tree models for the road transport explosion are shown in *Figure 4.2* and *Figure 4.3*. The fault tree models for explosive load initiation due to impact which follows the same methodology and derivation as the XRL study (ERM, 2009) are also presented in *Figure 2.4* and *Figure 2.5*. The frequencies of explosives initiation during road transport were therefore estimated at 6.64×10^{-9}/km on expressway and 6.84×10^{-9}/km on other road sections considering an additional 1% increase for "unsafe explosives" (i.e. a factor of 1.01), as justified in the WIL QRA (ERM, 2008).

Table 4.1 Explosives initiation fault tree inputs for HATS2A transport of explosives

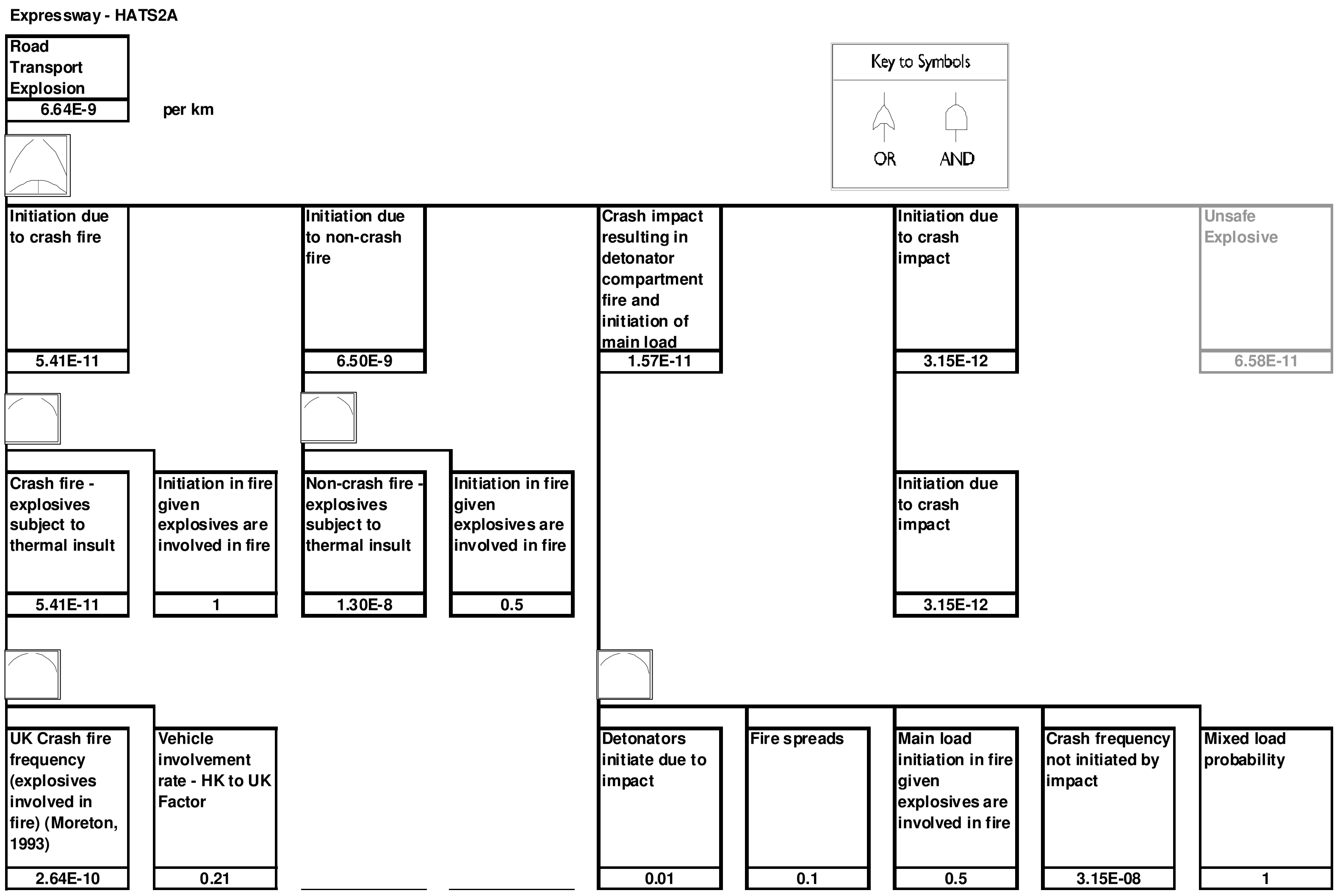
Event	Event type	Value
Vehicle crash (on expressway)	Frequency	1.27×10^{-7} /km
Vehicle crash (on non-expressway)	Frequency	4.68×10^{-7} /km
Crash fire (on expressway)	Frequency	5.41×10^{-11} /km
Crash fire (on non-expressway)	Frequency	1.99×10^{-10} /km
Non-crash fire	Frequency	1.30×10^{-8} /km
Explosives initiation in fire from crash fire	Probability	1
Explosives initiation in fire from non-crash fire	Probability	0.5
Explosives initiation in impact	Probability	0.0001
Detonators initiation in impact	Probability	0.01
Fire spreads from detonator initiation	Probability	0.1

