APPENDIX 7.01 HAZARAD TO LIFE ASSESSMENT FOR STORAGE AND TRANSPORT OF EXPLOSIVES

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1 INTRODUCTION

1.1 Background

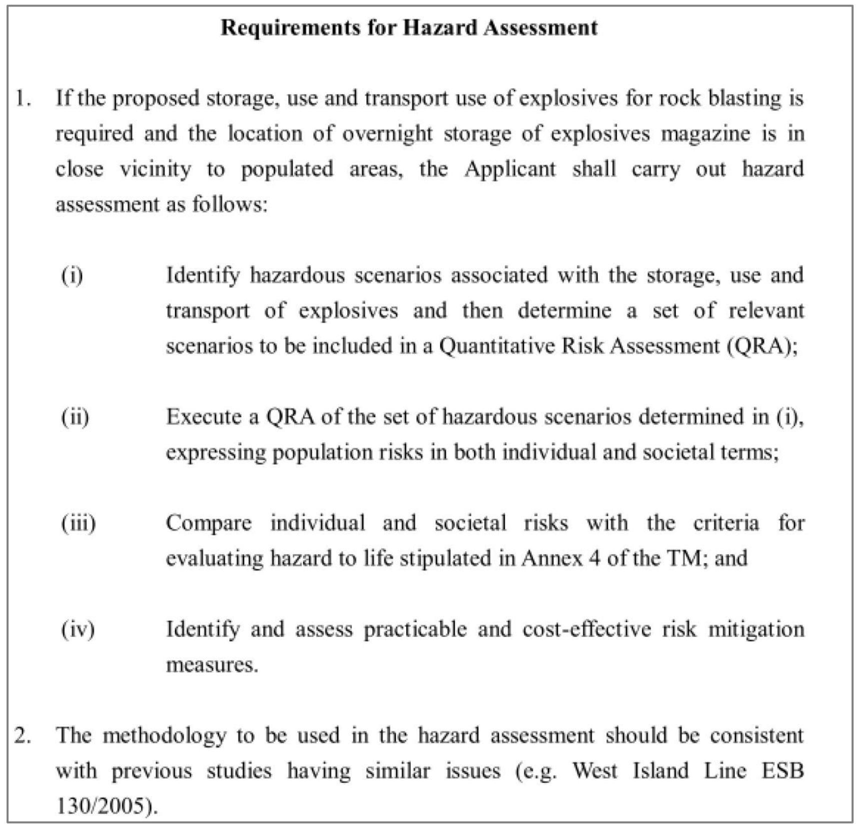
1.1.1.1 Explosives are classified as DG Category 1, and fall under the controlling authority of Mines Division, Civil Engineering and Development Department (CEDD). The storage of explosives during construction phase must be placed within a licensed 'Mode A' Store and a license must be obtained in accordance with certain safety and operational criteria to the approval of Mines Division. In addition, the Hazard to Life due to the explosives storage must fall within criteria acceptable to EPD. There will be no explosives handled during the operational phase of the Project.

1.1.1.2 While the use of explosives cannot be avoided, the storage quantities at the explosive magazine is to be kept to the minimum and the choice of the explosive magazine location is to be carefully considered such that the distance of transport route from the magazine to the blasting locations is minimised.

1.1.1.3 Choosing a suitable location of a magazine site is vital as the transport of explosives has shown to have direct impact to the nearby population along the transport route. Previous similar projects have shown the transport of explosives from a magazine to a project site to be a major contributor to the overall risk. As such, it is important for a magazine to be located close to the works site, minimizing risk from additional transportation but as far as possible from populated areas.

1.2 Objectives

1.2.1.1 The Hazard to Life Assessment requirements are detailed in Appendix G of the EIA Study Brief and are shown below in **Figure 1.1**.



Requirements for Hazard Assessment

1. If the proposed storage, use and transport use of explosives for rock blasting is required and the location of overnight storage of explosives magazine is in close vicinity to populated areas, the Applicant shall carry out hazard assessment as follows:

   (i) Identify hazardous scenarios associated with the storage, use and transport of explosives and then determine a set of relevant scenarios to be included in a Quantitative Risk Assessment (QRA);

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

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

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

2. The methodology to be used in the hazard assessment should be consistent with previous studies having similar issues (e.g. West Island Line ESB 130/2005).

Figure 1.1 EIA Study Brief – Hazard to Life Requirements

1.3 EIAO-TM Risk Criteria

1.3.1.1 Annex 4 of the EIAO-TM specifies the Individual and Societal Risk Guidelines. The Hong Kong Government Risk Guidelines (HKRG) per the EIAO-TM Annex 4 states that the individual risk is the predicted increase in the chance of fatality per year to an individual due to a potential hazard. The individual risk guidelines require that the maximum level of individual risk should not exceed 1 in 100,000 per year i.e. 1 x10^{-5} per year. Societal risk expresses the risks to the whole population. It is expressed in terms of lines plotting the cumulative frequency (F) of N or more deaths in the population from incidents at the installation. Two F-N risk lines are used in the HKRG that demark "Acceptable" or "Unacceptable" societal risks. To avoid major disasters, there is a vertical cut-off line at the 1000 fatality level extending down to a frequency of 1 in a billion years. The intermediate region indicates the acceptability of societal risk is borderline and should be reduced to a level which is "as low as reasonably practicable" (ALARP). It seeks to ensure that all practicable and cost effective measures that can reduce risk are considered. The HKRG is presented graphically in **Figure 1.2**.

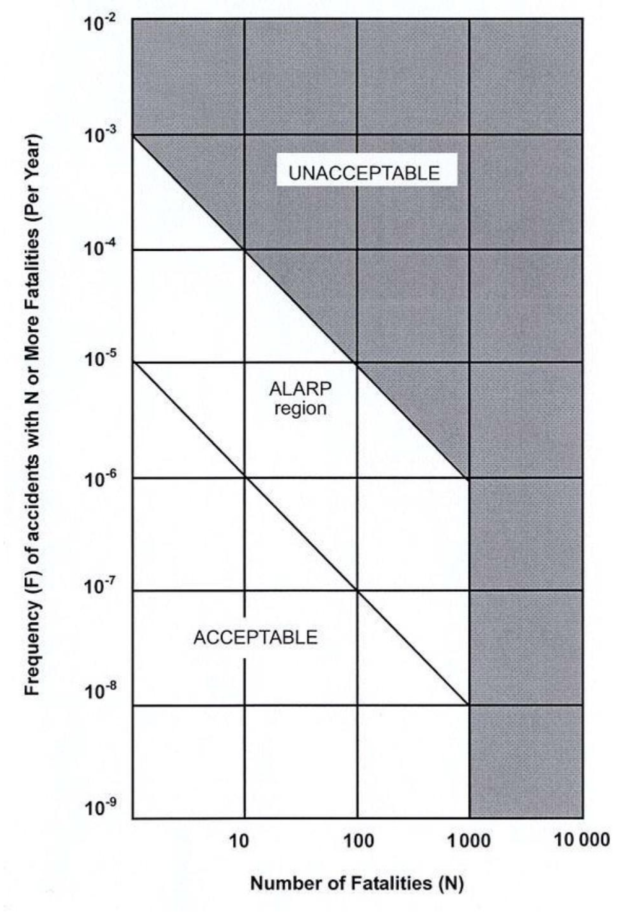


Figure 1.2 Societal Risk Guidelines for Acceptable Risk Levels

1.3.1.2 The risk guidelines specified in the EIAO-TM apply to risk of fatality due to storage, transport and use of explosives. They are only applicable to public outside the boundary of the hazardous installation. Risk to workers on the project construction site, Drainage Services Department (DSD) staff and its contractors have not been included in this study as they are considered as voluntary risk takers.

2 PROJECT DESCRIPTION

2.1 Project Overview

2.1.1.1 The existing STSTW has been proposed to be relocated to caverns and the location of the caverns is below Nui Po Shan and bounded by Mui Tsz Lam Road to the North and A Kung Kok Street to the West. The location of the overall project layout is shown in **Figure 2.2**.

2.1.1.2 The layout of the cavern complex has been developed based on considerations of a number of disciplines, especially the sewage treatment process. The footprint consists of a series of parallel caverns aligned along the long axis of the complex. The process caverns have a generally consistent excavated span of around 32m but the height of the caverns varies dependent on the sewage treatment process being undertaken in each cavern.

2.1.1.3 Two access tunnels are proposed to connect to the caverns. One of the tunnel portals is located at the junction of Mui Tsz Lam Road and A Kung Kok Street and the other portal is located close to the current DSD site on Mui Tsz Lam Road.

2.1.1.4 A ventilation shaft is also proposed at the southwest side of the cavern.

2.1.1.5 The proposed Sha Tin Cavern Sewage Treatment Works (CSTW) will be located in caverns excavated within fresh to slightly decomposed granite. Due to the high strength of the rock, the large excavation spans required, the number of access tunnels and connections, drill and blast excavation construction method is the only practical and economical method.

2.1.1.6 Construction of the Project is tentatively scheduled to commence in 2017 for completion in 2027, and the peak cavern excavation year will be around 2020 - 2022. After Year 2022, it is anticipated that civil, E&M, testing and commissioning works will be carried out inside the cavern and some building and landscaping works outside the cavern. Assessment year for construction stage is taken as 2022; no explosive will be used during operation stage of the Project and thus hazard assessment for explosives related issue is not necessary for operation stage.

2.2 Blasting Requirement

2.2.1.1 For the tunnels that require blasting, the construction will follow a maximum three-blasts-per-two-days cycle from tunnel portal. The tunnel will require an average face excavation area of approximately 170m^2. Each blast would require, on average 230 production holes and 85 perimeter holes. If a pull length of 2m per blast is assumed, then each blast would need approximately 13.6kg of detonating cord with a Pentaerythritol Tetranitrate (PETN) load density of 40g/m, 40kg of cartridged emulsion (assuming the use of 125g cartridged emulsion), 500 kg bulk emulsion (to be sensitised on site) and 315 detonators.

2.2.1.2 For the caverns that require blasting, the construction will also follow a maximum three-blasts-per-two-days cycle, with each blast consisting of up to eight blast faces. The cavern will require an average heading / bench excavation area of approximately 170m^2. Each blast face would require, on average 220 production holes and 27 perimeter holes. If a pull length of 5.5m per blast is assumed, then each blast face would need approximately 12kg of detonating cord with a PETN load density of 40g/m, 35kg of cartridged emulsion (assuming the use of 125g cartridged emulsion), 1070kg bulk emulsion (to be sensitised on site) and 247 detonators. Bulk emulsion will be adopted 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 Instantaneous Charge (MIC) envisaged for a particular blast is below 2kg. This prevents the occurrence of excessive vibrations due to potential bulk emulsion dosing inaccuracy [4]. Bulk emulsion is proposed to be used extensively for the cavern and some sections of the tunnels and ventilation shaft.

2.2.1.3 The blasting activities together with the required amount of explosives is summarised in **Table 2.1**. The actual amount of explosives (cartridged emulsion and detonating cord) is calculated based on different tunnels and caverns profiles described in **Table 2.2** and the types of explosives listed in **Table 2.3**.

Table 2.1 Drill and Blast – Explosives Requirements (Summary)

Works Area	Delivery Point	Blast Face	Approximate No. of Blasts	Explosive Load (kg/ blast)
Single Access Tunnel Top Heading	Mui Tsz Lam Road	Access Tunnel	40	76.1-433.5
Single Access Tunnel Bench	Mui Tsz Lam Road	Access Tunnel	40	21.7-178.5
Full Access Tunnel Top Heading	Mui Tsz Lam Road	Access Tunnel	202	70.9-382.5
Full Access Tunnel Bench	Mui Tsz Lam Road	Access Tunnel	101	25.1-255
Secondary Access Tunnel Top Heading	Mui Tsz Lam Road	Access Tunnel	81	70.9-382.5
Secondary Access Tunnel Bench	Mui Tsz Lam Road	Access Tunnel	81	20.5-453
Ventilation Shaft	A Kung Kok Shan Road	Ventilation Shaft	36	28.8-100
Ventilation Tunnel	Mui Tsz Lam Road	Ventilation Tunnel	198	51.5-255
Branch Tunnel Top Heading	Mui Tsz Lam Road	Tunnel	114	65.2-326.4
Branch Tunnel Bench	Mui Tsz Lam Road	Tunnel	114	19.7-140.3
Cavern Top Heading	Mui Tsz Lam Road	Cavern	1516	70.9-382.5
Cavern Bench	Mui Tsz Lam Road	Cavern	1516	38.2-510

Table 2.2 Drill and Blast – Typical Project Profiles

Tunnels /Caverns Profile Description	Section Area (m^2)	No. of production holes	No. of perimeter holes	Cartridged Emulsion (kg)	Detonating Cord (kg)	Detonators (kg)
Single Access Tunnel Top Heading (CE)	170	365	85	423.3	10.2	0.45
Single Access Tunnel Top Heading (BE)	170	160	85	45.5	30.6	0.25
Single Access Tunnel Bench (CE)	70	150	20	176.1	2.4	0.17
Single Access Tunnel Bench (BE)	70	68	20	14.5	7.2	0.088
Full Access Tunnel Top Heading (CE)	150	330	80	372.9	9.6	0.41
Full Access Tunnel Top Heading (BE)	150	145	80	42.1	28.8	0.23
Full Access Tunnel Bench (CE)	100	300	20	252.6	2.4	0.32
Full Access Tunnel Bench (BE)	100	95	20	17.9	7.2	0.12
Secondary Access Tunnel Top Heading (CE)	150	330	80	372.9	9.6	0.41
Secondary Access Tunnel Top Heading (BE)	150	145	80	42.1	28.8	0.23
Secondary Access Tunnel Bench (CE)	60	150	20	150.6	2.4	0.17
Secondary Access Tunnel Bench (BE)	60	58	20	13.3	7.2	0.078
Ventilation Shaft (CE)	50	150	40	96.8	3.2	0.19
Ventilation Shaft (BE)	50	70	40	20.8	8	0.11
Ventilation Tunnel (CE)	100	214	60	247.8	7.2	0.27
Ventilation Tunnel (BE)	100	95	60	21.6	21.6	0.16
Branch Tunnel Top Heading (CE)	128	280	76	317.3	9.1	0.36
Branch Tunnel Top Heading (BE)	128	120	76	37.8	27.4	0.20
Branch Tunnel Bench (CE)	55	140	20	137.9	2.4	0.16
Branch Tunnel Bench (BE)	55	52	20	12.5	7.2	0.072
Cavern Top Heading (CE)	150	330	80	372.9	9.6	0.41
Cavern Top Heading (BE)	150	145	80	42.1	28.8	0.23
Cavern Bench (CE)	200	400	20	507.6	2.4	0.42
Cavern Bench (BE)	200	200	20	31	7.2	0.22

Note 1: The following abbreviations apply: CE - Cartridged Emulsion, BE – Bulk Emulsion Explosives

Note 2: Typical project profiles given for an assumed pull length of 4.5m. For some tunnel sections, this is not achievable due to the proximity of sensitive receivers.

Table 2.3 Drill and Blast – Initiating Explosive Types

Explosive Type	Quantity per Production/ Perimeter Hole
Cartridged emulsion	0.125 kg (125 g per cartridged emulsion) [1]
Detonating cord	0.08 kg/m based on density of 0.04 kg/m (40 g/m)

Explosive Type	Quantity per Production/ Perimeter Hole
Detonator	0.001 kg (0.9 g each)

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

2.3 Explosives Types

2.3.1 Proposed Explosives

2.3.1.1 Two types of explosives will be used for the construction of cavern by drill and blast method. They are:

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

2.3.1.2 The cartridged emulsion and bulk emulsion contain an oxidising agent mainly composed of ammonium nitrate, water, and a hydrocarbon such as fuel oil. The cartridged emulsion may also contain 2-3% aluminium powder (depending on the manufacturer) to increase the explosion temperature and the explosion power.

2.3.1.3 Cartridged emulsion will be delivered from the Explosive Magazine to the construction site by the appointed contractor using Contractor's licensed explosives carrying vehicles.

2.3.1.4 Bulk emulsion precursor (an oxidizing agent) will be transported to the blasting sites by the appointed third party supplier. The bulk emulsion precursor will only become classified as an explosive after being sensitised at the blast location or work face, by the addition of a gassing agent as it is pumped into the blast holes at the excavation face.

2.3.1.5 Detonators, cartridged emulsion and detonating cords will be used to initiate the blast at the work faces depending on the blasting requirements. The primer will comprise one cartridge of emulsion explosives, into which the detonator will be inserted. Small loops of detonating cord will be used to connect all detonators within one delay sector in the blast pattern. The detonators approved for use in Hong Kong are of the non-electric type and are initiated by shock tube.

2.3.2 Explosives Properties

2.3.2.1 Properties of the two types of explosives to be used in this Project are shown in **Table 2.4**.

Table 2.4 Explosives Types

Type	Function	Use	Example
Initiating explosives	To initiate the main blasting explosives	Initiation of secondary explosives	Cartridged emulsion, Detonators, Detonating cord
Blasting explosives	Used as the main blasting explosives	General blasting, shattering rock / structures	Bulk emulsion, Cartridged emulsion in closed proximity to sensitive receivers

2.3.3 Cartridged Emulsion

2.3.3.1 The cartridged emulsion is packaged in plastic films with the tips clipped at each end to form a cylindrical sausage, or wrapped in waxed paper. It can be used for both priming and full column applications, such as mining, quarrying and general blasting work.

2.3.3.2 Cartridged emulsion 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. 0.96kg of TNT in 1kg of emulsion.

2.3.3.3 Cartridged emulsion consists of a mixture of oxidisers and fuel. It contains high quantity of water which is typically around 14%. The oxidisers are typically ammonium nitrate, calcium nitrate or sodium nitrate. The fuels are waxes or oils such as diesel fuel. The whole mixture is complete with small amounts of emulsifiers to keep the water and oil mixture homogeneous. It is detonator sensitive and does not require the use of booster to cause it to detonate.

2.3.4 Bulk Emulsion Precursor

2.3.4.1 Bulk emulsion has a similar composition to cartridged emulsion except that it does not contain aluminium. The bulk emulsion precursor has a density of 1.38-1.40 g/cc. Prior to sensitisation, it is not considered as an explosive, and is classified as UN 5.1 oxidising agent and DG Category 7 strong supporters of combustion. They are stored in a DG Category 7 store and controlled by the Fire Services Department.

2.3.4.2 Before sensitisation, bulk emulsion precursor is stable under normal conditions and there is no major fire hazard. The oxidising properties of bulk emulsion precursor are considered the major hazard of it, which can cause irritation to eyes and skin. Explosion of bulk emulsion precursor is only possible under prolonged fire, supersonic shock or very high energy projectile impact.

2.3.4.3 Due to its stability under normal conditions, the storage and transport of bulk emulsion precursor will not be further considered in this study.

2.3.5 Blasting Explosives

2.3.5.1 Bulk emulsion will be used as the main blasting explosives to excavate rock by rock blasting. It will be manufactured on-site and requires the use of initiating explosives.

2.3.5.2 The bulk emulsion precursor will be sensitised at the blasting site by adding a gassing solution which contains sodium nitrate.

2.3.5.3 The gassing solution will be injected into the bulk emulsion precursor to reduce the density to 0.8-1.1 g/cc at the discharge end of the loading hose. This produces nitrogen gas bubbles that aid the propagation of the detonation wave, and the emulsion is said sensitised. The sensitised emulsion can then be detonated with the assistance of a small booster and a detonator.

2.3.5.4 The bulk emulsion, once being gassed, is classified as UN 1.5D explosive or a DG Category 1 explosive under the Hong Kong classification system. The bulk emulsion blasting explosives once it is mixed should be pumped into and completely fill the blast hole.

2.3.6 Detonating Devices

2.3.6.1 Detonators are small devices used to safely initiate the blasting explosives in a controlled manner. The detonators commonly used in Hong Kong are of the non-electric type and are initiated by shock tube. Unlike normal tunnelling projects in Hong Kong, multi-face blasting is necessary for the timely completion of this Project. It is expected that up to eight faces will be blasted per day during construction. Centralised Blasting System (CBS) is thus being considered to be implemented, and electronic detonators will be used associated with this system.

2.3.6.2 Detonators are classified as either UN 1.1B, 1.4B or 1.4S, and DG Category 1 explosive under the Hong Kong classification system. Although detonators contain the most sensitive types of explosives in common use, they are packaged in a manner that no serious effects outside the package if accidentally initiated, this minimises the risk associated with handling and use of the detonators.

2.3.6.3 Detonators are manufactured with in-built delays of various durations to facilitate effective blasting and allow shots to be initiated at one time but to fire sequentially. The delay time of a detonator is controlled by the burning time of a pyrotechnic ignition mixture pressed into a 6.5mm diameter steel tube. This delay element causes the primary explosive to detonate. This in turn causes the secondary explosive PETN to detonate. The delay time of a detonator is based on the length of steel tube and the compaction of the pyrotechnic mixture. In designing the blasting of a blasting face, the general principle is to select the required detonators to ensure that each individual detonating blast hole is separated by a minimum of 8ms.

2.3.6.4 Detonating cords are thin and flexible tubes with explosive core. They detonate along its length continually and are suitable for initiating explosives that are detonator sensitive such as the cartridged emulsion. The core of the cord is a compressed powdered explosive which is usually the PETN, and it is initiated by the use of detonator.

2.4 Statutory/Licensing Requirement and Best Practice

2.4.1 Storage of Explosives

2.4.1.1 The explosives magazine will comply with the general requirements from the Commissioner of Mines. These general requirements are stated in the document “How to Apply for a Mode A Store Licence for Storage of Blasting Explosives”. Each magazine will be a single storey detached bunded structure with dimensions as specified on Mines and Quarries Division Drawing MQ1630 “Typical Details of Explosives Magazine – Plan A”. The magazine buildings will each be fenced and secured, and surfaced road access for 11 tonne trucks will be provided for delivery of explosives.

2.4.1.2 The general requirements for the approval of an explosives magazine are listed as follows in accordance with “Guidance Note on How to Apply for a Mode A Store Licence for Storage of Blasting Explosives” by Mine’s Division of CEDD:

- The maximum storage quantity should normally not exceed 1000kg;
- Regarding the suitability of the proposed magazine location, the safety distance requirements as stated in the Explosives Regulations 2014, United Kingdom will be referenced;
- The proposed magazine should be located on plan at least 45m and 75m from any high tension power cables carrying 440V and 1KV respectively;
- The security aspects of the Mode A store location and the security company should be approved by the Commissioner of Police; and
- Other materials likely to cause fire or explosion should not be transported in the explosives carrying vehicles, and only the persons assigned to assist in handling explosives should be permitted on an explosives carrying vehicle. Driver and all workers engaged in the loading, unloading and conveying of explosives should be trained in firefighting and precautions for the prevention of accident by fire or explosion.

2.4.1.3 The general requirements for the construction of an explosives Mode A store magazine are listed as follows:

- The store should be a single storeyed detached structure with lightning protection and outer steel store doors;

- All hinges and locks should be made of non-ferrous metal;
- No ferrous metal should be left exposed in the interior of the Mode A store;
- The interior and exterior walls of the Mode A store should be printed white;
- The outer side of the steel door of the Mode A store should be painted red. The words “DANGEROUS – EXPLOSIVES” and “危險 – 爆炸品” should be written in white on the outside of the door. The letters and characters should be at least 100mm high. No ferrous metal shall be exposed on the inner face of the door forming part of an interior of the Mode A store;
- A security fence surrounding the Mode A store should be installed and set back at least 6m from the store. The fence should be 2.5m high, stoutly constructed of chain link fencing with a mesh size not exceeding 50mm. the fence should be firmly fixed to metal or concrete posts and topped with a 0.7m high outward overhang of razor wire. The base of the fence located between the posts should be secured with pegs to prevent intrusion;
- The area between the security fence and the Mode A store should be cleared of all vegetation. Vegetation clearance should also apply to a minimum distance of 1m on the exterior of the fence. A uniform cross-fall of at least 1 in 100 away from the store to a drainage system should be constructed;
- The road leading to the Mode A store should have a concrete surface and it should be constructed and maintained so that 11 tonne trucks can use it under all weather conditions. A suitable turning circle or other alternative means for these trucks to turn should be provided so that the trucks can be driven up to the gate of the security fence;
- The gate in the security fence should be fitted with a lock of close shackle design with a key-intention feature. A warning signboard with prohibited articles and substances painted in red and black, shown in symbols and in Chinese and English characters should be posted at the gate. Each symbol should be at least 100mm in diameter. A typical warning signboard is available in Annex 4 of “How to Apply for a Mode A Store Licence for Storage of Blasting Explosives”;
- A guardhouse should be provided. For surface Mode A store, security guards should be on duty outside the inner security fence adjacent to the fate when there is no receipt or issue of explosives inside the Mode A store. A separate outer security fence should be installed to protect this guardhouse;
- Inside the guardhouse, an arms locker constructed as an integral part of the house and fitted with a lock is required;
- A telephone should be provided for use by the guard in the guardhouse. A watchdog should normally be provided for the store; and
- Fire-fighting installations consisting of at least four 6 litre foam and one 4.5kg dry powder fire extinguishers to be positioned on two racks and four buckets of sand should be provided at the nearest convenient locations to the Mode A door.

2.4.2 Transport of Explosives

Supply of Detonators and Cartridged Emulsion Explosives

2.4.2.1 Detonators are imported into Hong Kong and stored at the Mines Division Kau Shat Wan (KSW) explosives depot. Users will place orders from Mines Division for delivery to their on-site explosives magazine or to their blasting sites as appropriate on a daily basis as required.

Application for Removal of Explosives

2.4.2.2 A Removal Permit is required for any person to move explosives in and out of the explosives stores under Regulation 4 of the Dangerous Goods (General) Regulations.

Application for Approval of an Explosives Delivery Vehicle

2.4.2.3 The explosives trucks should comply with the safety requirements set in the "Guidance Note on Requirements for Approval of an Explosives Delivery Vehicle" issued by the Mines Division.

2.4.2.4 The minimum safety requirements are listed as follows:

Condition of Vehicle

- The vehicle should be powered by a diesel engine;
- The vehicle's design, construction and strength must comply with the Road Traffic (Construction and Maintenance of Vehicles) Regulations, Chapter 374; and
- The vehicle should be kept clean, in sound mechanical condition and roadworthy.

Condition of Cargo Compartment

- The cargo compartment including the roof should be constructed with sheet metal at least 3mm thick and lined internally with at least 13mm thick plywood, and there should be no exposed ferrous metal in the interior of the goods compartment;
- The interior of the cargo compartment including doors should be kept in good condition and free from defects or projections which might cause accidental damage to the packages;
- Electric wiring or electrical devices should not be installed inside the cargo compartment;
- The door of the cargo compartment should be capable of being locked; and
- Proper stowage facilities should be provided to secure the load in a stable manner during transportation.

Safety Provisions

- The driver's cabin should be separated by a distance of not less than 150mm from the cargo compartment of the vehicle;
- The exhaust system must be located as far from the cargo compartment as possible, preferably at the front of the vehicle;
- An emergency fuel cut-off device should be located at an easily accessible position with a label, in Chinese and English, prominently and legibly stating: "EMERGENCY ENGINE STOP 緊急死火掣";
- For a typical vehicle with gross vehicle weight of 9 tonnes or above, four fire extinguishers, comprising two 2.5kg dry powder and two 9-litre foam fire extinguishers of an approved type, with certificates, shall be provided. They shall be mounted in front and on both sides of the rear body in easily accessible positions with securely mounted brackets and quick release clamps;

- 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 to ensure that the risk of this occurring will be minimized in the event of a traffic accident. All electrical wiring and fittings shall be shrouded in fire resisting conduits;
- The fuel tank shall be located 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;
- Fire resistant material shall be fitted between the wheel arches and the cargo compartment;
- Detonators and other types of blasting explosives shall not be loaded or transported within the same cargo compartment of the vehicle, unless the cargo compartment fulfils the additional requirements as specified in Annex B of "Guidance Note on Requirements for Approval of an Explosives Delivery Vehicle".; and
- A hand-held lightning detector shall be provided in the vehicle for detection of lightning before and during loading and unloading of explosives. Should lightning be detected within a distance of 16 km from the loading/unloading point by the hand-held detector, loading or unloading of explosives shall cease until the lightning signal has cleared.

Display on Vehicle

- Whenever the vehicle is carrying explosives, it shall display: (i) on both sides and on the rear door of the cargo compartment, placards (of minimum dimensions 250mm x 250mm) showing the label of the highest Hazard Code of explosives, and (ii) a rectangular red flag, in a prominent position, of dimensions not less than 230mm x 300mm;
- Placards showing "EMPTY 空車" or blank placards shall be displayed when the vehicle is empty; and
- The vehicle should be printed in white with warning words in the Chinese and English of at least 150mm height. The word "DANGER – EXPLOSIVES" and "危險 – 爆炸品" should be printed in red colour and displayed on both sides and rear face of the goods compartment.

2.4.3 Use of Explosives

2.4.3.1 Bulk emulsions are manufactured at the blast sites and use immediately for rock blasting. A licence is required to manufacture a nitrate mixture outside a factory as DG Category 1 under Regulation 31A of the Dangerous Goods (General) Regulations Cap. 295B.

2.4.3.2 For the manufacturing of bulk emulsion at blast sites, ammonium nitrate (AN), which is classified as DG Category 7 – Strong Supporters of Combustion under Regulation 3 of the Dangerous Goods (Application and Exemption) Regulations Cap. 295A, is used. A licence for the storage of DG Category 7 is required according to "A Guide to Application for Dangerous Goods Licence" from the Fire Services Department.

2.4.3.3 For the use of explosives, a blasting permit is required from the Mines Division so that the use of explosives at a work site for the carrying out of blasting is allowed; and a Mine Blasting Certification is required so that the shotfirer is permitted to use explosives in blasting.

2.5 Design and Location of the Explosives Magazine

2.5.1.1 The site is located in area of low population density. A configuration that comprises 3 magazine structures storing maximum 500kg of explosives each will be adopted. A preliminary magazine design plan is shown in **Figure 2.1**. Location of the magazine and the transport route of explosives from the magazine to project site are shown in **Figure 2.2**.

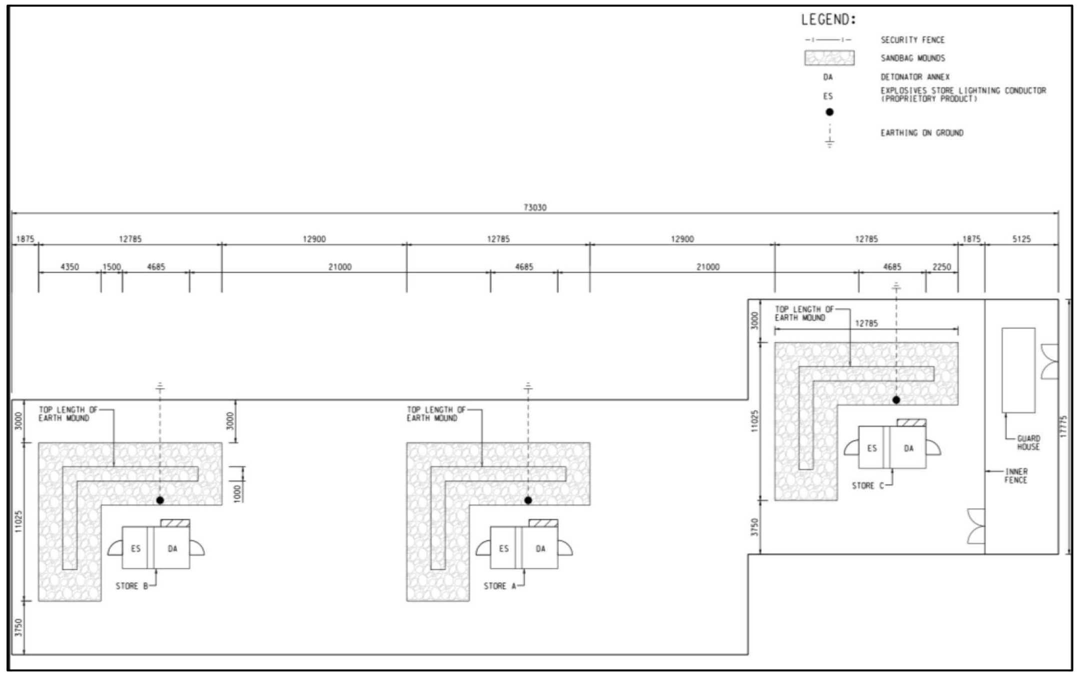


Figure 2.1 General Magazine Site Layout

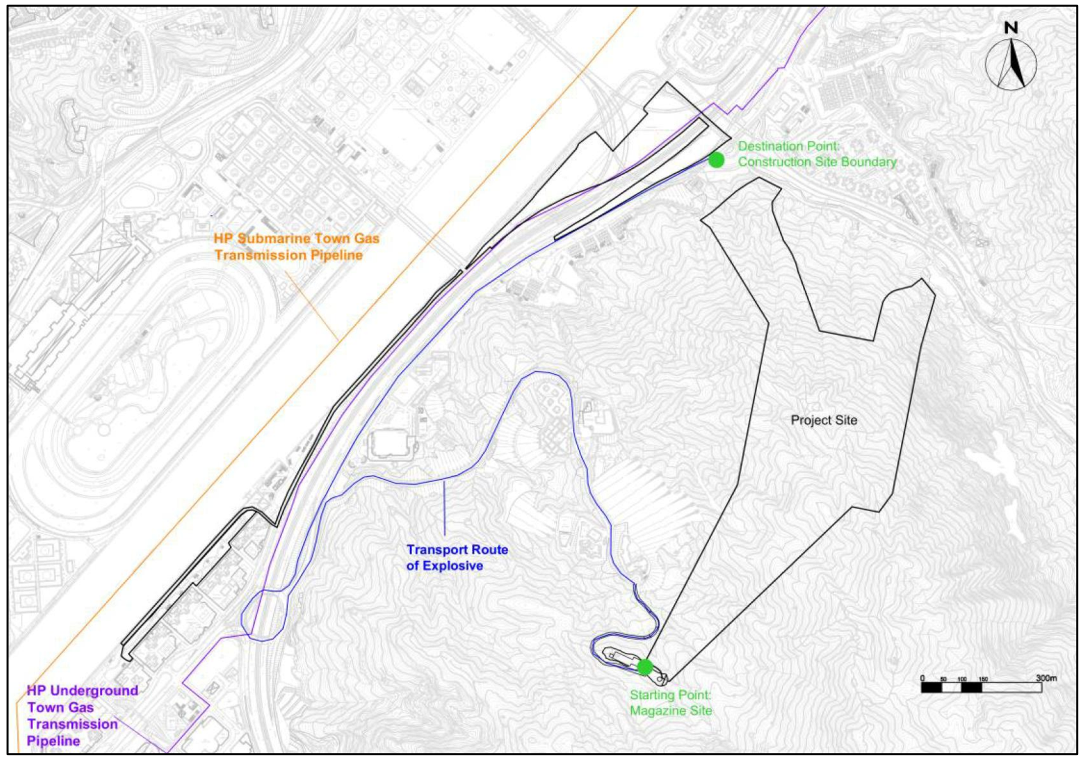


Figure 2.2 Location of Explosive Magazine, HP Pipeline and Transport Route of Explosive

2.6 Construction Cycle and Programme

2.6.1 Construction Cycle

2.6.1.1 After commissioning of the magazine the proposed delivery-storage-blasting cycle will consist of the following elements:

- Weekdays and Saturdays morning deliveries of explosives and initiating systems to magazine by Mines Division as needed;
- Storage in the magazine stores;
- Transfer from the explosive stores to the delivery points of the construction areas utilizing public roads, the transport route is shown in **Figure 2.2**;
- Transfer to the working faces of the excavation; and
- Load and fire the faces 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, blasting works will be conducted on both Weekdays and Saturdays.

2.6.2 Explosives Transport Requirements

Base Case for the Hazard to Life Assessment

2.6.2.1 When a three blasts in two days scenario is expected, consumption of explosives is estimated to be 540kg in total per day. Delivery frequency for explosives will be 3 times a day (e.g. cartridge explosives and detonating cord) with maximum loading of 200kg per truck. Detonators shall be separately transported in explosives carrying vehicles.

2.6.2.2 For a yearly estimation, average blasting will be carried out 25 days per month, and the annual number of explosives delivery is thus estimated to be 900. The corresponding explosive load transported in the peak 12- month delivery period is shown in **Table 2.5**.

Table 2.5 Explosive Deliveries for every 12 month period during construction

12 month delivery period	**Total Explosive Delivery Trips within the 12 month period**	
	Main Access Tunnel Portal (via A Kung Kok Shan Road and A Kung Kok Street)	**Ventilation Shaft (via access road uphill by hand delivery)**
Apr 2019 - Mar 2020	651	20
Apr 2020 - Mar 2021	730	448
Apr 2021 - Mar 2022	900	0
Apr 2022 - Mar 2023	240	0

Worst Case for the Hazard to Life Assessment

2.6.2.3 There is a possibility that the actual construction programme may differ from the envisaged construction programme due to construction uncertainties or contractors' method of working. In such case, more delivery trips and return trips may be resulted. Typically, a 20% increase in the number of deliveries compared to the base case scenario may result in the worst case based on previous similar project experience.

2.7 Transport of Explosives and Initiation Systems

2.7.1 Explosives Transport Strategy

2.7.1.1 Explosives will be transferred from the magazine to the cavern construction site by the contractor. Two licensed explosive trucks will be required for each delivery. One of them will only transport detonators while the other will transport a cargo of cartridged emulsion and detonating cord.

2.7.1.2 No more than one truck convoy loaded with explosives (made up of vehicle carrying the detonators and the vehicle carrying the cartridged emulsion and detonating cord) is generally expected within the magazine complex at any one time. The explosives carrying vehicles will also maintain separation headway of about 10 minutes.

2.7.2 Explosive Delivery Route

2.7.2.1 The explosives will be delivered from the magazine, via the *access road to A Kung Kok Shan Road, A Kung Kok Shan Road and A Kung Kok Street* to the construction site boundary as shown in **Figure 2.2**. The total length of transport route is around 4km.

2.7.2.2 There will only be one delivery point from magazine to construction site. For the blasting of ventilation shaft, explosives will be hand delivered to blasting site due to the relatively short distance away from magazine site. This section of hand delivery is carried out within the construction site of ventilation shaft and hence considered as part of Use of Explosives. The assessment is presented in **Appendix 7.02 - Use of Explosives**.

2.8 Concurrent Projects during Construction Phase

2.8.1.1 Apart from during construction phase, explosives are not expected to be used, stored or transported, particularly during operation and decommissioning. However, as no other concurrent, planned or committed projects leading to any other hazardous events have been identified at the present stage, it is then reasonable to conclude there will be no potential cumulative impacts expected to arise during the Project cycle.

3 HAZARD TO LIFE ASSESSMENT METHODOLOGY

3.1 Study Approach

3.1.1.1 In dealing with the risk issues concerning on-site overnight storage of explosives, the “Avoid – Minimize – Mitigate” approach will be adopted. Quantitative Risk Assessment (QRA) is required as part of mitigation measures when avoidance and minimization are not possible. From risk perspectives, the choice of alternative options for cavern formation will aim at avoiding/ minimizing the use of explosives if its use and storage cannot be avoided.

3.1.1.2 The elements of the QRA are shown schematically in **Figure 3.1**. It consists of the following 6 main tasks:

(a) **Data / Information Collection and Update:** Collect relevant data / information which is necessary for the hazard assessment.