Figure 4.2 Explosives initiation fault tree for non-expressway – road transport events for HATS2A transport of explosives



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

Figure 4.3 Explosives initiation fault tree for expressway – road transport events for HATS2A transport of explosives



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

Figure 4.4 Explosive load initiation due to impact fault tree for non-expressway

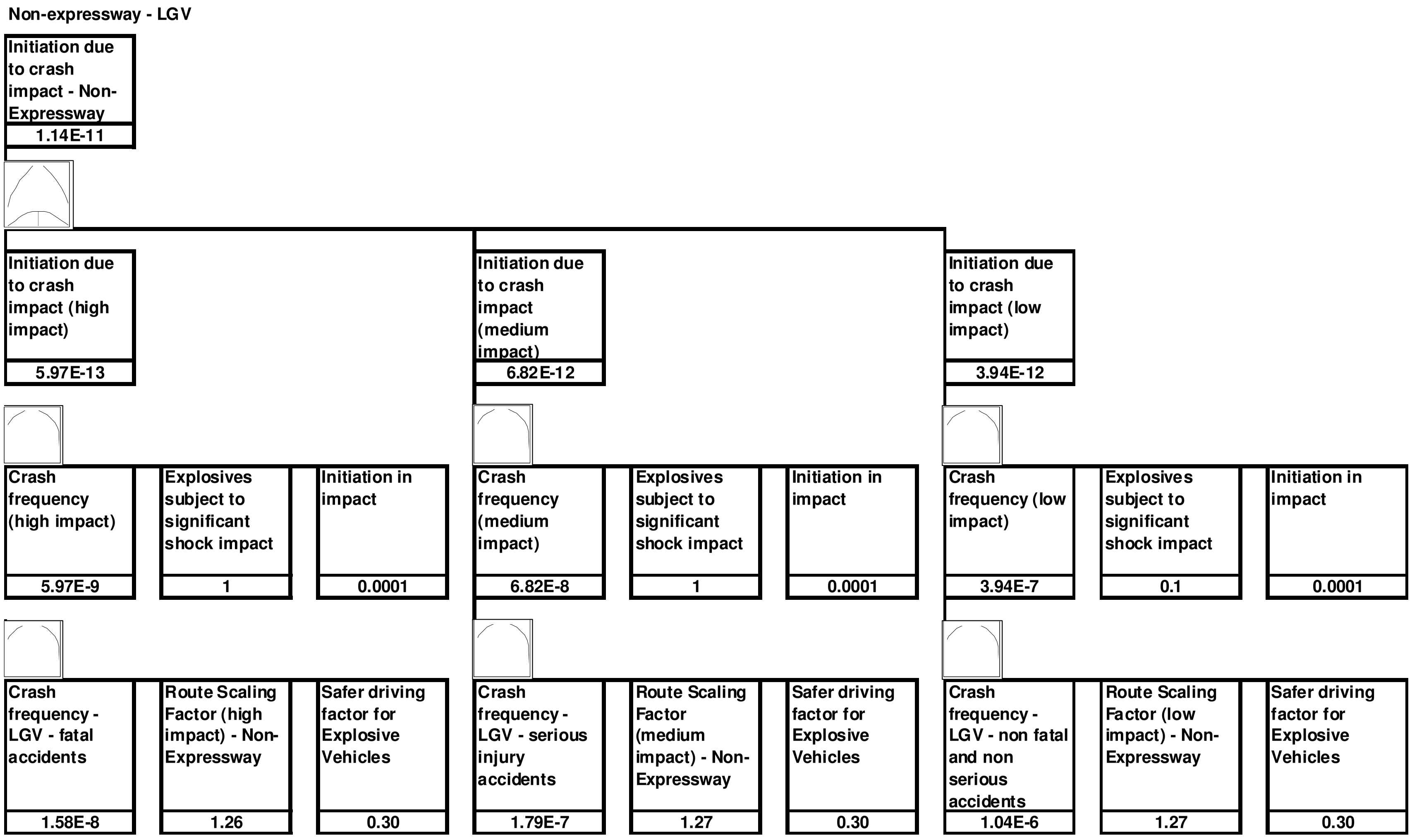
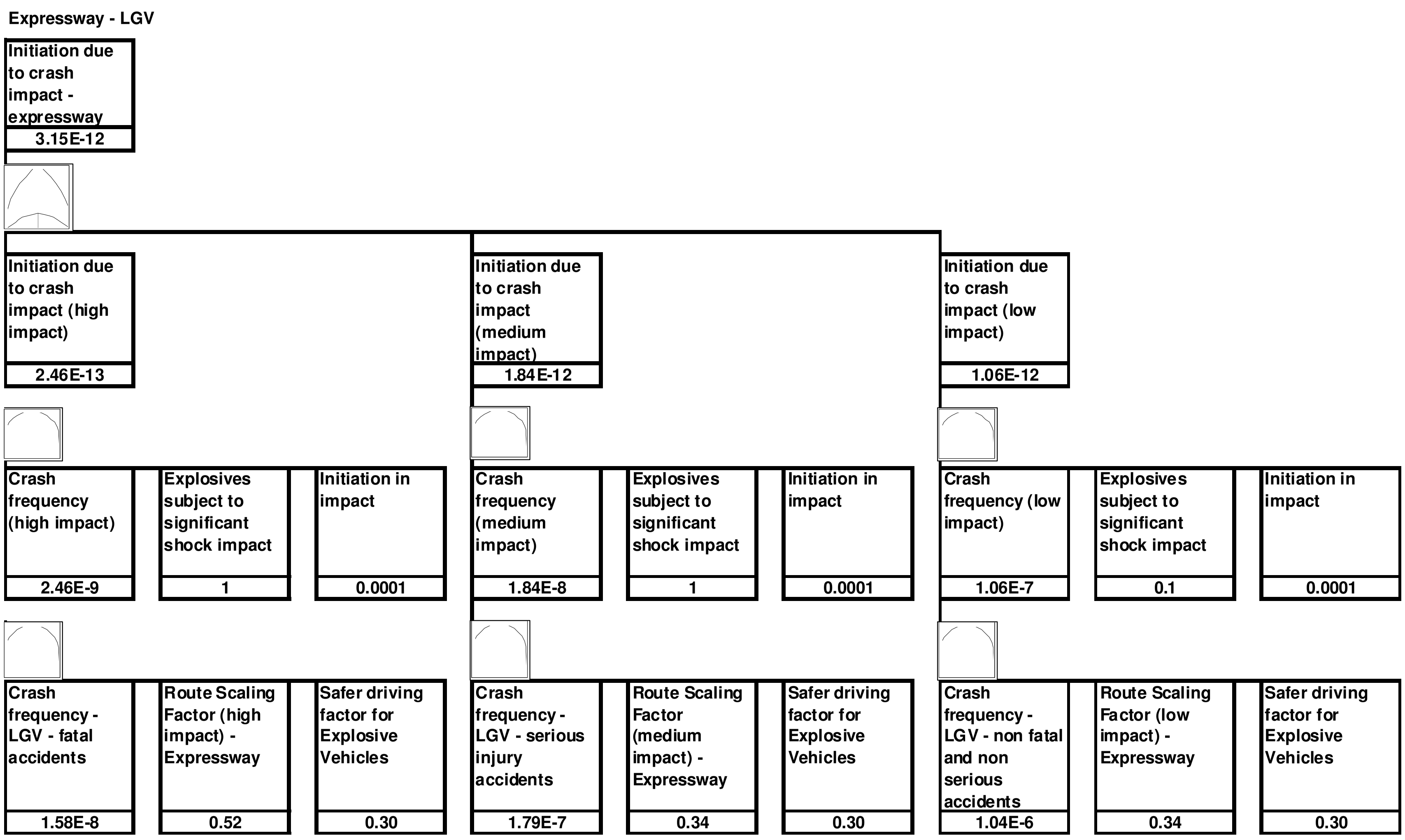


Figure 4.5 Explosive load initiation due to impact fault tree for expressway



5 CONSEQUENCE ASSESSMENT

5.1 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.