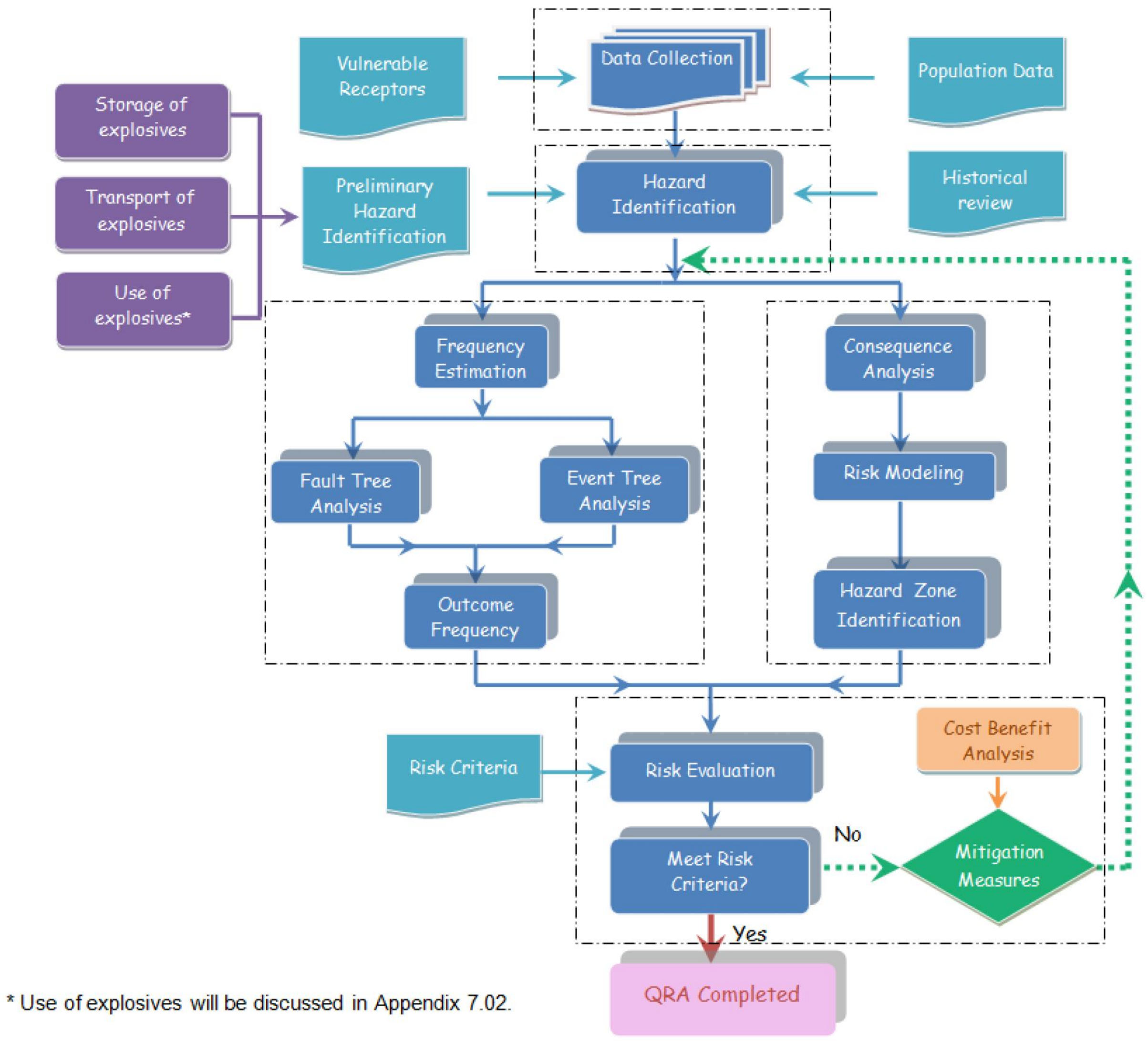
(b) **Hazard Identification:** Identify hazardous scenarios associated with storage, transport and use of explosives.

(c) **Frequency Estimation:** Estimate the frequencies of each hazardous event leading to fatalities with full justification by reviewing historical accident data and previous similar projects.

(d) **Consequence Analysis:** Analyse the consequences of the identified hazardous scenarios.

(e) **Risk Integration and Evaluation:** Evaluate the risks associated with the identified hazardous scenarios. The evaluated risks will be compared with the HKRG to determine their acceptability. Where necessary, risk mitigation measures will be identified and assessed to comply with the “as low as reasonable practicable (ALARP) principle used in the HKRG.

(f) **Identification of Mitigation Measures:** Review the recommended risk mitigation measures from previous studies, practicable and cost-effective risk mitigation measures will be identified and assessed as necessary. Risk outcomes of the mitigated case will then be reassessed to determine the level of risk reduction.



* Use of explosives will be discussed in Appendix 7.02.

Figure 3.1 Schematic Diagram of QRA Process

3.2 Domino Effects of High Pressure (HP) Town Gas Transmission Pipelines

3.2.1.1 The Hong Kong and China Gas Company (HKCG) operates the town gas network to supply gas for domestic and industrial uses. Town gas is a mixture of hydrogen, methane and carbon dioxide. It is produced at the Tai Po Gas Production Plant and supplied through a network of high pressure (HP) underground town gas transmission pipelines (operating at 35 bar) to various districts of Hong Kong.

3.2.1.2 The HP underground town gas transmission pipelines to Sha Tin originates at the Tai Po Gas Production Plant, runs subsea along Tolo Harbour and Shing Mun River to the offtake and pigging station in City One, Sha Tin. The HP underground town gas transmission pipeline continues towards Ma On Shan along Tate's Cairn Highway and Sai Sha Road, and arrives the downstream Sai O pigging station. According to the information provided by the Hong Kong and China Gas Company (HKCG), the length of HP underground town gas transmission pipeline between the 2 pigging stations is approximately 7.8km, of which 1.9km lies in the vicinity of the proposed transport route of explosives between A Kung Kok Shan Road and the Project Site.

3.2.1.3 Along this section, there is also one HP submarine town gas transmission pipeline running along Shing Mun River more than 150m away from the transport route of explosives as well as the Project Site. With reference to the approved East Rail Extensions – Tai Wai to Ma On Shan EIA Report, the individual risk of 1E-09 per year is well confined within 150m from

the HP underground town gas transmission pipeline. The technical specifications of the HP submarine town gas transmission pipelines provided by HKCG including the most critical parameter, i.e. operating pressure, shows that it is similar to those of the HP underground town gas transmission pipeline, and also the submarine gas pipelines are at least 2m beneath the seabed. It is thus considered that the hazard distance from the submarine gas pipelines would not be greater than that of the underground one. Therefore, with the separation distance of more than 150m between the HP submarine town gas transmission pipelines and the explosives transport route / the Project Site, they are not further considered in this study. **Figure 2.2** shows the locations of the HP pipelines.

3.2.1.4 The transport route of explosives is in close vicinity of a section of the HP underground town gas transmission pipelines from the Sha Tin Hospital to Mui Tsz Lam Road. Separation distance between the transport route of explosives and the pipelines is around 50m. Thermal outcomes from town gas release may trigger failure of explosives when the explosives carrying vehicles hit the point of pipelines failure. This HA assesses the domino effects of the failure of HP underground town gas transmission pipelines affecting the failure of the transport of explosives.

3.2.1.5 For the HP underground town gas transmission pipelines, major hazards arising from failure of explosives during storage, transport and use are the pipelines failure due to ground vibration and the subsequent release consequences. These are treated as secondary and/or tertiary hazards as discussed in Section 7.

4 ESTIMATION OF POPULATION

4.1 Population near the Explosives Magazine

4.1.1.1 **Figure 4.1** shows the location of the proposed explosive magazine on a hill. It is remote from buildings and inhabited areas. There are no known buildings or any structures in the hazard zone of the explosive magazine. The nearest building is Manor Harmony, which is located over 200m away from the explosive magazine.

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

Figure 4.1 Aerial Photo of the Magazine Site

4.2 Population along Explosives Delivery Route

4.2.1 General

4.2.1.1 Four types of population are considered:

- Building population;
- Road population;
- Train Population; and
- Pedestrian population on footpaths and pavements next to the delivery route.

4.2.1.2 Considering that the maximum licensing limit of 200kg for the transport of explosives, all buildings within a 100m corridor each side of the transport route are included in the assessment. **Figure 4.2** and **Table 4.1** show all population groups included in this study. Detailed population data can be found in **Annex 2** of this Appendix.

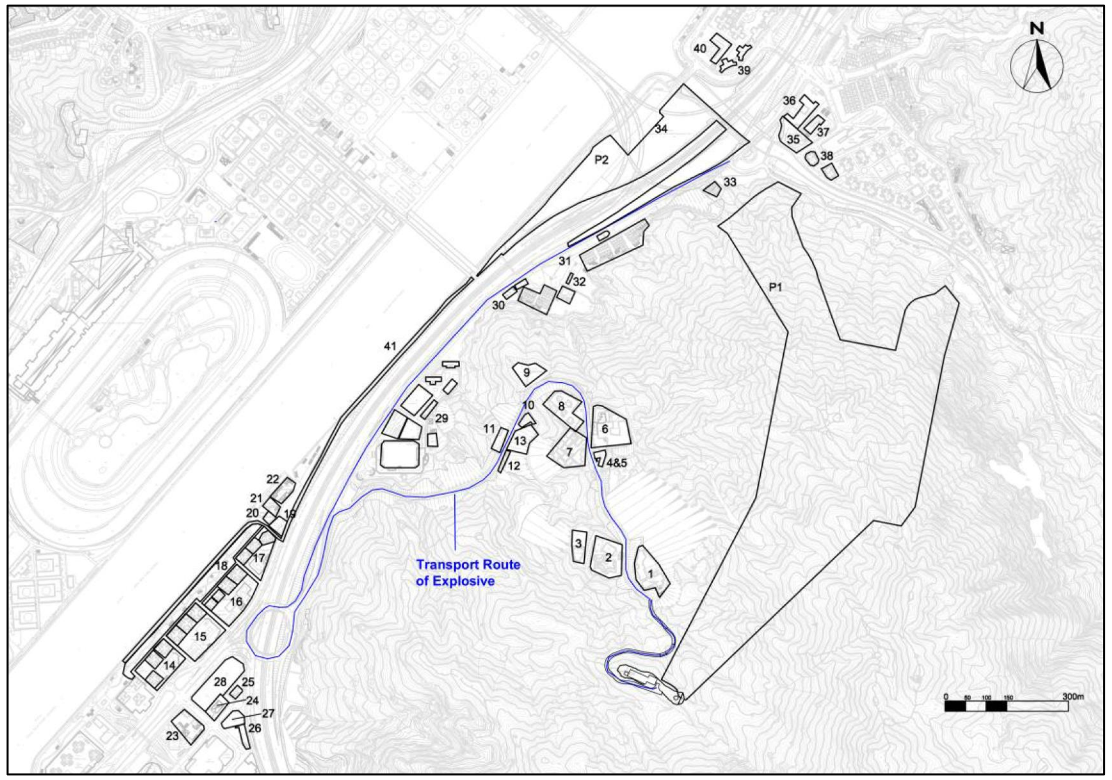


Figure 4.2 Population Groups

Table 4.1 Population Groups Considered

Population ID	Description
1	The Neighbourhood Advice-Action Council Manor Harmony
2	Shing Mun Springs
3	Hang Fook Camp
4	Substation (on A Kung Kok Shan Road, near Breakthrough Youth Village)
5	Open Car Park (near Breakthrough Youth Village)
6	Breakthrough Youth Village
7	Richard Butler Chalets
8	Cheshire Home Shatin
9	A Kung Kok Fresh Water Service Reservoir
10	Open Car Park (near Bradbury Hospice)
11	Bradbury Hospice
12	Pump House (on A Kung Kok Shan Road)
13	Jockey Club Home for Hospice
15	Pictorial Garden (Stage 1)
15a	Abbey Court
15b	Belleve Court
15c	Capilano Court
15d	Car park under podium

Population ID	Description
15e	Podium
16	Pictorial Garden (Stage 2)
16a	Delite Court
16b	Elegant Court
16c	Forum Court
16d	Galaxy Court
16e	Car park under podium
16f	Podium
17	Pictorial Garden (Stage 3)
17a	Hillview Court
17b	Iris Court
17c	Juniper Court
17d	Car park under podium
17e	Podium
18	On King Street Park
19	Open Car Park (near Jockey Club Shek Mun Rowing Centre)
20	Jockey Club Shek Mun Rowing Centre
21	Hong Kong China Dragon Boat Association Shatin Shek Mun Training Centre
22	Hong Kong Canoe Union Shatin Training Centre
23	Site Offices (DSD / LandsD)
24	Petrol Station
25	Shek Mun Fresh Water Booster Pumping Station
28	Open Car Park (near Pumping House on On Ping Street)
29	Shatin Hospital
29a	Shatin Hospital
29b	Open Car Park
29c	Transport Terminus
29d	Football Field
29e	Basketball Court
29f	Jockey Club Centre for Positive Ageing
29g	A Kung Kok Government Quarters Block B
29h	A Kung Kok Government Quarters Block C
29i	Tennis Court
30	A Kung Kok Sewage Pumping Station
31	Ah Kung Kok Fishermen's Village
31a	Ah Kung Kok Fishermen’s Village (a)
31b	Ah Kung Kok Fishermen’s Village (b)
31c	Basketball Court
31d	Football Field
31e	A Kung Kok Sitting-out Area
32	Hong Kong Mountaineering Union

Population ID	Description
33	Evangelical Lutheran Church of Hong Kong Shatin Youth Centre Recreational Camp and Training Centre
34	Custom and Excise Department Shatin Vehicle Detention Centre (will be relocated)
35	A Kung Kok Street Garden
36	Ma On Shan Tsung Tsin Secondary School
37	Kowloon City Baptist Church Hay Nien Primary School
38	Chevalier Garden
38a	Chevalier Garden Block 6
38b	Chevalier Garden Block 5
41	Shing Mun River Promenade
P1	Proposed Project Site
P2	Proposed Project Site Office and works area

4.2.2 Land and Building Population

4.2.2.1 All buildings within the 200m study corridor (both sides of transport route), including those extended only part into the corridor, are included in the assessment. Populations in each building along the transport route are analysed individually.

4.2.2.2 **Table 4.2** below presents data sources that are considered and adopted in this report. Moreover, the data sources are supplemented with site surveys to fill out unavailable information and/or to serve as cross-reference where necessary.

Table 4.2 Land and Building Population Data Sources

Sources	Details
Census and Statistic Department	Domestic Household Size and Population; Characteristics for Shatin and Ma On Shan Districts and relevant Tertiary Planning Units (TPU); 2011 Population Census Data published in the website
Planning Department	Projections of Population Distribution for the project construction year using enhanced 2011-based TPEDM; Future land use and planned developments
Education Bureau	School Information lists by District
Centamap	Buildings and Population groups
Lands Department	GeoInfo Map; Buildings, Institutional and Social Facilities
Others	Community and Health Care Facilities; Public Utilities

4.2.2.3 Population in private residential developments are generated based on the number of households in each building and the average household size defined by different Tertiary Planning Units (TPU) as adopted in census and planning data. Centamap is a source to obtain building information including number of storeys and number of units per floor. It is considered that data shown in the website is reasonably reliable and accurate.

4.2.2.4 GeoInfo Map is a web-based application showing common facilities with the latest street map. The service is provided by Lands Department. Although GeoInfo Map does not contain building information in details, it is considered that information on its website is updated more frequent than Centamap. It is appropriate data source for cross checking.

4.2.2.5 Regarding the population in community and health care facilities, relevant information is collected from the individual website and verified by site surveys.

4.2.2.6 Moreover, the latest Outline Zoning Plan (OZP) in the Statutory Planning Portal is studied to assess any potential population in the project construction year.

Adjustment of Building Population

4.2.2.7 The maximum hazard zone for 1% fatality level for the detonation of explosives in an explosives carrying vehicle will be determined in the consequence assessment. This maximum hazard zone will be used to determine the number of floors of a building that will be affected and an adjustment factor to be assigned to the maximum population of each buildings in the risk analysis.

4.2.2.8 Centamap is one of the publicly available sources to obtain building information including number of storeys and number of units per floor. It is considered data shown in the website is reasonably reliable and accurate. Building height data is also available from the GIS database for most buildings, the number of floors for those buildings without information from the Centamap will be estimated from the GIS data assuming floor-to-floor height of 3m. When neither of the above information is available, building information will be supplemented by site surveys.

4.2.3 Road Population

4.2.3.1 Traffic population considered in this report covers population on A Kung Kok Shan Road, A Kung Kok Street, Tate's Cairn Highway, Ma On Shan Road and Mui Tsz Lam Road.

4.2.3.2 It is considered that the road population being affected by an explosion event is dependent on the explosion scenarios. A spontaneous explosion due to vehicle collision or transport of unsafe explosives would impact free flowing traffic. In case of vehicle fire, traffic could be jammed and an explosion initiated following a vehicle fire impacting on the queuing traffic. In low traffic conditions such as non-peak hours, road users may use alternative lanes or reverse when there is a vehicle fire, it is thus assumed in this study that probability to develop into jammed traffic for such fire scenarios is 50%.

4.2.3.3 The traffic density information is based on the latest Annual Traffic Census (ATC) 2014 and Based District Traffic Model (BDTM) developed by the Transport Department, and supplemented by site surveys where necessary. The population associated with the road vehicles is modelled as 100% indoor.

Flowing Traffic Condition

4.2.3.4 The Annual Average Daily Traffic (AADT) data is extracted from the latest ATC and used to estimate normal traffic flows at non-peak hours, and the vehicle mix and vehicle occupancy will also be obtained from the same data source. The road population during normal traffic flow condition is calculated by the following equation:

$$\text{Population density (persons/m}^2\text{)} = \frac{\text{AADT x No. of person per vehicle}}{\text{24 x Vehicle speed x Road width}}$$

4.2.3.5 An annual growth rate of 1% is assumed to project the current data to the project construction year.

4.2.3.6 The BDTM data is used to estimate traffic flows at peak flowing traffic condition. The vehicle mix during peak hour at respective assessment years is also obtained from the same data source. The vehicle occupancy used for calculating the road population during normal traffic flow condition is adopted for the calculation of road population during peak flowing traffic condition. The road population during peak traffic flow condition is calculated by the following equation:

$$\text{Population density (persons/m}^2\text{)} = \frac{\text{Peak traffic flow x No. of person per vehicle}}{\text{Vehicle speed x Road width}}$$

Traffic Jam Condition

4.2.3.7 As mentioned above, it is possible that the traffic flow might be disrupted when an explosion initiation occurs on the explosives carrying vehicles. If a traffic accident is severe enough to lead to a vehicle fire, a traffic jam could be developed before the fire spreads to the explosive load causing initiation. Population of traffic in a traffic jam is estimated based on the total length of road, number of traffic lanes, length of vehicle, vehicle mix, and occupancy rate of different vehicles.

4.2.3.8 The length of road occupied by different vehicle types would be based on those used in previous similar studies [1][2][3], as follows:

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

4.2.3.9 The occupancies for each vehicle type and vehicle mix are taken from the latest ATC. Four core stations (**Table 4.3**) are selected to represent the transport route from the magazine to the construction site.

Table 4.3 Core Stations Considered

Core Station	Description
5022	Tate's Cairn Tunnel (from Toll Plaza to South Portal)
5024	Lion Rock Tunnel (from Toll Plaza to South Portal)
5037	Eagle's Nest Tunnel (from Toll Plaza to South Portal)
5013	Tolo Highway (from North of Ma Liu Shiu Interchange to Yuen Shin Road Interchange)

4.2.4 Train Population

4.2.4.1 The Ma On Shan Line runs along the Tate's Cairn Highway and Ma On Shan Road, and is in close proximity of the transport route of explosives. The maximum carrying capacity of Ma On Shan Line is currently 30,500 people per hour per direction with the use of 4 train compartments per train [11]. With the commissioning of the section between Tai Wan and Hung Hom stations of SCL in 2018, the number of train compartments of Man On Shan Line will be increased to 8 [11]. It is assumed that the maximum carrying capacity will then be increased to 61,000 per hour per direction. The maximum train population density is calculated by the following equation:

$$\text{Population density (persons/m)} = \frac{\text{Passengers per hour}}{\text{Train speed}}$$

4.2.4.2 The population density is calculated to be 1.5 persons/m, assuming that the train is operating with its average speed of 80km/hr.

4.2.5 Pedestrian Population

4.2.5.1 Pedestrian flow on pavement along the explosives delivery route is assessed by site survey. The pedestrian density is estimated by the following equation:

$$\text{Pedestrian density (persons/m}^2\text{)} = \frac{\text{Number of pedestrians passing a given point}}{\text{Pedestrian speed x Pavement width}}$$

4.2.5.2 Roads to be covered in the assessment are A Kung Kok Shan Road, A Kung Kok Street and Mui Tsz Lam Road.

4.3 Time Periods and Occupancy

4.3.1.1 To be consistent with previous similar studies [1][2][3], 3 day categories (Weekdays, Saturdays and Sundays) with 4 time periods (AM Peak, Daytime, PM Peak and Night) for population have been considered in this study. The time periods are summarised in **Table 4.4**.

Table 4.4 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

4.3.1.2 The 12 time periods are further grouped into 6 time modes for risk assessment and are summarised into **Table 4.5**.

Table 4.5 Definitions of Time Modes

Time Mode	Definition	Proportion of Time
Night	All days 8:00pm to 7:00am	0.4583
AM Peak	All days 7:00am to 9:00am	0.0833
PM Peak	All days 6:00pm to 8:00pm	0.0833
Weekday Daytime	Weekdays 9:00am to 6:00pm	0.2679
Saturday Daytime	Saturdays 9:00am to 6:00pm	0.0536
Sunday Daytime	Sundays 9:00am to 6:00pm	0.0536

4.3.1.3 Occupancy of populations during each time mode is based on assumptions as listed in **Table 4.6**. For building populations, the distribution across time modes are referred to previous similar studies [1][2][3]. For road, train and pedestrian populations, distribution across time modes are based on data provided in Annual Traffic Census, BDTM and site surveys.

Table 4.6 Occupancies of Different Population Time Modes

Day Category	Occupancy					
	Night (Weekdays / Saturdays / Sundays)	AM Peak (Weekdays / Saturdays / Sundays)	PM Peak (Weekdays / Saturdays / Sundays)	Weekday Daytime	Saturday Daytime	Sunday Daytime
Residential Building	100%	50%	50%	20%	50%	80%
Hospital	80%	80%	80%	100%	90%	80%
Leisure	0%	10%	10%	70%	85%	100%
MTR / bus terminus	10%	100%	100%	70%	60%	50%
Car Park / Podium - residential	10%	100%	100%	70%	70%	70%

4.4 Features Considered in this Study

4.4.1.1 A number of manmade slopes have been identified in the vicinity of the A Kung Kok Shan magazine site as shown in **Table 4.7**. These features are considered in this assessment.

Table 4.7 Slope Identified

Slopes	Slope height (m)	Slope length (m)	Slope angle (m)	Slope Material	Distance from Explosives Stores (m)	Population
7 SE-A/F 140	15	23	35	Soil & Rock	130	Adjacent to A Kung Kok Shan Road
7 SE-A/C 274	7.1	15	50	Soil & Rock	130	Adjacent to A Kung Kok Shan Road
7 SE-A/F 44	15	40	31	Soil	170	Adjacent to A Kung Kok Shan Road
7 SE-A/C 272	38	155	50	Soil & Rock	130	Adjacent to The Neighbourhood Advice-Action Council Harmony Manor
7 SE-A/C 141	5	27	40	Soil	210	Adjacent to Shing Mun Springs

5 HAZARD IDENTIFICATION

5.1 Overview

5.1.1.1 Hazard identification consists of a review of the following:

- Properties of the explosives;
- Scenarios presented in previous similar studies;
- Historic accidents; and
- Discussion with blasting specialists

5.2 Accidental Initiation due to Hazard Properties of Explosives

5.2.1 Explosives Types and their Properties

5.2.1.1 The types and properties of explosives to be stored and transported in this project are shown in **Table 5.1** below.

Table 5.1 Types and Properties of Explosives

Explosives Type	TNT Equivalent	Melting Point at 1atm	Auto-ignition Point @ 1atm	UN Hazard Division
Cartridged Emulsion	0.96	170	230-265	1.1D
PETN (for detonating cords)	1.4	135-145	190	1.1D
PETN (for detonators)	1.4	120	190	1.4B / 1.4S

5.2.1.2 Explosives can be 'initiated' by a self-sustaining exothermic reaction. Explosives initiation can result in a vigorous burning without progression to explode, a deflagration or a detonation. It is noted that a deflagration may transit to a detonation and the corresponding mechanism is still under research. Travelling speed of the flame front is the major difference between deflagration and detonation, whereas deflagration produces a subsonic flame front while detonation produces a supersonic one. However, either kind of explosion can lead to severe fatalities and hence should be considered in the Hazard Assessment.

5.2.1.3 The possibility of accidental initiation when explosives are stored under controlled conditions in a temporary magazine or stores is low as the storage environment is unlikely to be under extreme heat, shock, impact or vibration with sufficient intensity to trigger a detonation. The most common scenario of accidental initiation is basically the cause of fire. Other scenarios of accidental initiation include severe impact and friction.

5.2.1.4 In general, an event with casualty concerns should be at least a deflagration. To induce a deflagration, the explosives should be, at least but not only, exposed to the following stimulus:

- Local stimulus: to generate a 'hot spot' like sparks, friction, impact, static electricity, etc;
- Shock stimulus: shock or high velocity impact such as bullet impact, detonation of other explosives, etc; or
- Thermal stimulus: intense heat or fire. It can be assumed that there can be no significant event until the medium becomes molten. In the case of the emulsion, there can be no significant event until much of the water has lost.

5.2.1.5 However, not all of these causes are necessarily leading to a deflagration or detonation for the types of explosives used in this project.

5.2.1.6 Accidental initiation of explosives has been categorized as either fire or non-fire induced in this study.

5.2.2 Hazard Properties of Emulsion Type Explosives

5.2.2.1 Typical emulsion explosives contain more than 78% Ammonium Nitrate (AN), which is considered as a powerful oxidizing agent. Friction or impact found in normal handling would not trigger initiation of emulsion based explosives. However, heat and confinement or severe shock (e.g. from other explosion) can cause explosion of them. The sensitivity of AN based explosives to deflagration or detonation is proportional to temperatures.

5.2.2.2 There are two broad categories of emulsions:

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

5.2.2.3 Cartridged emulsions are sensitized before transportation in ordered to fulfill their intended function. They are sensitized by either adding gassing solution or plastic microspheres at the point of manufacture. Bulk emulsions are sensitized at the point of use on sites. The difference of chemical properties for these two categories of emulsion is hence mainly due to the presence of sensitizer.

5.2.2.4 Matrix or bulk emulsion (no voids) is not shock-sensitive since there is no know mechanism for the shock front to propagate. Also, heating a void-free liquid requires a very high pressure.

5.2.2.5 A local stimulus generating 'hot spots' including sparks, friction, impact, static electricity, extreme ambient temperature etc. does not cause packaged emulsions (sensitized) to readily deflagrate in normal atmosphere conditions. To generate a deflagration which may subsequently transit to a detonation, a pressure in excess of 5 bars above atmospheric pressure is additionally required in the "deflagration mass".

5.2.2.6 The behaviour of packaged emulsion following a shock or thermal stimulus is discussed in the following sections.

5.2.3 Accidental Packed Emulsion Initiation by Fire

5.2.3.1 Pools of molten AN may be formed in a fire. They may explode particularly if they are contaminated with other materials such as copper. AN may also melt and decompose with a release of toxic fumes which are mainly oxides of nitrogen. AN's sensitivity to local stimuli increases when the temperature is beyond 140˚C [3] or in its molten form.

5.2.3.2 When the explosives are subjected to fire engulfment, many of them ignite and burn, deflagrate, and in some cases even detonate. These were indicated by a number of tests. The time for an explosive to ignite is dependent to its physical characteristics and chemical composition.

5.2.3.3 Cartridged emulsions are generally considered less sensitive to fire engulfment as a mean of initiation due to their high water content. However, the water content of the emulsion will be driven off when exposed to heat or fire. If the energy level of the heat is high enough, long duration and confinement pressure increases, cartridge emulsions may initiate.

5.2.3.4 The temperature of any reactive media would be clearly raised by a fire surrounding the explosive load and enable evaporation of components such as water. The rate at which evaporation occurs is dependent on the extent of fire and the heat transfer based on the design of the cargo container wall. The external part of the container wall would be heated by direct contact with the flame. Heat is eventually transferred to the explosive loads.

5.2.3.5 The transport accident statistics for Ammonium Nitrate/Fuel Oil (ANFO) indicate a minimum time to deflagration is about 30 minutes. Emulsions are considered more difficult to be initiated than ANFO as they have higher water content.

5.2.3.6 The consequences of an accidental explosion due to thermal stimulus could be a thermal explosion or detonation or sometimes a combination of the two.

5.2.4 Accidental Packaged Emulsion Initiation by Means Other than Fire

5.2.4.1 There are commonly two distinct groups of non-fire initiation mechanisms: mechanical and electrical energy. Both shock and friction initiation are classified as mechanical as in most accidental situations, they are difficult to be distinguished. It has been recorded some non-emulsion type explosives can initiate (in the absence of piercing) mechanically at an impact velocity as low as 15 m/s. It the explosives are pierced, it is likely that the required velocity will be far less than 15m/s. It is because localized heat generation resulting from frictional rubbing between layers of explosives, and is regarded as ‘stab-initiation’.

5.2.4.2 However, as demonstrated by the bullet impact test from a high velocity projectile, cartridged emulsions are insensitive to initiation by impact. According to the bullet impact test, it requires at least 10 times the energy level of that required to detonate nitroglycerine (NG) based explosives.

5.2.4.3 There are minimum ignition energy levels for all explosives, above which initiation would occur. Minimum ignition energy levels typically range between 0.015J and 1.26J.

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

5.2.4.5 Water loss and prolonged temperature cycling above and below 34˚C are possible causes of degradation of cartridged emulsion. Degradation of cartridged emulsion leads to potential caking or a change in ammonium nitrate crystalline state and increase in volume. Detonation by means other than fire is not caused by both modes of degradation.

5.2.5 Hazard Properties of Detonating Devices

5.2.5.1 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 or vapours produced in fire could be lead fumes, nitrogen oxides and carbon monoxide. Nevertheless, these gases depend on the type of material used in the detonators.

5.2.5.2 Pentaerythritol tetranitrate (PETN) is the main explosive component in detonating devices including detonating cord and detonators. A primary explosive substance (e.g. lead azide) is included in detonators as it is very sensitive to initiation.

5.2.5.3 PETN in detonating cord has similar sensitivities to NG based explosives and it is generally more sensitive than emulsions.

5.2.5.4 PETN has the potential to deflagrate at ambient pressure following a local stimulus. A deflagration under ambient pressure or higher can be led by a local initiation. A detonation may occur from a deflagration. As an explosive, it has a comparatively small critical diameter for detonation. PETN has a shock sensitivity higher than emulsions but lower than NG based explosives. According to the bullet impact test, it requires at least 10 times the energy level of that required to detonate an NG based explosive [3].

5.3 Accidental Initiation Associated with Storage at Magazine

5.3.1.1 The possible means of accidental initiation of the explosives at the proposed magazine include the followings:

- Inadequately controlled maintenance work;
- Improper method of work;
- Poor housekeeping;
- Electric fault within the store;
- Arson;
- Dropping of explosives during handling (applicable to detonators only); and
- Crushing of explosives under the wheel of vehicles during loading and unloading (applicable to detonators and detonating cords only)

5.3.1.2 The detonators are packaged within plastic separating strips, and the initiation of a single detonator will not propagate to the adjacent detonator. The packaged detonators are classified as Class 1.4B explosives, and the total mass of detonators is negligible in terms of the total explosive mass in storage.

5.4 Accidental Initiation Associated with Transportation from Magazine

5.4.1.1 The cartridged emulsion and detonating cords will be transported together within the same compartment on a truck. The vehicle cargo is designed to minimise all sources of local stimulus, only a significant crash impact or a fire will cause a concern to the explosives. A low speed traffic accident is unlikely to cause a concern to the explosives as stated in the ACDS study [5]. As conservative approach is adopted in this study, low speed traffic accident is still considered possible but with a lower probability [3]. Based on the bullet tests and review with explosives specialists, the activation energy of PETN or emulsion explosives is one order of magnitude higher than nitroglycerine (NG). Therefore, the probability of imitation under impact conditions can be reduced by one order of magnitude based on impact energy consideration [3] since NG was considered as the basis in previous studies (assessed at 0.001).

5.4.1.2 Time and possibility to full fire development on the vehicle (typically 5-10 minutes) and the amount of heat transferred to the loads are the major leading causes to the response of the explosives to an accidental fire. For emulsion explosives, if they are isolated from detonating cords, it may take at least another 30 minutes for the explosives to reach critical conditions based on accident statistics. For mixed loads of cartridged emulsions and detonating cords, this time may be considerably lowered but no precise time can be predicted from detonating cord transport accident data [3].

5.4.1.3 The behaviour of explosives used in this project as transported was considered to be similar to the XRL Study [2]. In the XRL Study, a review was conducted on the explosive properties with assistance from specialists in the explosives industry. The main findings for emulsion based explosives are as follows.

5.4.1.4 The radical change in explosive properties at higher temperatures compared to the original emulsion must be taken into account. At high temperatures (> melting point), emulsion explosives would lose water content which may result in a refined explosive (small droplet/

crystal size Ammonium Nitrate (AN)). This could lead to a thermal explosion, deflagration or detonation and the probability of 0.1 may not therefore be applicable to emulsion. Also, some limited accident statistics have some bearing on this hazard scenario: these accidents may include a combination of both thermal and mechanical stimuli, which would likely have resulted in explosion or detonation. The consensus was that the probability of an explosion for the case of an emulsion was less than 0.5 but further refinement of this upper estimate would require additional data and more detailed analysis [2].

5.5 Incident Review

5.5.1 General

5.5.1.1 Historical incidents that involve explosives will be reviewed in this study. Incident records are retrieved mainly from the UK Health and Safety Executive (UK HSE)'s Explosives Incidents Database Advisory Service (EIDAS), US Mine Safety and Health Administration (MHSA), Western Australia's Department of Consumer and Employment Protection (DOCEP) and Hong Kong SAR Government's Annual Controlling Officers Report. The overseas records will be reviewed and compared with the situation in Hong Kong.

5.5.1.2 In this study, the historical records of the following incidents are reviewed.

- Incidents involve storage of explosives; and
- Incidents involve transport of explosives

5.5.2 Explosive Storage Incidents

5.5.2.1 A UK study identified 79 major incidents related to manufacture and storage of explosives during the period from 1950 to 1997 [12]. A total of 16 major incidents were attributed to the storage of explosives, among which 13 incidents related to the storage of gunpowder, ammunition, nitroglycerine and fireworks, 1 incident related to the storage of detonators and the remaining 2 incidents related to the storage of blasting explosives.

5.5.2.2 Some initiating causes of accidents were identified from the above incident records, they are:

- Impact;
- Friction;
- Overheating;
- Electrical effects (such as lightning or static discharges);
- Sparks;
- Spontaneous reactions; and
- Malicious action or mishandling

5.5.2.3 Not all of these causes are applicable to the magazine of this Project. These are further discussed in **Section 6.1**.

5.5.3 Explosive Transport Incidents

5.5.3.1 In Hong Kong, there are no incident records related to road transport of explosives with significant consequence. In September 2010, there was a minor incident involving a Mines Division truck on Queens Road West, the crash impact was not significant in that accident and the integrity of the explosives was not affected.

5.5.3.2 The international EIDAS database identified a number of incidents related to transport of commercial explosives during the period from 1950 to 2008. One of the incidents was related to the transport of emulsion, the emulsion load was detonated due to a tyre fire on the truck. There were also some incidents involving mixed cargoes of emulsion or water-gel carried with other types of explosives. The EIDAS database identified 2 fire incidents involving explosives carrying vehicles in Australia in 1998 and 2007, and none of these incidents resulted in fatality or injury.

5.5.3.3 The Western Australia DOCEP database recorded 3 incidents involving blasting explosives, detonators, ammonium nitrate or Ammonium nitrate emulsion. All these 3 incidents related to articulated vehicles overturning with no fire or explosion.

5.5.3.4 The US National Institute of Occupational Safety and Health study [13] investigated data from 1998 to 2006, and found that among the study period accidents related to the transport of explosives and ammonium nitrate used in mining and construction had only resulted in 5 major injuries, 11 minor injuries and no fatality.

5.6 Hazard Scenarios

5.6.1 Explosives Magazine

5.6.1.1 A possible hazardous scenario is associated with the storage of explosives is the detonation of a full amount of explosives stored within a store.

5.6.1.2 The explosives loads considered are listed in **Table 5.2**. The detonator explosives load has been considered in the total explosive load.

Table 5.2 Explosives Storage Quantities

Magazine	Mass of explosives per site (kg) Note 1,2	No. of detonators per site Note 3	TNT equivalent per site (kg) Note 4	No. of stores	TNT equivalent per store (kg)
A Kung Kok Shan Road	1,500	5,000	1,710	3	570

Note 1: Assumed 40% detonating cord & 60% cartridged emulsion
Note 2: Detonating cord are made of PETN
Note 3: Each detonator contains about 0.9g PETN
Note 4: 1kg of cartridged emulsion equals 0.96kg of TNT, and 1kg PETN equals 1.4kg of TNT

5.6.2 Explosives Transport

5.6.2.1 A possible hazardous scenario associated with the transport of explosives is the accidental detonation of a full load of explosives on an explosives carrying vehicle during the transfer from magazine site gate to the construction site boundary as shown in **Figure 2.2**. Onsite transport of explosives is considered as a part of use of explosives and detailed in **Section 3.4** in **Appendix 7.02**.

5.6.2.2 Explosion of the detonator load during transport is not quantified since they are transported on a separated truck within the same convoy, and the detonator packages is classified as HD 1.4B or HD 1.4S (articles which present no significant hazard outside their package). For detonators packaged in such a way, the consequences potentially leading to fatalities would be limited to remain within the explosive truck boundaries.

5.6.3 Scenarios Considered in the Assessment

5.6.3.1 A Base Case and a Worst Case have been considered in the risk assessment, and the assessed scenarios are summarized **in Table 5.3** and **Table 5.4** respectively.

Table 5.3 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 A Kung Kok Shan site	570	-	Total of 3 stores
Transport of Explosives				
02	Detonation of full load of explosives in one contractor truck on public roads	227	900	

Table 5.4 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 A Kung Kok Shan site	570	-	Total of 3 stores
Transport of Explosives				
02	Detonation of full load of explosives in one contractor truck on public roads	227	1,080	

6 FREQUENCY ANALYSIS

6.1 Storage of Explosives

6.1.1.1 Explosives stored in the magazine could be initiated by the following causes:

- Generic causes
- Manual transfer from store to contractor’s explosives carrying vehicle
- Lightning strike
- Aircraft Crash
- Earthquake
- Hill / vegetation fire
- Escalation

6.1.2 Generic causes

6.1.2.1 The generic causes of all explosions in UK magazines (other than military stores and ordnance factories) were unstable explosive material caused by product degradation, corrosion, and contamination; escalation of an external incident such as fire; or malicious acts such as vandalism or attempted theft. A generic failure frequency of 1 × 10^{-4} per year per magazine site is adopted [1][2][3].

6.1.2.2 The explosive types to be used in this project are stable and less likely to undergo initiation due to degradation or impact. However, the explosives to be used in this project are detonator sensitive, thus the detonators have to be stored in a dedicated chamber in the magazine.

6.1.2.3 The explosives stored in the magazine are protected from external fire since they are housed inside a concrete or brick wall building, and the provision of fire-fighting measures could further lower the probability of initiation due to external fire.

6.1.2.4 As mentioned in Section 2.4.1, the magazine will be provided with a comprehensive security system to reduce the possibility of vandalism or robbery. With provision of the above measures, the failure rate of 1 × 10^{-4} per year per magazine site is considered conservative and retained to represent all generic causes of explosion that are comment to nearly all magazines. Other site specified causes are addressed separated in following sections.

6.1.3 Manual transfer from store to contractor’s explosives carrying vehicle

6.1.3.1 Explosives are transferred from the store to the explosives carrying vehicle or vice versa manually without the use of any tools which are susceptible to initiate the explosives. Failure due to manual transfer is already covered in the generic failure frequency mentioned above and will not be assessed separately.

6.1.4 Lightning strike

6.1.4.1 The explosive magazine is a ground facility provided with lightning protection for each store. No additional risk due to lightning strike compared to the UK magazines. Failure due to lightning strike is already covered in the generic failure frequency and will not be assessed separately.

6.1.5 Aircraft Crash

6.1.5.1 Aircrafts crashing into the magazine are taken into account in this study by using the methodology given in HSE (1997) [6] for calculation of aircraft crash frequency. This model has been used in previous assessments of aircraft accidents [2][3]. Calculation of aircraft crash frequency is provided in **Annex 1**. Since the calculated failure rates are much smaller than order of 10^{-9}, failure caused by aircraft crash is not further considered in the assessment.

6.1.6 Earthquake

6.1.6.1 Hong Kong is a region of low seismicity [14][15], and an earthquake is an unlikely event. The generic failure frequency adopted is based on historical incidents with earthquakes already included in their cause of failure; it is considered that it is not necessary to address the failure due to earthquake separately.