5.2 CONSEQUENCE ASSESSMENT FOR HATS2A TRANSPORT OF EXPLOSIVES

The same methodology is used in conducting the consequence assessment for HATS2A transport of explosives as presented in Appendix 13A for SCL (TAW-HUH) project. The main difference in HATS2A Contractor's trucks is the total explosive load of 500kg compared to SCL Contractor's trucks total explosive load of 200kg. This difference mainly affects the results for the blast effect distances in the transport of explosives.

The consequence results for each transport scenario are summarized in *Table 5.1*. The 1% fatality effects from the initiation of 500kg of explosives for the transport of explosives scenarios are 72m and 26m for indoor and outdoor, respectively. These results fall within the 100m blast radius as considered in Appendix 13A for the transport of explosives around the explosives delivery vehicles and is similarly carried out for the consequence assessment.

Table 5.1 Summary of results for HATS2A transport of explosives consequence scenarios

No.	Scenario	TNT eqv. kg	Fatality Prob.	*Indoor* Impact distance (m)	*Outdoor* Impact distance (m)
Transport of Explosives					
01	Detonation of full load of explosives in one HATS2A Contractor's truck on public roads – from KED to Kwun Tong Pier delivery point	500	90% 50% 10% 3% 1%	24 28 42 56 72	20 20 23 24 26
02	Detonation of full load of explosives in one HATS2A Contractor's truck on public roads – from KED to Stonecutters Island delivery point	500	90% 50% 10% 3% 1%	24 28 42 56 72	20 20 23 24 26

6 RISK SUMMATION

6.1 OVERVIEW

The Consultants' in-house software has been used for risk calculation and summation. The risk summation considers the frequency and consequence assessment including the risks to other road users, nearby buildings and outdoor population.

6.2 RISK MEASURES

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

6.2.1 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.