6.1.7 Hill / vegetation fire

6.1.7.1 Hill / vegetation fires are quite common in Hong Kong, and the proposed magazine could be potentially affected. According to the statistics data in the Annual Report published by the Agriculture, Fisheries and Conservation Department, there are 16 – 67 hill fire per year between years 2004 and 2012, and the average vegetation area affected by fire was around 1% each year (**Table 6.1**), frequency of hill / vegetation affecting a specific site is estimated to be 1×10^{-2} per year.

Table 6.1 Hill Fire Data for Hong Kong

Year	Number of Hill Fire	Area Affected (Ha)	% of Total Country Park Affected
2004	67	371	0.89
2005	44	144	0.35
2006	41	872	2.10
2007	42	189	0.45
2008	49	501	1.14
2009	34	275	0.62
2010	45	897	2.03
2011	16	27	0.06
2012	18	79	0.18

6.1.7.2 The explosive magazine is to be constructed of fire resistance materials such as bricks, cement rendering and steel doors, and the ground surface is to be constructed of concrete or stone to prevent fire ingress to the explosive store. Moreover, the land within the magazine site will be cleared of vegetation to remove any combustible materials, and fire-fighting measures will be in place. With consideration of the above, the chance of explosives being initiated due to hill / vegetation fire is considered to be negligible. Failure due to hill fire is already covered in the generic failure frequency mentioned above and will not be assessed separately.

6.1.8 Escalation

6.1.8.1 An Ardeer Double Cartridge (ADC) test for cartridged emulsion showed that the consequence of a detonation is not able to propagate once the separation distance is beyond 2 cartridge diameters. Previous study [4] considered that it is impossible for an explosion within one magazine store to directly initiate an explosion within an adjacent store, hence the direct propagation by blast pressure wave and thermal radiation effects of an explosion within one store initiating an explosion with an adjacent store is not considered.

However, ground shock induced from an explosion may cause damage within the adjacent stores if the vibration level exceeds the vibration threshold of the store structure, and leading to subsequent explosion.

6.1.8.2 Ground vibrations can be assessed by the following equation [7],

$$\boldsymbol{A = K(R/Q^{d})^{-b}}$$

Where A = predicted particle velocity in mm/s
K = a ‘rock constant’
Q = maximum charge weight per delay interval in kilograms
R = distance in meters between the blast and the measuring point
d = charge exponent, assumed to be 0.5 [17]
b = attenuation exponent, assumed to be 1.22 [3]

6.1.8.3 The WIL Study [4] stated that a building can withstand a vibration level lower than 229 mm/s without significant structural damage. From the International Society of Explosives Engineers (ISEE) handbook [16], a range of rock constant K = 173 to K = 4320 is identified for construction activities, depending on the degree of confinement. The rock constant K for aboveground storage of explosives is hence conservatively considered as 200 since there is no coupling with the ground.

6.1.8.4 The maximum ground vibration generated from detonating of 500kg explosives is calculated at 216 mm/s for a separation of 21m. This vibration level is lower than 229 mm/s and hence the possibility of explosives within adjacent stores being initiated is considered negligible.

6.2 Transport of Explosives

6.2.1.1 The HA adopts the causes of potential accidental explosion during transport already being identified in the WIL Study [4]. Explosives during transport from magazine to construction site could be initiated by the following causes:

- Non-crash fire
- Crash fire
- Crash impact
- Spontaneous explosion of ‘unsafe explosives’

6.2.1.2 For non-crash fire, it includes explosion instance where the explosives loads are subject to thermal stimulus that was not resulted from a vehicle collision.

6.2.1.3 For crash fire, it is similar to non-crash fire but the fire was resulted from a vehicle collision.

6.2.1.4 In both non-crash fire and crash fire scenarios, the explosives load will be initiated once the load is engulfed by a fire for a period of time.

6.2.1.5 For crash impact, a significant mechanical impact during vehicle collision is required to affect the stability of the explosives load and initiate the explosion.

6.2.1.6 For spontaneous explosion, it is mainly due to badly packaged or manufactured explosives, and / or explosives which do not meet the specifications.

6.2.1.7 The ACDS study [5] assessed risks related to the transport of explosives in ports. The DNV study [8] then adjusted the basic frequencies presented in ACDS to address the risk associated with transport of commercial explosives by Mines Division trucks. Previous similar studies such as the SIL (East) Study [1], XRL Study [2], SCL Study [3] and WIL Study [4], all adopted the frequencies derived in DNV study for the transport of explosives in trucks operated by contractors from explosives magazine to construction sites, and fine-tuned the failure frequencies based on the latest knowledge on the explosives' properties, vehicle impact frequencies and specific design features of the explosives carrying vehicles. Derivations of each frequency component are presented in the XRL Study [2]. The explosives initiation fault tree inputs in XRL Study is presented in **Table 6.3** and the fault tree models for the road transport explosion are shown in **Figure 6.1**.

6.2.1.8 The XRL Study [2] reviewed the fire incidents applicable to explosives trucks in Hong Kong from 2004 to 2008, and an average goods vehicle rate of 2.19× 10^{-8} / km, excluding 99% of arson and smokers material event provided strict controls are applied, was derived. With the consideration of the crew intervention with fire screen and extinguishers, FSD intervention, fire severity and time for fire escalation to the explosives load, the overall explosion event frequency of 1.30× 10^{-9} / km was derived for non-crash fire in which explosives are subject to thermal stimulus. The development of a non-crash fire scenario is presented in **Figure 6.1**.

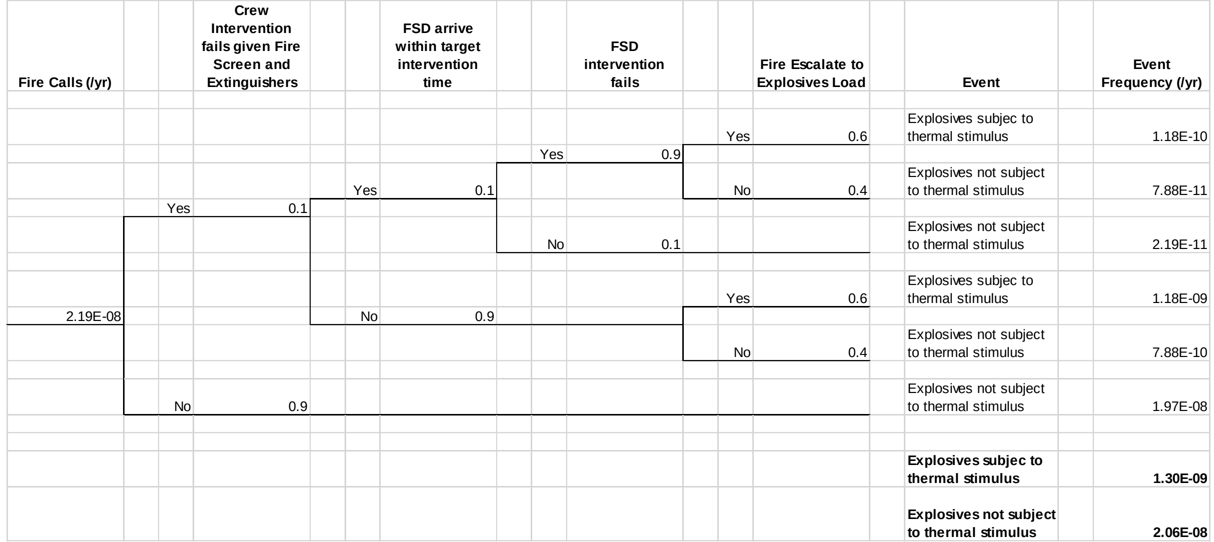


Figure 6.1 Event Tree for Non-Crash Fire Scenario

6.2.1.9 The explosives initiation fault tree inputs in XRL Study is presented in **Table 6.2** and the fault tree models for the road transport explosion are shown in **Figure 6.1**. The explosives initiation frequencies derived in the XRL Study [2] for the transport of explosives are adopted in this study. **Figure 6.2** only presents the explosives initiation fault tree model for road transport events for non-expressway since there is no expressway along the transport route.

Table 6.2 Explosives Initiation Fault Tree Inputs from the XRL Study [2]

Event	Event Type	Value
Vehicle crash (on non-expressway)	Frequency	4.68 × 10^{-7} / 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

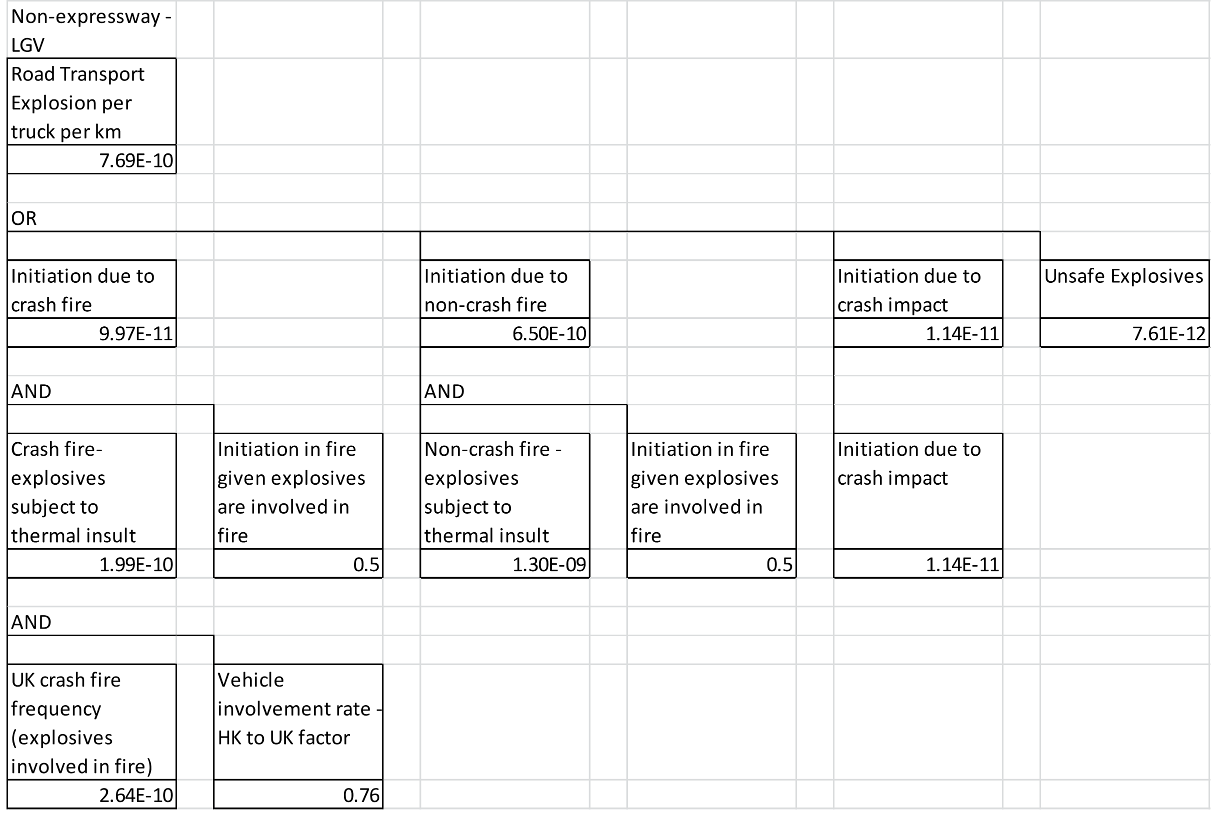


Figure 6.2 Explosives Initiation Fault Tree for Non-Expressway – Road Transport Events from XRL Study [2]

6.3 Domino Effects of High Pressure (HP) Underground Town Gas Transmission Pipelines

6.3.1.1 The transport route of explosives is in close proximity of a section of the HP underground town gas transmission pipelines between the Sha Tin Hospital and Mui Tsz Lam Road. Separation distance between the transport route of explosives and the pipelines is around 50m. Thermal outcomes from town gas releases may trigger failure of the explosives if the explosives carrying vehicles are passing close to the pipeline when it fails.

6.3.1.2 With reference to **Appendix 7.03** the event outcome frequency of fireball / jet fire is 4.58×10^{-8} per km per year. Thermal outcomes from town gas releases may only trigger failure of the explosives if the explosives carrying vehicles are passing close to the pipeline when it fails. Assuming that the explosives carrying vehicle is traveling at 50km/hr and it takes less than 3 minutes to travel pass this 1.9km interfacing section. Time fraction of an explosives carrying vehicle present on the 1.9km interfacing section is only around 5.7×10^{-6} per year. Therefore, the domino effect of HP underground town gas transmission pipeline is estimated to be around 2.6×10^{-13} per km per year, this value is rather low compared to the frequency of potential accidental explosion during transport (i.e. 7.69×10^{-10} per km per year) and thus is not further considered in this assessment.

7 CONSEQUENCE ANALYSIS

7.1 General

7.1.1.1 Possible outcomes from hazardous events associated with the storage, transport and use of explosives include:

- Blast and pressure wave;
- Flying fragments or missiles;
- Thermal radiation; and
- Ground shock

7.2 Physical Effect Modeling

7.2.1 Blast and Pressure Wave

7.2.1.1 The *Explosives Storage and Transport Committee (ESTC)* model developed by the UK Health and Safety Committee (HSC) [9] will be utilized to determine the probability of fatality due to blast and pressure waves. The ESTC model analyses the blast effects for people indoors and outdoors separately.

People Indoors

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

where $\boldsymbol{S = R/Q^{1/3}}$;

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

People Outdoors

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

7.2.1.2 Population in vehicles, buildings are assumed to be indoors and the indoor consequence model will be applied; pedestrians and cyclers are considered as outdoor populations and the outdoor consequence model is applied.

7.2.1.3 The distance to 1%, 3%, 10%, 50% and 90% fatality contours is used in the modeling.

7.2.1.4 The consequences of accidental explosion during transferring explosives from delivery points into the cavern are also assessed by the above ESTC model.

7.2.2 Flying Fragments or Missiles

7.2.2.1 The ESTC model already considered fatality due to flying fragments or missiles due to explosion; therefore, debris will not be considered in a separate model.

7.2.3 Thermal Radiation

7.2.3.1 The initiation of an explosion would result in thermal radiation from a fireball as the explosives initiate. Models that are available describing the fireball duration and diameter are based on TNT or similar explosives, e.g. nitroglycerine, PETN, etc. The diameter and duration of a fireball from high explosives are calculated using equations shown in [10].

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

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

where D is the fireball diameter in meters;
M is the mass of explosive charge mass in kg (TNT equivalent mass);
t_d is the duration of the fireball in seconds.

7.2.3.2 For the largest explosive mass of 570kg (initiation of an entire store contents), the fireball radius is calculated to be 14.5m and duration is 2.5 seconds.

7.2.3.3 The surface emissive power (Ef) is calculated from the following equation:

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

where ΔH is the heat released from the explosives in kJ/kg, around 4.01 MJ/kg for cartridged emulsion;
M is the mass of explosive charge mass in kg (TNT equivalent mass);
f_s is the fraction of heat that is radiated, assumed to be 0.4.

7.2.3.4 For the largest explosive mass of 570kg (initiation of an entire store contents), the surface emissive power of the fireball is calculated to be 138kW/m^2.

7.2.3.5 Thermal dose is defined as $\mathrm{L = tI^{4/3}}$, where I is the thermal radiation flux in kW/m^2 and t is the exposure duration. The UK HSE Safety Report Assessment Guides (HSE HFLs) suggests 1,000, 1,800 and 3,200 TDU levels for 1%, 50% and 90% fatality levels. For a fireball with duration of 2.5s, the incident radiation fluxes to cause the respective fatality levels are 89kW/m^2, 139kW/m^2 and 214kW/m^2.

7.2.3.6 Comparing these values with the fireball surface emissive power of 138kW/m^2, these levels of thermal flux will only be existed in very close proximity to the fireball. With consideration of the layout of the magazine, no off-site hazard is anticipated. Therefore, hazards from fireball are not further considered in this assessment.

7.2.4 Ground Shock

7.2.4.1 There are some slopes situated close to the road along the transport route of explosives. It is possible that an accidental detonation of the explosives may trigger a landslide or a boulder fall. This is identified as a secondary hazard. The *Landslide Consequence Classification System* and *Boulder Fall Consequence Analysis* published in GEO Report No.81 is adopted to evaluate the possible outcomes.

7.2.4.2 In this project, explosives transport and storage will be carried out aboveground while explosives usage will be carried out underground. Aboveground explosion will result in a lower pressure wave as the explosives are less confined. The consequence is considered to be of less concern compared to the hazards posed by the overpressure wave and debris generated by the explosion. Ground shock can be calculated by the following equation:

$$\boldsymbol{A = K(R/Q^{d})^{-b}}$$

When A = predicted particle velocity in mm/s
K = a ‘rock constant’, assumed to be 200
Q = maximum charge weight per delay interval in kilograms
R = distance in meters between the blast and the measuring point
d = charge exponent, assumed to be 0.5 [17]
b = attenuation exponent, assumed to be 1.22 [3]

7.2.4.3 A comparison of 1% fatality impact distance calculated by ground vibration model and ESTC model are provided in **Table 7.1**, and the results shows that the effect of ground vibration are less significant than that of air shockwave and debris for indoor population. The effect of ground vibration is more significant to the outdoor population who is close by a structure, however, there is no identified structure within this effect zone and any potential structure within the area will be cleared for construction site works. As such, the effect of ground vibration is not further assessed.

Table 7.1 Blast Effect Distance for 1% Fatality Probability from Detonation of 570kg TNT Equivalent of Explosives

Consequence	Receiver’s Location	Effect Radius (m)
Shockwave and debris – ESTC model	Indoor	78
	Outdoor	27
Ground shock – Object falling threshold (PPV = 100mm/s)	Indoor / Outdoor close by a structure	39.5

7.2.4.4 Excess ground vibration may lead to slope failure and creates a secondary hazard. Based on the effect thresholds defined in previous similar projects [2][3], 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 66mm/s.

7.2.4.5 The effect radius of 66 mm/s is calculated as 55m for detonation of 500kg of explosives, which is corresponding to the maximum quantity of explosives to be stored in each magazine store. From **Table 4.7**, all slopes are too far away to be affected and thus hazards from ground shock due to accidental initiation of explosives in the Magazine are not further considered in this assessment.

7.3 Results of Consequence Analysis

7.3.1.1 Consequence results for each transport and storage scenario are summarised in **Table 7.2**. The consequence results in both Base Case and Worst Case are the same since the same amounts of explosives are transported each time in both cases.

7.3.1.2 The proposed explosives magazine is located 200m away from the nearest public footpaths and 240m away from the nearest building structure. These design separation distances substantially exceed the 1% fatality distance and hence no significant risk of fatality due to explosives storage is expected.

Table 7.2 Summary of Consequence Results

No.	Scenario	TNT eqv. kg	Fatality Prob.	Impact Distance (m)	
				Indoor	Outdoor
Storage of Explosives					
01	Detonation of full load of explosives in one store in A Kung Kok Shan site	570	90%	26	21
			50%	30	22
			10%	45	24
			3%	60	26
			1%	78	27
Transport of Explosives					
02	Detonation of full load of explosives in one contractor truck on public roads	227	90%	19	15
			50%	22	16
			10%	33	18
			3%	44	19
			1%	58	20

7.4 Secondary Hazards

7.4.1 Impact on buildings

7.4.1.1 The nearest building is approximately 240m away from the magazine. This separation distance is substantially exceeds the 1% fatality distance. Moreover, the magazine is not within Consultation Zone of any PHIs and is not close to any other vulnerable risk receptors. Location of the nearest building is shown in **Figure 7.1**.

Figure 7.1 Location of A Kung Kok Shan Magazine in Relation to Nearest Building

7.4.2 Impact on Slope and Boulders

7.4.2.1 There are some slopes close to the road along the transport route of explosives, in particular along the A Kung Kok Shan Road. There is a possibility that an explosion on an explosives carrying vehicle may trigger a landslide or a boulder fall. The potential consequences of this hazard were evaluated using the approach adopted in the WIL study [4] and it was found that any landslide or boulder fall event would only impact the same area along the road that was already affected by the primary explosion consequences. No significant additional fatality would occur and thus this secondary hazard is not further considered.

7.4.2.2 Similarly, the explosives magazine is a surface magazine and there are some natural terrains close to the magazine site. There is a possibility that an explosion on an explosives store may trigger a landslide or a boulder fall. It was found that any landslide or boulder fall event would only impact the same area in vicinity to the magazine site that was already affected by the primary explosion consequences. No significant additional fatality would occur and thus this secondary hazard is not further considered.