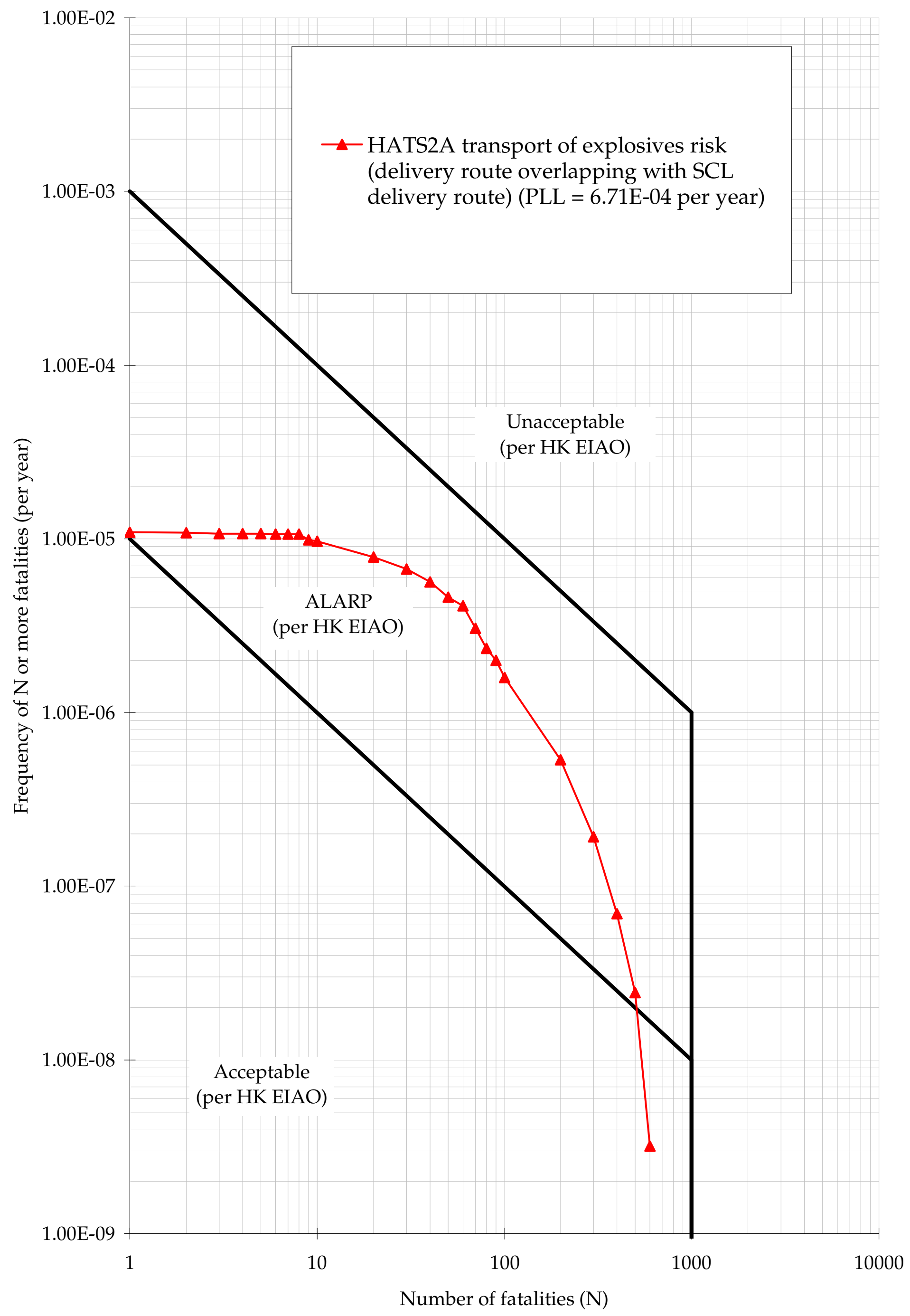
6.2.2 Individual Risk

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

6.3 SOCIETAL RISK

Figure 6.1 shows the F-N curve for HATS2A transport of explosives. The PLL due to HATS2A transport of explosives is shown as 6.71E-04 per year for the worst case scenario.

Figure 6.1 F-N curve for HATS2A transport of explosives



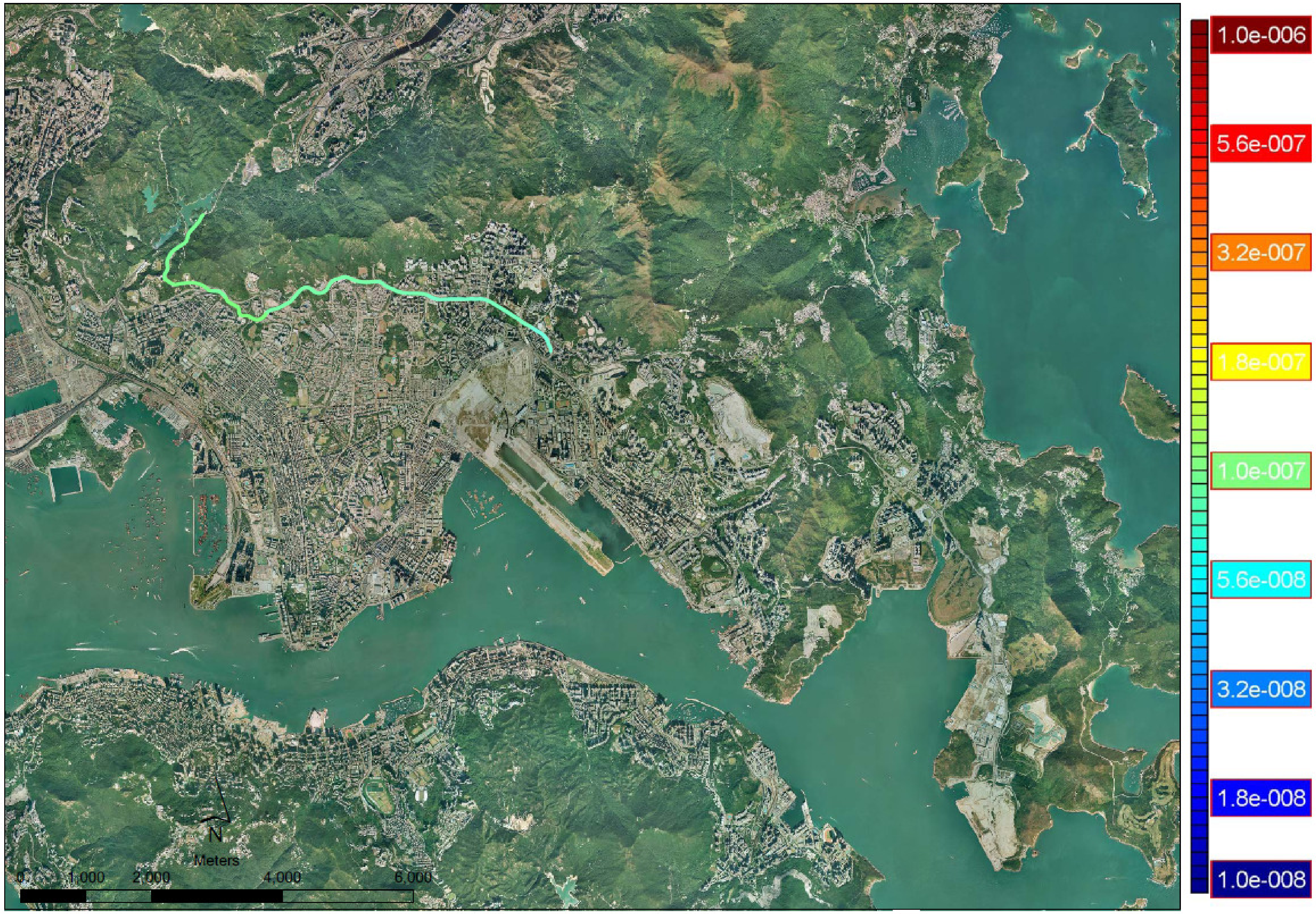
6.4 INDIVIDUAL RISK

The individual risk (IR) for each section of the transport route is listed in *Table 6.1* and is shown graphically in *Figure 6.2*. The IR results presented below represent the maximum individual risk occurring on the road in the same lane as the explosives delivery truck. It can be seen that the maximum IR is about 8×10^{-8} per year. The IR summation takes into account the overlapping road sections and the worst case scenario with the consideration of a 20% increase in the number of deliveries to the delivery points.

Table 6.1 Maximum Individual Risk for the delivery route in common with the SCL (TAW-HUH) project for transport of explosives

Section ID	Description	Maximum IR (per year)
Route 1H (Kowloon Explosives Depot – Kwun Tong Pier)		
Road 1Ha	Lung Cheung Rd (Clear Water bay Rd - Wong Kuk Ave)	7.88E-08
Road 1Hb	Lung Cheung Rd (Wong Kuk Ave - Hammer Hill Rd)	7.83E-08
Road 1Hc	Lung Cheung Rd (Hammer Hill Rd - Po Kong Village Rd)	8.00E-08
Road 1Hd	Lung Cheung Rd (Po Kong Village Rd - Fung Mo St)	8.00E-08
Road 1He	Lung Cheung Rd (Fung Mo St - Waterloo Rd)	8.02E-08
Road 1Hf	Lung Cheung Rd (Lion Rock Tunnel Rd - Nam Cheong St)	8.12E-08
Road 1Hg	Lung Cheung Rd / Cornwall St (Nam Cheong St - Tai Po Rd)	1.17E-07
Road 1Hh	Tai Po Rd (Lung Cheung Rd - Tai Po Rd INT)	7.88E-08
Road 1Hi	Tai Po Rd (Tai Po Rd INT - Caldecott Rd)	7.83E-08
Road 1Hj	Tai Po Rd - Shatin Heights (Caldecott Rd - KED)	8.00E-08
Route 2H (Kowloon Explosives Depot – Stonecutters Island)		
Road 2Ha	Tai Po Rd (Lung Cheung Rd - Tai Po Rd INT)	1.06E-07
Road 2Hb	Tai Po Rd (Tai Po Rd INT - Caldecott Rd)	1.09E-07
Road 2Hc	Tai Po Rd - Shatin Heights (Caldecott Rd - KED)	1.08E-07

Figure 6.2 Maximum IR for the delivery route in common with the SCL (TAW-HUH) project for transport of explosives



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