7.4.3 Impact on High Pressure Underground Town Gas Transmission Pipelines

7.4.3.1 As mentioned in Section 3.2 of this Appendix, there is a HP underground town gas transmission pipeline running along Tate’s Cairn Highway and Ma On Shan Road towards the downstream Sai O pigging station, and the transport route of explosives is in close proximity of a section of the HP underground town gas transmission pipelines between the Sha Tin Hospital and Mui Tsz Lam Road. Separation distance between the transport route of explosives and the pipelines is around 50m.

7.4.3.2 A higher than expected ground vibration from an accidental explosion or during the blasting process can potentially cause leakage or rupture of a gas pipeline. The typical maximum allowable PPV for town gas pipelines is 25mm/s PPV, it is considered a tolerable level at which no significant damage is expected. This represents the threshold PPV that is the onset of damage at which there may be some cosmetic damage but is extremely unlikely to result in gas leakage [3].

7.4.3.3 As the pipeline is located below ground, and 50m away from the transport route of the explosives, there is no hazard from thermal or air blast pressure effects. Accidental detonation would occur above ground, and therefore there would be no transmission of shockwave into the ground. The gas transmission pipeline would be able to safely withstand a ground vibration of 25mm/s, so in the event that some minimal amount of shockwave could be transmitted from the air into the ground there would still be no hazard.

8 RISK EVALUATION

8.1 Introduction

8.1.1.1 Consequences and their corresponding frequencies are summed up using PhastRisk 6.7. This integrates the risks associated with the temporary Explosives Magazine with those from the transport of explosives from the magazine to the work site.

8.1.1.2 The Base Case considered a realistic construction scenario; while the Worst Case considered scenario considered is associated with potential changes in the construction programme due to construction uncertainties.

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

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

8.2 Individual Risk

8.2.1 Transport of Explosives

8.2.1.1 The individual risk (IR) contours for the transport route is shown in **Figure 8.1** and **Figure 8.2** for Base Case Outdoor and Indoor Population respectively and **Figure 8.3** and **Figure 8.4** for Worst Case Outdoor and Indoor Population respectively. The maximum individual risk is less than $1×10^{-7}$ per year. The difference between the two maximum IR contours is not significant as shown in **Figure 8.1** and **Figure 8.3** and in **Figure 8.2** and **Figure 8.4**. It is because the event occur frequency between two cases only has a 20% increase. On this basis, it would appear that the level of individual risk associated with transport of explosives should be acceptable since it meets the Hong Kong Risk Guidelines.

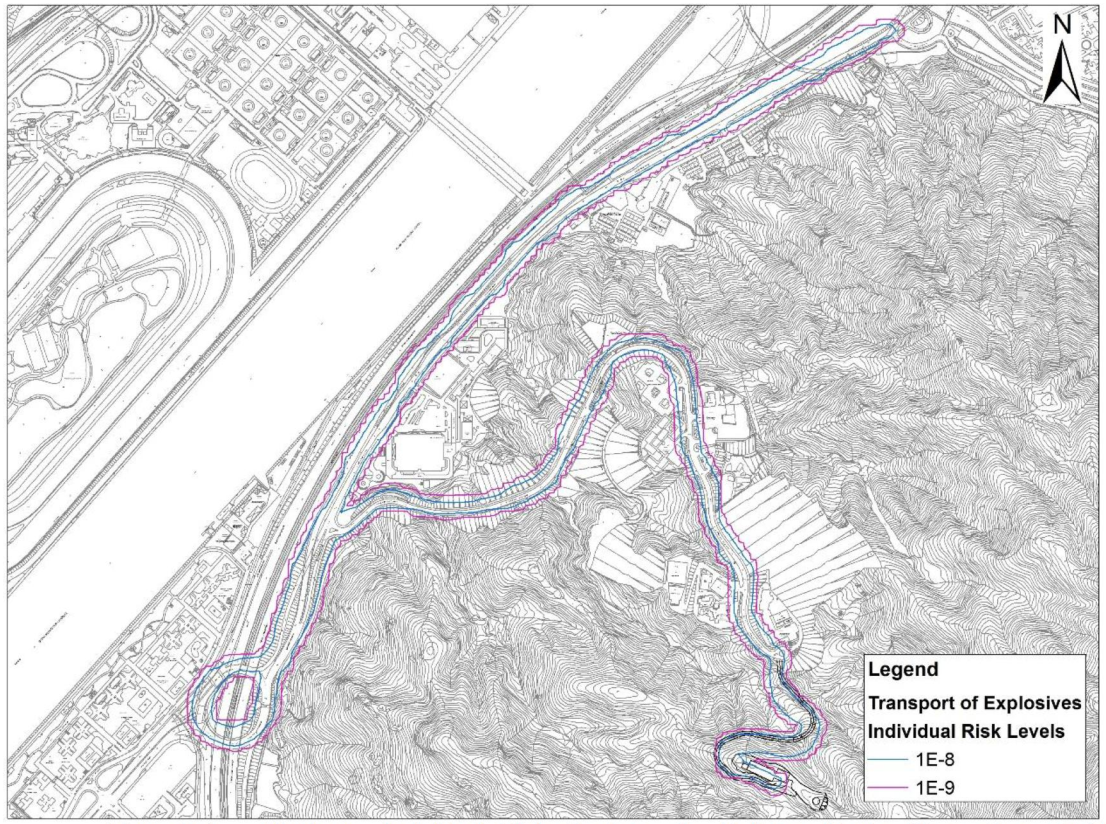


Figure 8.1 Maximum Individual Risk Contours for Delivery Route (Base Case Outdoor Population)

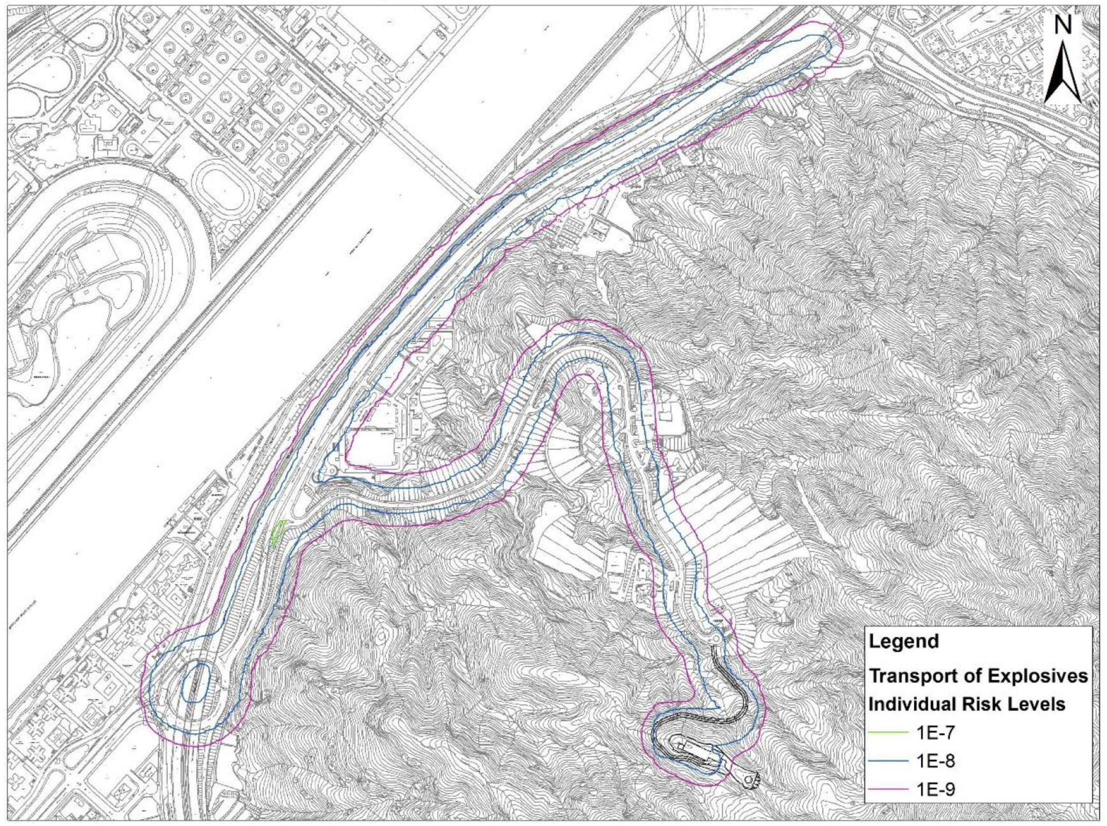


Figure 8.2 Maximum Individual Risk Contours for Delivery Route (Base Case Indoor Population)

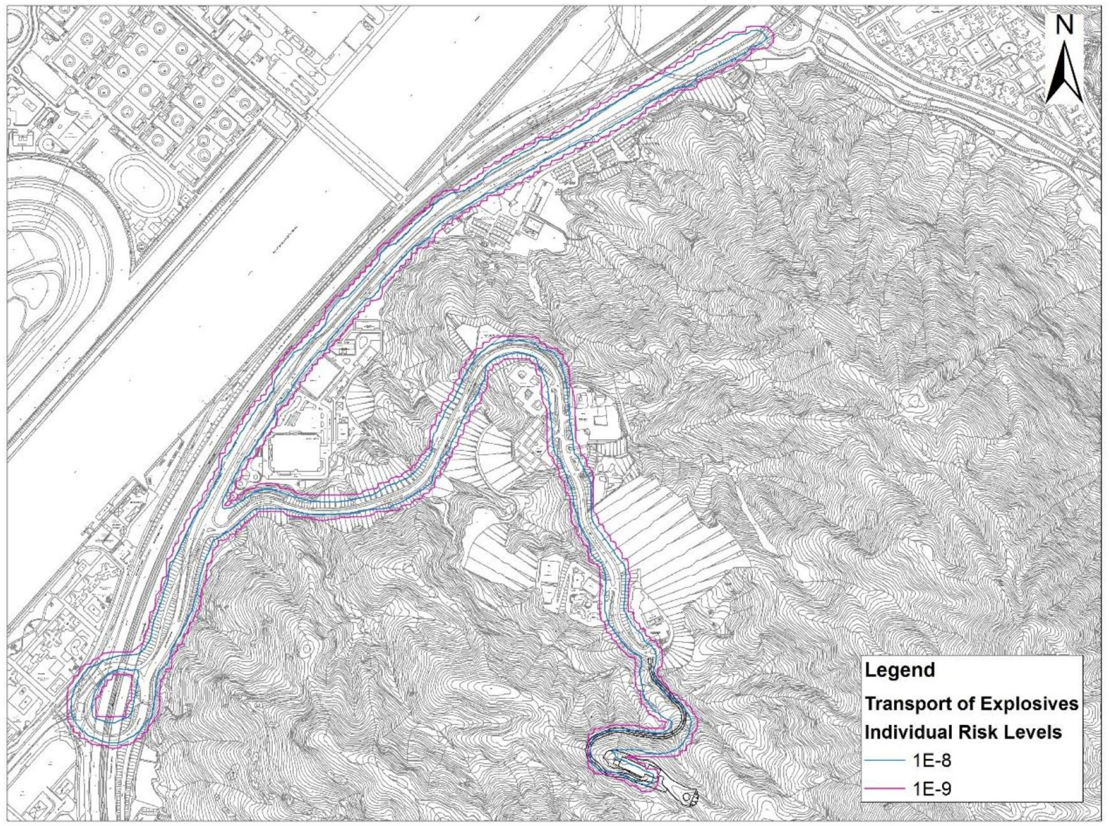


Figure 8.3 Maximum Individual Risk Contours for Delivery Route (Worst Case Indoor Population)

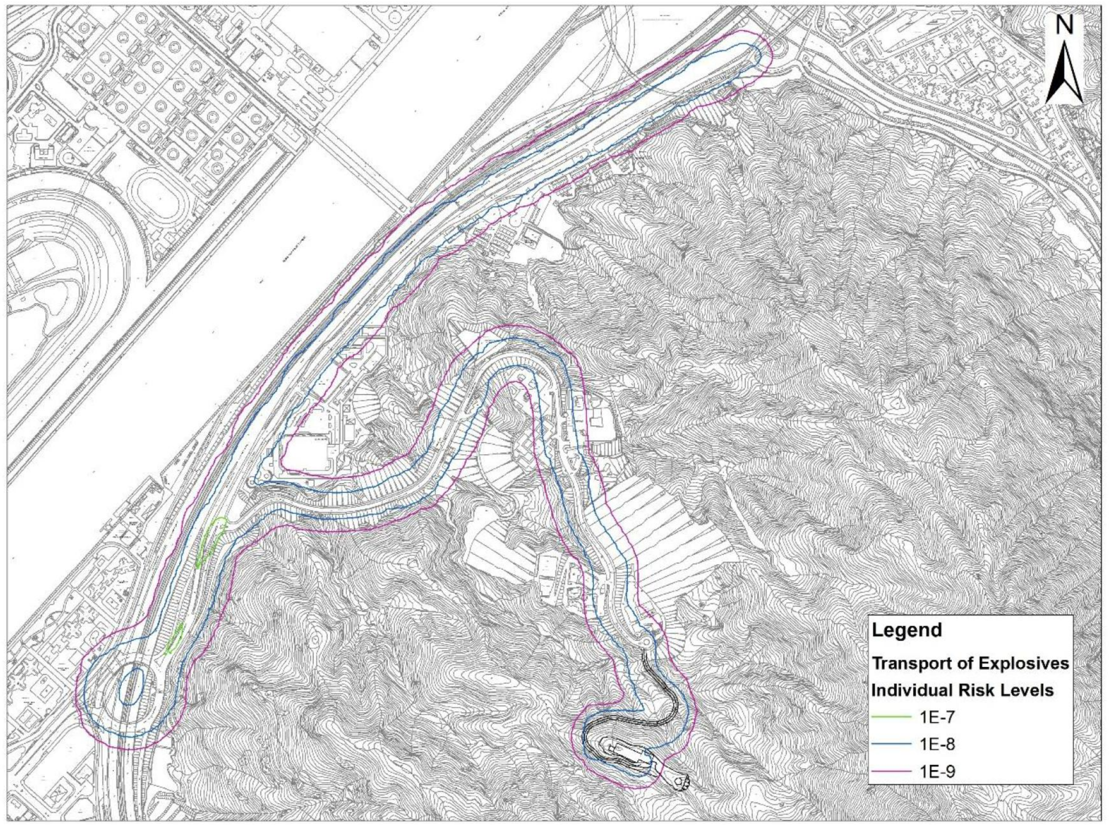


Figure 8.4 Maximum Individual Risk Contours for Delivery Route (Worst Case Indoor Population)

8.2.2 Storage of Explosives

8.2.2.1 Individual risk contours associated with storage of explosives are plotted in **Figure 8.5** and **Figure 8.6** for outdoor population and indoor population respectively. The individual risk of 1×10^{-5} per year extends offsite in both cases. Population indoors will experience higher risks due to breaking windows and risk of building collapse. The temporary explosives magazine is located in a remote area and with a gate at the entrance of the magazine access road. There will be no non-construction population entering the magazine access road. Therefore, no public is exposed to an individual risk of 1×10^{-5} per year, and thus the level of individual risk associated with storage of explosives should be acceptable.

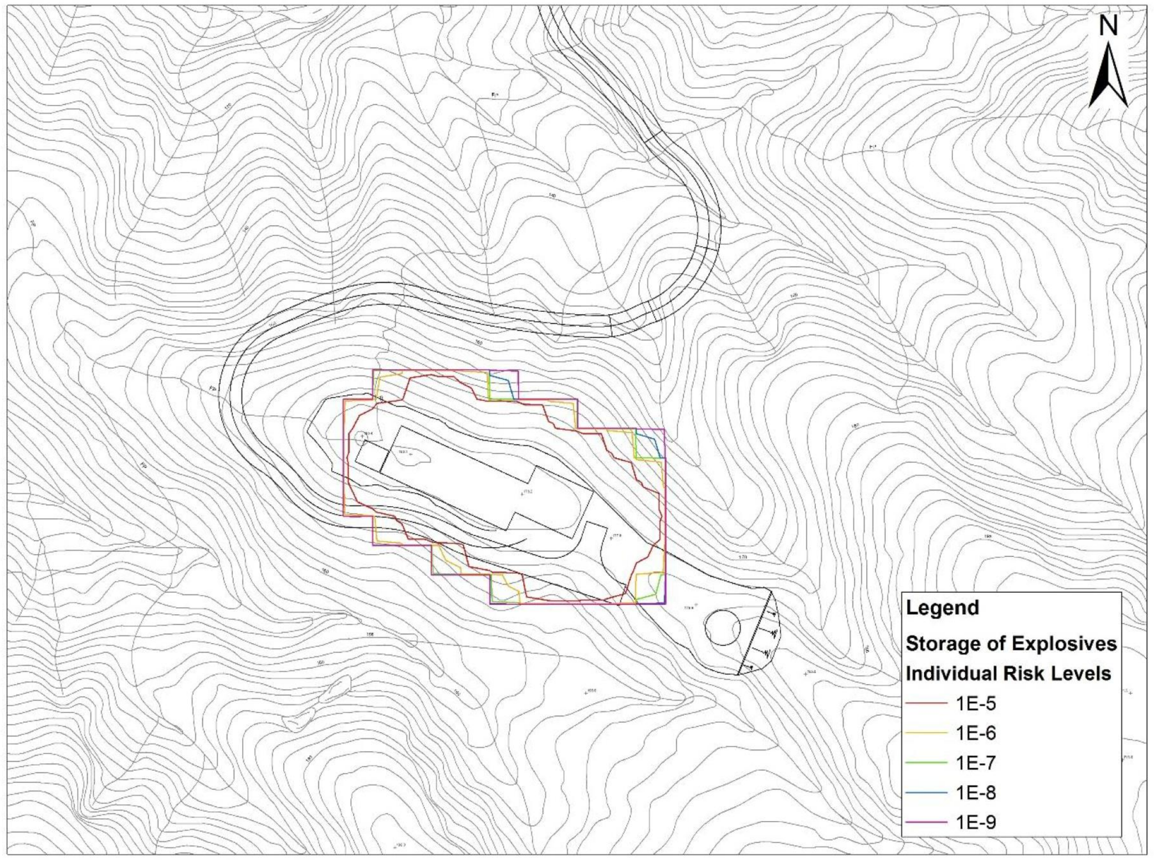


Figure 8.5 Individual Risk Contours for Magazine (Outdoor Population)

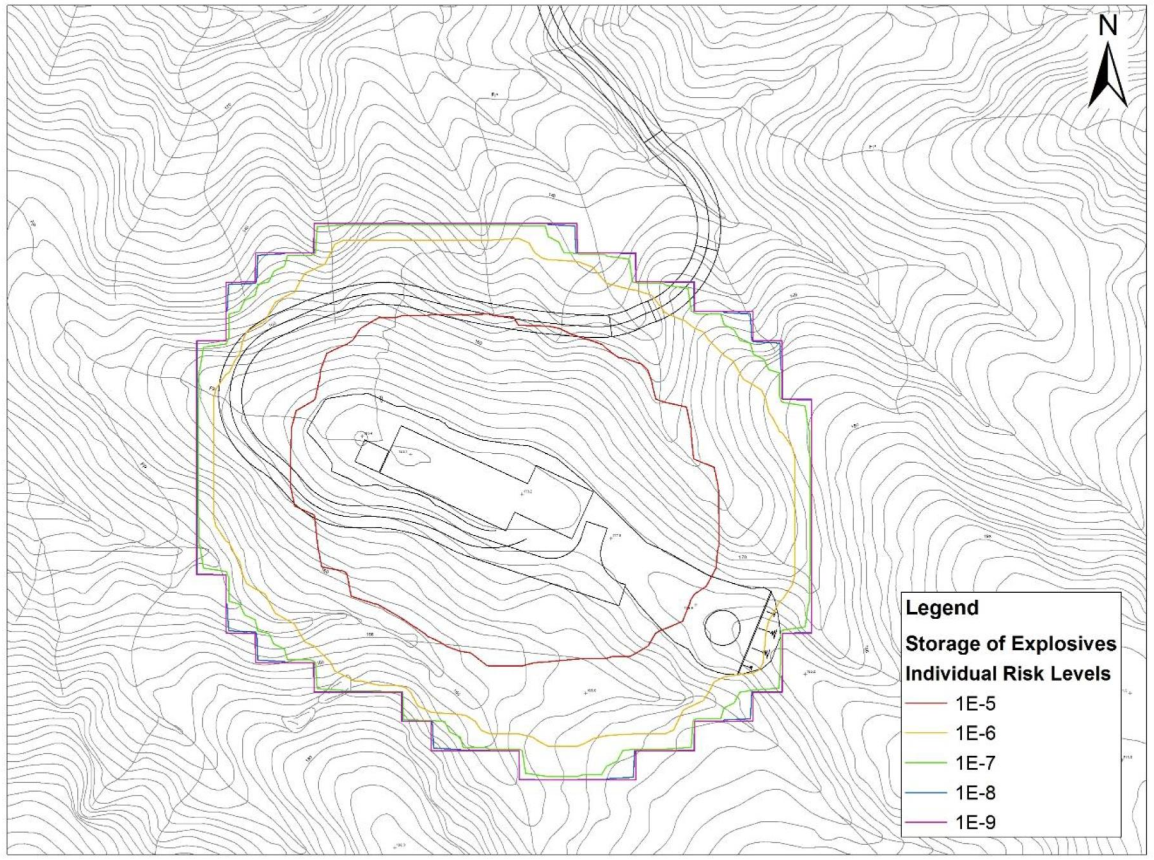


Figure 8.6 Individual Risk Contours for Magazine (Indoor Population)

8.3 Societal Risk

8.3.1 Potential Loss of Life

8.3.1.1 The potential loss of life (PLL) for storage and transport of explosives is 2.76×10^{-5} per year. PLL of 3.31×10^{-5} per year is calculated for the Worst Case, which is higher than PLL for the Base Case.

8.3.1.2 The temporary explosives magazine has negligible contribution to the overall risks since it is located in a remote area with a gate at the magazine access road. There will be no permanent population or pedestrians nearby.

8.3.2 F-N Curves

8.3.2.1 The overall fN curves for the storage and transport of explosives are shown in **Figure 8.7**. The Base Case represents the risks associated with the expected blasting programme, while the Worst Case has considered a 20% increase in the number of deliveries to account for any construction uncertainties. It can be seen that the risks lie in lower ALARP region for both cases. Mitigation measures are thus required to be considered to reduce the risks.

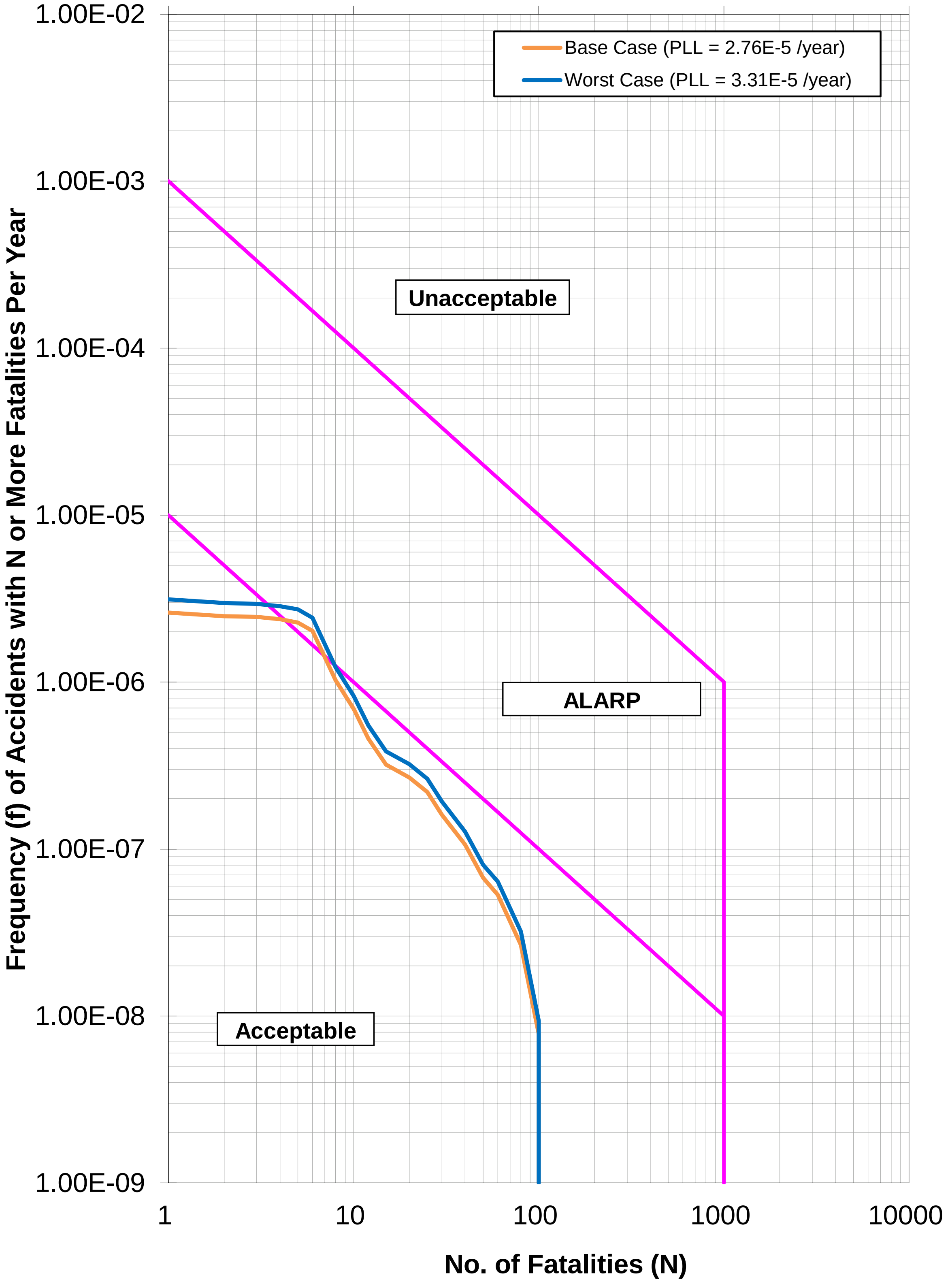


Figure 8.7 F-N Curves for Storage and Transport of Explosives

8.4 Uncertainty Analysis

8.4.1.1 This study is performed based on several assumptions as highlighted in previous sections. A discussion on the uncertainties of the results is given below.

8.4.2 Storage of Explosives

Frequency of Explosion

8.4.2.1 The frequency of explosion adopted in this study is 1×10^{-4} per year, which is based on the data from the UK HSE. The generic causes of all explosions in UK magazines (other than military stores and ordnance factories) were unstable explosive material caused by product degradation, corrosion, and contamination; escalation of an external incident such as fire; or malicious acts such as vandalism or attempted theft.

8.4.2.2 The explosive types to be used in this project are stable and less likely to undergo initiation due to degradation or impact. However, the explosives to be used in this project are detonator sensitive, thus the detonators have to be stored in a dedicated chamber in the magazine.

8.4.2.3 The explosives stored in the magazine are protected from external fire since they are housed inside a concrete or brick wall building, and the provision of fire-fighting measures could further lower the probability of initiation due to external fire.

8.4.2.4 The magazine will be provided with a comprehensive security system to reduce the possibility of vandalism or robbery. With provision of the above measures, the failure rate of 1 × 10^{-4} per year per magazine site is considered conservative.

8.4.3 Transport of Explosives

Explosion Consequence Model

8.4.3.1 The ESTC models being adopted tend to over-predict the number of fatalities when compared to the actual fatalities involved in past incidents related to explosives. There is no recorded incident involving road transport has resulted in more than 12 fatalities even in urban location, while the maximum fatalities due to road transport is estimated to be about 100 in this study. There is some conservatism in the models although it is acknowledge that given the dense urban environment in Hong Kong, the fatalities estimated during transport of explosives may not be too conservative.

8.4.3.2 Several recent research studies performed by HSE indicated that the ESTC models may under-predict the fatalities caused by flying glass in highly built-up areas. Nevertheless, the ESTC models are still considered to be the best available models.

Intervention of the Explosives truck crew

8.4.3.3 The crew may be able to control a fire developing on the vehicle by using the onboard safety devices in certain circumstances. Credit has been given to the fire extinguishers in combination with the fire screen protection. A failure probability of 0.1 was applied to account for these safety features.

8.4.3.4 Between, it may be possible for the crew to secure the explosives load before the fire fully develops. However, since a fire could fully develop and critical explosive temperature could be reached within a couple of minutes, to be conservative, no credit was given for the intervention of the crew.

Intervention of the Fire Services Department

8.4.3.5 For non-crash fire incident involving an explosives carrying vehicle, it is most likely that a fire would already fully developed before the fire brigade arrive. The intervention of the fire brigade would be limited to fight the fire from a safe distance. As such, little credit has been given for FSD intervention (probability of arriving on time: ~0.1 and successful intervention probability ~0.1) as even if FSD arrives within specified time, the fire on the explosives carrying vehicle would likely be fully developed and explosives subject to thermal stimulus.

8.4.3.6 All crash fires are considered to be severe enough to cause damage to the explosives load and thus no credit was given for such cases.

8.4.3.7 Regarding the evacuation of the scene, it may be possible to evacuate the vehicle occupants and people on the pavement surrounding the accident zone, however, it would be difficult to evacuate the people in buildings. As such, no credit has been given for the intervention of the fire brigade for evacuation of the scene as a conservative approach.

Escape and Evacuation

8.4.3.8 It may be possible for people to escape from the scene of accident by themselves before an explosion event in certain circumstance, for example in case of fire on truck in which the explosives cargo is not initially involved but is only affected after a period of gradual escalation. However, modeling such escape scenario would only slightly reduce the consequence and the impact on risk would be minimum. As such, no credit was given for people to escape.

Explosives Initiation under Thermal Stimulus

8.4.3.9 There are some uncertainties associated with the probability of explosion for an explosives load composed of a mix of cartridged emulsion and detonating cords in a fire during transportation. The probability used in this report is based on the accident statistics applicable to ANFO, which is more sensitive than emulsion and transported in a different manner. The assumption made in this study may be conservative in the absence of test data.

Actual Consumption of Explosives

8.4.3.10 There is a possibility that the actual construction programme may differ from the envisaged construction programme due to construction uncertainties or contractors' method of working. In such case, more delivery trips and return trips may be resulted. A 20% increase in the number of deliveries compared to the base case scenario has been assumed as the worst case scenario.

9 RISK MITIGATION MEASURES

9.1 Risk Results

9.1.1.1 The hazard to life assessment of the Project has assessed the risks arising from storage of explosives at the proposed magazine as well as the risks associated with the road transport of explosives to the construction site. From Section 8, the risks posed by the Project lie within the lower "ALARP" region specified in EIAO-TM Annex 4 for both Base Case and Worst Case.

9.1.1.2 The results shown in Section 8 imply that the risks arising from transport of explosives are much more significant than that from storage of explosives. Hence, the assessment in this Section focuses on the transportation aspect of the explosives.

9.2 Approach

9.2.1.1 Practicability of risk mitigation measures is usually evaluated by cost-benefit analysis, which is a trade-off between the risk mitigation, i.e. the safety benefits, and the cost of the risk mitigation measure.

9.2.1.2 The safety benefits are calculated by the following equation:

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

9.2.1.3 The Value of Preventing a Fatality (VPF) represents the monetary value that the society is willing to invest to prevent a fatality, i.e. the tolerability of risk by the society. The VPF value will be taken as HK$33M per person in this project. The VPF value will be adjusted according to different level of risks to reflect people's aversion to high risks with probability of multiple fatalities. The application of the aversion factor of this study follows the EPD's Technical Note on Cost Benefit Analysis developed in 1996. 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 of the Risk Guidelines). The adjusted VPF using the aversion factor of 20 is HK$660M. This is the value to measure how much the society is willing to invest to prevent a fatality, where there is potential for an event to cause multiple fatalities.

9.2.1.4 The cost of implementing potential justifiable mitigation measures will be checked against the Maximum Justifiable Expenditure first. The value of Maximum Justifiable Expenditure will be calculated by assuming that risk is reduced to zero. Justifiable mitigation measures will be further analysed considering the actual reduction in PLL in the calculation of safety benefit. The equation of Maximum Justifiable Expenditure is as follows:

Maximum Justifiable Expenditure = Value of Preventing a Fatality x Aversion Factor x Maximum PLL value x Design Life of mitigation measure

9.2.1.5 For a justifiable mitigation measure, its cost should not be greater than the value of Maximum Justifiable Expenditure. If the cost of implementation of the mitigation measure is less than the calculated safety benefits, the mitigation measure will be considered.

9.2.1.6 The cost of implementation of mitigation measures should only include capital and operational costs but not any costs related to design or change of design.

9.2.1.7 It is noted that in some cases, it may not be able to quantify the cost-benefits of a particular measure. A qualitative approach will be used in those cases.

9.3 Maximum Justifiable Expenditure

9.3.1.1 The maximum justifiable expenditure for this project is calculated based on the Worst Case Scenario with 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

= HK$33M x 20 x 3.31×10^{-5} x 4

= HK$0.09M

9.3.1.2 The design life is assumed as 4 years based on the construction phase of this project during which storage and transport of explosives will be involved.

9.3.1.3 For a mitigation measure to be potentially justifiable, its cost should be less than the Maximum Justifiable Expenditure.

9.4 Potential Mitigation Measures

9.4.1 Options

9.4.1.1 The potential mitigation measures are listed in the following:

- Options eliminating the need for a Magazine;
- Options considering alternative delivery route;
- Options reducing the quantities of explosives to be used;
- Options reducing the number of trips to be carried out by contractor's explosives trucks;
- Options reducing the quantities of explosives to be transported at each trip by contractor's explosives truck;
- Options considering improved explosives carrying vehicle design; and
- Options considering better risk management systems and procedures

9.4.2 Need for the Magazine

9.4.2.1 The proposed CSTW will be located underneath Nui Po Shan within a granitic pluton, which comprises some of the freshest and hardest crystalline rocks in Hong Kong. Approximately 2.2 million m^3 of rock will need to be excavated based on the proposed cavern layout. To ensure the timely completion of the Project, the only feasible, practical and economical method of excavation for such a large volume of rock is by drill and blast method with multi blast faces. Other construction methods, such as drill and break, and the use of tunnel boring machine (TBM), are considered not suitable for cavern construction, taking into account the various cavern geometries, cost, programme and practicability. Opting for an alternative construction method will cost significantly more than the Maximum Justifiable Expenditure.

9.4.2.2 The provision of a magazine site would provide a more reliable explosive supply, allowing flexible blasting time and multiple faces under different excavation sequence, giving maximum tunnel production rates. In view of the large quantity of rock to be excavated, an explosives magazine is therefore required.

9.4.3 Alternative Delivery Route

9.4.3.1 There is only one road from the magazine to A Kung Kok Street, the delivery route is then directly east to the site. The only alternative would be to head westwards, which is away from the site and can only increase the extent of area exposed to hazard. Hence the route studied has met the ALARP principle.

9.4.4 Use of Smaller Quantities of Explosives

9.4.4.1 This project has already considered the minimum amount of explosives for transportation. Only initiating explosives will be transported, and the bulk emulsion explosives will be manufactured on site. There is an option for using cast boosters to replace cartridged emulsion as primers for bulk emulsion blasting. Use of cast boosters can reduce the amount of explosives carried per delivery trip.

9.4.4.2 The main explosives component of cast booster is PETN, which has a higher TNT equivalency. And the use of cast booster will not eliminate the need for detonating cord.

9.4.4.3 The unit cost of cast booster is around HK$7.5 higher than the unit cost of cartridged emulsion based on information provided by the supplier. With the consideration that over 620,000 cast booster will be required in this project, the cost of this option is estimated to be at least HK$4.6M higher than the cost of using the cartridged emulsion for initiating bulk emulsion.

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

9.4.4.5 In addition, there are limitations in availability of cast boosters since the supply of this material is limited in the market.

9.4.5 Lower Frequency of Explosives Transport

9.4.5.1 The frequency of explosives transport has been minimised with the use of bulk emulsion. No further options have been identified. The possibility of reducing the frequency of explosives transport has not been further evaluated.

9.4.6 Reduction of Explosives Quantities to be Transported at Each Trip

9.4.6.1 It is possible to reduce the quantities of explosives to be transported at each trip to reduce the hazard zones due to accidental initiation of explosives on the explosives carrying vehicles. However, the frequency of explosives transport will be increased to fit the construction programme.

9.4.7 Safer Design of the Explosives carrying vehicle

9.4.7.1 The use of fire screen between cabin and the load could reduce the risk of fire escalating to the load. This measure is recommended for the Contractor's trucks as an improvement measure. Besides, several simple measures such as reducing the combustible load on the explosives carrying vehicle by using fire retardant materials wherever possible and limiting the fuel tank capacity are also possible to be implemented.

9.4.7.2 The safety benefits of such measures are difficult to evaluate quantitatively, and they have been included in the recommendation section.

9.4.8 Reduction of Accident Involvement Frequency

9.4.8.1 It is possible to reduce the accident involvement frequency of the explosives carrying vehicle through implementation of several administrative measures, such as providing training programme to the driver, regular "tool box" briefing session, implementing a defensive driving attitude, selecting driver with good safety record, and providing regular medical checks for the driver. Implementation of this option is further detailed in the recommendation section.

9.4.9 Reduction of Fire Involvement Frequency

9.4.9.1 The fire involvement frequency could be reduced by carrying better types of fire extinguishers and with bigger capacity onboard of the explosives carrying vehicle. Emergency plans and trainings could also be provided. Implementation of this option is further detailed in the recommendation section.

9.4.10 Summary

9.4.10.1 In summary, the practicable options to be assessed in the cost-benefit analysis are the reduction of explosives quantities to be transported for each delivery trip and use of smaller quantities of explosives.

9.5 Cost-Benefit Analysis

9.5.1 Sensitivity Case 1 – Reduction of Explosives Quantities to be Transported for each Delivery Trip

Frequency Analysis

9.5.1.1 Frequency of explosion due to accidental initiation of explosives during transport is increased due to more frequent of explosives delivery. The relevant explosion frequency is listed in **Table 9.1**.

Table 9.1 Frequency of Explosion during Transport

Scenario	Base frequency (per km per trip per year)	Distance travelled (km)	No. of trips	Total frequency (per year)
Base Case	7.69×10^{-10}	4	900	2.77×10^{-6}
Sensitivity Case	7.69×10^{-10}	4	1,800	5.54×10^{-6}

Consequence Analysis

9.5.1.2 Impact distances from the accidental initiation of explosives during transport are reduced due to less explosives mass to be travelled at each trip. The relevant impact distance is listed in **Table 9.2**.

Table 9.2 Consequence of Explosion during Storage and Transport

No.	Scenario	TNT eqv. kg	Fatality Prob.	Impact Distance (m)	
				Indoor	Outdoor
Transport of Explosives					
02	Detonation of full load of explosives in one contractor truck on public roads	114	90%	15	12
			50%	18	13
			10%	26	14
			3%	35	15
			1%	46	16

Assessment Results for Sensitivity Case 1

9.5.1.3 The total amount of explosives to be transported per trip is reduced from 200kg (227 TNT equivalent kg) to 100kg (114 TNT equivalent kg) in the Sensitivity Case. The societal risk associated with the implementation of the proposed option is presented in both fN curve and total PLL.

9.5.1.4 The fN curve for implementing the option is presented in **Figure 9.1**. The curve for base case is also presented for comparison.

9.5.1.5 The PLL obtained from implementing the option is estimated to be 3.33×10^{-5} per year. This is higher than the PLL of 2.73×10^{-5} per year for Base Case.

9.5.1.6 The maximum number of fatalities is reduced in the Sensitivity Case, but the frequency of 1 to 5 fatalities is higher than those in the Base Case. It is due to the increased frequency of explosives transport fitting the construction programme. The PLL for Sensitivity Case is higher than that for Base Case, and the option for reducing the quantities of explosives to be transported at each trip is considered not justifiable.

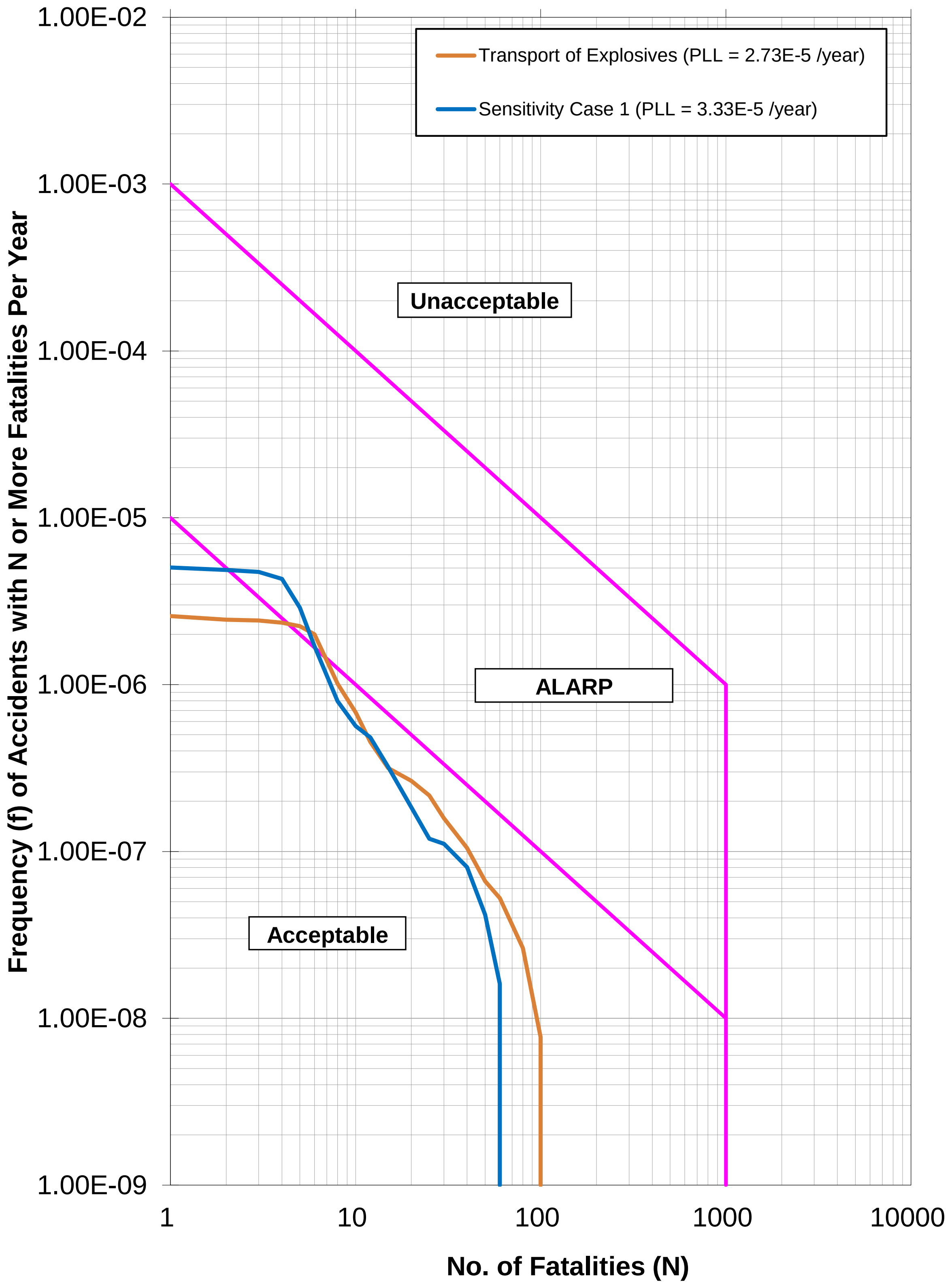


Figure 9.1 F-N Curves for Sensitivity Case 1

9.5.2 Sensitivity Case 2 – Use of Cast Boosters to Reduce the Amount of Explosives Carrying per Delivery Trip

9.5.2.1 The main explosives component of cast booster is PETN, which has a higher TNT equivalency, and the use of cast booster will not eliminate the need for detonating cord.

9.5.2.2 The unit cost of cast booster is around HK$7.5 higher than the unit cost of cartridged emulsion based on the information provided by the supplier. With the consideration that over 620,000 cast booster will be required in this project, the cost of this option is estimated to be at least HK$4.6M higher than the cost of using the cartridged emulsion for initiating bulk emulsion.

9.5.2.3 The additional cost of utilizing cast boosters would be much higher than the Maximum Justifiable Expenditure (HK$0.09M) and therefore not justifiable on a cost basis.

9.5.2.4 In addition, there are limitations in availability of cast boosters since the supply of this material is limited in the market.

10 CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

10.1.1.1 A Hazard to Life Assessment of the risks associated with storage and transport of explosives has been conducted for the construction stage of the Project.

10.1.1.2 The individual risk complies with the criterion of Annex 4 of the EIAO-TM. The societal risk expressed in the form of FN curves lies in the lower “ALARP” region when compared to the criteria stipulated in the EIAO-TM. An ALARP analysis has been conducted considering various mitigation measures, and the results shows compliance with the ALARP principles provided that the following recommendations are followed.

10.2 Recommendations

10.2.1 Recommendations for Meeting the ALARP Requirements

10.2.1.1 The following recommendations are justified to be implemented to meet the EIAO-TM requirements:

- The truck should be designed to minimise the amount of combustible in the cabin. The fuel carried in the fuel tank should also be minimized to reduce the duration of any fire;
- The accident involvement frequency of the explosives carrying vehicle should be minimized through implementation of several administrative measures, such as providing training programme to the driver, regular “tool box” briefing session, implementing a defensive driving attitude, selecting driver with good safety record, and providing regular medical checks for the driver;
- Avoidance of returning unused explosives to the magazine, only the required quantity of explosives for a particular blast should be transported;
- Maintain a minimum headway of 10 minutes between two consecutive truck convoys whenever practicable;
- The fire involvement frequency should be minimised by carrying better types of fire extinguishers and with bigger capacity onboard of the explosives carrying vehicle. Emergency plans and trainings could also be provided to make sure that the fire extinguishers are used adequately.

10.2.2 Recommendations for Explosives Storage in Magazine

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

- The security plan should address different alert security level to reduce opportunity for arson or deliberate initiation of explosives;
- Emergency plan should be developed to address uncontrolled fire in magazine area, and drill of the emergency plan should be regularly carried out;
- Suitable work control system should be set-up to ensure that work activities undertaken during operation of the magazine are properly controlled;
- Good house-keeping within the magazine to ensure no combustible materials are accumulated;

- Good house-keeping outside the magazine stores to ensure no combustible materials are accumulated; and
- Regular checking of the magazine store to ensure no water seepage through the roof, walls or floor.

10.2.3 Recommendations for Explosives Transport

10.2.3.1 The following recommendations should be implemented:

- Emergency plan should be developed to address uncontrolled fire during transport. Case of fire near an explosive carrying vehicle in jammed traffic should be included in the plan. Activation of fuel and battery isolation switches on vehicle when fire breaks out should also be included in the emergency plan to reduce likelihood of prolonged fire leading to explosion;
- Working guideline should be developed to define procedure for explosives transport during adverse weather such as thunderstorm;
- Detonators should be transported separately from other Class 1 explosives. Separation of vehicles should also be maintained through the trip;
- Develop procedure to ensure the availability of parking space on site for the explosives carrying vehicle. Delivery should not be commenced if parking space on site is not secured;
- Hot work or other activities should be banned in the vicinity of the explosives offloading or charging activities;
- Fire screen should be used between cabin and the load on the vehicle;
- Lining should be provided within the transportation box on the vehicle;
- Ensure packaging of detonators remains intact until handed over at blasting site;
- Ensure that cartridged emulsion packages are not damaged before every trip; and
- Use experienced driver with good safety record.

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Annex 1 Calculation of Aircraft Crash Frequency

The model considers specific factors such as target area of the proposed magazine site and its longitudinal (x) and perpendicular (y) distances from the runway threshold for landing and take-off movement. The aircraft crash frequency per unit ground area (per km^2) is calculated as:

$$g(x,y) = NRF(x,y) \tag{1}$$

Where N is the number of runway movements per year; R is the probability of an accident per movement (landing or takeoff). F(x,y) gives the spatial distribution of crashes and is given by:

For aircraft landing, for x > -3.275km,

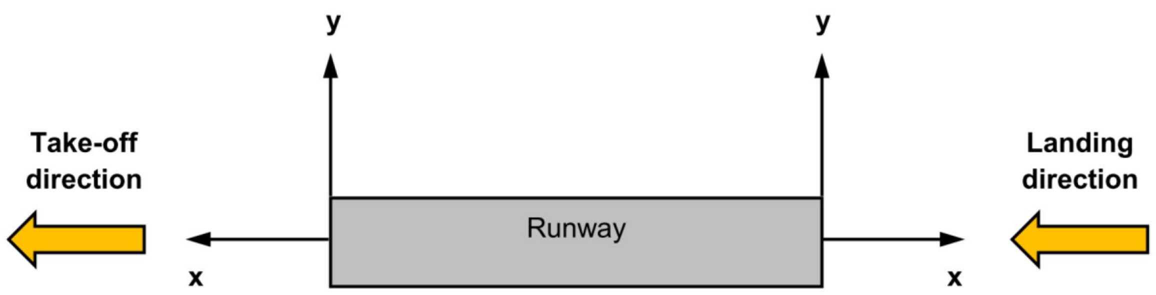
$$F_L(x,y) = \frac{(x+3.275)}{3.24} e^{\frac{-(x+3.275)}{1.8}} \left[\frac{56.25}{\sqrt{2\pi}} e^{-0.5(125y)^2} + 0.625 e^{-\frac{|y|}{0.4}} + 0.005 e^{-\frac{|y|}{5}} \right] \tag{2}$$

For aircraft takeoff, for x > -0.6km,

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

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

Distances between the proposed magazine and the runways are measured and transformed into longitudinal (x) and perpendicular (y) distances in the Aircraft Crash Coordinate System according to the following figure.



The probability of an accident per movement R is interpreted from NTSB data for fatal accidents in the U.S. involving scheduled airline flights during the period 1986-2005. The 10-year moving average suggested a downward trend with recent years showing a rate of about 2×10^{-7} per flight. There are only 13.5% of accidents associated with the approach to landing, 15.8% associated with take-off and 4.2% are related to the climb phase of the flight [6]. Thus it is assumed that the accident frequency for the approach to landings is taken as 2.7×10^{-8} per flight and for take-off is 4.0×10^{-8} per flight.

The number of runway movements of aircraft N is provided by yearly statistics of the Hong Kong International Airport in 2005-2014. Number of movements at year 2022 is estimated by linear regression respectively for landing and take-off cases. The movement number of both landing and take-off adopted in the calculation has been divided by 4 to take into account that only a quarter of landing or take-off use a specific runway. For aircraft landing on the Hong Kong International Airport, only those arriving from north-east using either 25R or 25L arrival flight path would have potential impact to the proposed magazine site; for those arriving from south-west using either 07R or 07L arrival flight path, the longitudinal distance from the runway is around -31km, which is much smaller than -3.275km and thus the potential impact is considered to be zero. For aircraft departing from the Hong Kong International Airport, only those departing towards north-east using either 07R or 07L departure flight path would have potential impact to the proposed magazine site; for those departing towards south-west using either 25R or 25L departure flight path, the longitudinal distance from the runway is around -31km, which is much smaller than -0.6km and thus the potential impact is considered to be zero.

The aircraft crash frequency is finally obtained by multiplying g(x,y) to target area which is estimated to be 1.2×10^{-3} km^2 for the magazine.

The calculations are presented in **Table 1** and the total crash frequency per year is summarised in **Table 2**.

Table 1 Calculation for Aircraft Crash Frequency

Year	Runway	x (km)	y (km)	F(x,y)	N (per year)	R (per flight)	Crash frequency (per unit area)	Target area (km^2)	Crash Frequency (per year)
2022	25R Landing	31.4	9.1	3.7E-11	69422	2.7E-08	7.0E-14	1.20E-03	8.4E-17
2022	25L Landing	31.0	10.7	3.3E-11	69422	2.7E-08	6.3E-14	1.20E-03	7.5E-17
2022	07R Landing	-31.0	10.7	0	69422	2.7E-08	0.0E+00	1.20E-03	0.0E+00
2022	07 L Landing	-31.4	9.1	0	69422	2.7E-08	0.0E+00	1.20E-03	0.0E+00
2022	07L Take-off	31.4	9.1	5.0E-16	69407	4.0E-08	1.4E-18	1.20E-03	1.7E-21
2022	07R Take-off	31.0	10.7	1.4E-16	69407	4.0E-08	3.9E-19	1.20E-03	4.6E-22
2022	25L Take-off	-31.0	10.7	0	69407	4.0E-08	0.0E+00	1.20E-03	0.0E+00
2022	25R Take-off	-31.4	9.1	0	69407	4.0E-08	0.0E+00	1.20E-03	0.0E+00

Table 2 Total Aircraft Crash Frequency

Year 2022	Total Crash Frequency (per year)
Landing	1.6E-16
Take-off	2.1E-21
Total	1.6E-16

Annex 2 – Population Data

Study Buffer Zone

A study buffer zone of 100m is adopted to identify the potential affected populations in vicinity to the magazine site and transport route. Building population and road population are considered as indoor population while pedestrian population is considered as outdoor population in our model.

Building Populations

ID	Description	Maximum Population (2022)	% Occupancies					
			Night	AM Peak	PM Peak	Weekday Daytime	Saturday Daytime	Sunday Daytime
1	The Neighbourhood Advice-Action Council Manor Harmony	716	80%	80%	80%	100%	90%	80%
2	Shing Mun Springs	231	80%	80%	80%	100%	90%	80%
3	Hang Fook Camp	40	80%	80%	80%	100%	90%	80%
4	Substation (on A Kung Kok Shan Road, near Breakthrough Youth Village)	0	100%	100%	100%	100%	100%	100%
5	Open Car Park (near Breakthrough Youth Village)	5	10%	100%	100%	70%	70%	70%
6	Breakthrough Youth Village	790	100%	50%	50%	20%	50%	80%
7	Richard Butler Chalets	60	80%	80%	80%	100%	90%	80%
8	Cheshire Home Shatin	375	80%	80%	80%	100%	90%	80%
9	A Kung Kok Fresh Water Service Reservoir	0	100%	100%	100%	100%	100%	100%
10	Open Car Park (near Bradbury Hospice)	10	10%	100%	100%	70%	70%	70%
11	Bradbury Hospice	52	80%	80%	80%	100%	90%	80%
12	Pump House (on A Kung Kok Shan Road)	0	100%	100%	100%	100%	100%	100%
13	Jockey Club Home for Hospice	90	80%	80%	80%	100%	90%	80%
15	Pictorial Garden (Stage 1)	1924						
15a	Abbey Court	605	100%	50%	50%	20%	50%	80%
15b	Belleve Court	605	100%	50%	50%	20%	50%	80%
15c	Capilano Court	605	100%	50%	50%	20%	50%	80%
15d	Car park under podium	40	10%	100%	100%	70%	70%	70%
15e	Podium	69	10%	100%	100%	70%	70%	70%
16	Pictorial Garden (Stage 2)	1796						
16a	Delite Court	281	100%	50%	50%	20%	50%	80%
16b	Elegant Court	281	100%	50%	50%	20%	50%	80%
16c	Forum Court	562	100%	50%	50%	20%	50%	80%
16d	Galaxy Court	562	100%	50%	50%	20%	50%	80%
16e	Car park under podium	40	10%	100%	100%	70%	70%	70%
16f	Podium	70	10%	100%	100%	70%	70%	70%
17	Pictorial Garden (Stage 3)	1180						
17a	Hillview Court	373	100%	50%	50%	20%	50%	80%
17b	Iris Court	373	100%	50%	50%	20%	50%	80%
17c	Juniper Court	373	100%	50%	50%	20%	50%	80%
17d	Car park under podium	30	10%	100%	100%	70%	70%	70%
17e	Podium	31	10%	100%	100%	70%	70%	70%
18	On King Street Park	100	0%	10%	10%	70%	85%	100%
19	Open Car Park (near Jockey Club Shek Mun Rowing Centre)	10	10%	100%	100%	70%	70%	70%
20	Jockey Club Shek Mun Rowing Centre	50	0%	10%	10%	70%	85%	100%
21	Hong Kong China Dragon Boat Association Shatin Shek Mun Training Centre	50	0%	10%	10%	70%	85%	100%
22	Hong Kong Canoe Union Shatin Training Centre	50	0%	10%	10%	70%	85%	100%
23	Site Offices (DSD / LandsD)	60	10%	10%	10%	100%	55%	10%
24	Petrol Station	10	100%	100%	100%	100%	100%	100%
25	Shek Mun Fresh Water Booster Pumping Station	0	100%	100%	100%	100%	100%	100%
28	Open Car Park (near Pumping House on On Ping Street)	20	0%	100%	100%	70%	45%	20%
29	Shatin Hospital	1296						
29a	Shatin Hospital	975	80%	80%	80%	100%	90%	80%
29b	Open Car Park	10	10%	100%	100%	70%	70%	70%
29c	Transport Terminus	30	10%	100%	100%	70%	60%	50%
29d	Football Field	22	0%	10%	10%	70%	85%	100%
29e	Basketball Court	16	0%	10%	10%	70%	85%	100%
29f	Jockey Club Centre for Positive Ageing	25	80%	80%	80%	100%	90%	80%
29g	A Kung Kok Government Quarters Block B	104	100%	50%	50%	20%	50%	80%
29h	A Kung Kok Government Quarters Block C	104	100%	50%	50%	20%	50%	80%
29i	Tennis Court	10	0%	10%	10%	70%	85%	100%
30	A Kung Kok Sewage Pumping Station	10	10%	10%	10%	100%	55%	10%
31	Ah Kung Kok Fishermen's Village	1061						
31a	Ah Kung Kok Fishermen's Village (a)	374	100%	50%	50%	20%	50%	80%

ID	Description	Maximum Population (2022)	% Occupancies					
			Night	AM Peak	PM Peak	Weekday Daytime	Saturday Daytime	Sunday Daytime
31b	Ah Kung Kok Fishermen's Village (b)	639	100%	50%	50%	20%	50%	80%
31c	Basketball Court	16	0%	10%	10%	70%	85%	100%
31d	Football Field	22	0%	10%	10%	70%	85%	100%
31e	A Kung Kok Sitting-out Area	10	0%	10%	10%	70%	85%	100%
32	Hong Kong Mountaineering Union	0	0%	10%	10%	70%	85%	100%
33	Evangelical Lutheran Church of Hong Kong Shatin Youth Centre Recreational Camp and Training Centre	0	0%	10%	10%	70%	85%	100%
34	Custom and Excise Department Shatin Vehicle Detention Centre (will be relocated)	0	10%	10%	10%	100%	100%	100%
35	A Kung Kok Street Garden	10	0%	10%	10%	70%	85%	100%
36	Ma On Shan Tsung Tsin Secondary School	1406	0%	10%	10%	100%	55%	10%
37	Kowloon City Baptist Church Hay Nien Primary School	1124	0%	10%	10%	100%	55%	10%
38	Chevalier Garden	1136						
38a	Chevalier Garden Block 6	568	100%	50%	50%	20%	50%	80%
38b	Chevalier Garden Block 5	568	100%	50%	50%	20%	50%	80%
41	Shing Mun River Promenade	36	0%	10%	10%	70%	85%	100%
P1	Proposed Project Site	500	100%	100%	100%	100%	100%	100%
P2	Proposed Project Site Office and works area	500	100%	100%	100%	100%	100%	100%

Pedestrian Populations

Pedestrian populations of the pavements along A Kung Kok Shan Road, A Kung Kok Street and Mui Tsz Lam Road are in the form of population density. Site survey was conducted on 12-18 July 2015 to estimate the pedestrian population. As the pavements along A Kung Kok Shan Road, A Kung Kok Street and Mui Tsz Lam Road are linked, it is assumed that their pedestrian densities are the same.

Street Name	Pedestrian Population Density (persons / m^2)					
	Night	AM Peak	PM Peak	Weekday Daytime	Saturday Daytime	Sunday Daytime
A Kung Kok Shan Road Pavement	0.000428	0.000428	0.000428	0.000428	0.000428	0.000428
A Kung Kok Street Pavement	0.000428	0.000428	0.000428	0.000428	0.000428	0.000428
Mui Tsz Lam Road Pavement	0.000428	0.000428	0.000428	0.000428	0.000428	0.000428

Road Populations

Annual Traffic Census 2014 is adopted in our calculation of road population densities.

Street Name	Road Population Density (persons / m^2)					
	Night	AM Peak	PM Peak	Weekday Daytime	Saturday Daytime	Sunday Daytime
Tai Chung Kiu Road	0.0105	0.0362	0.0362	0.0108	0.0108	0.0108
On King Street	0.0056	0.0193	0.0193	0.0057	0.0057	0.0057
On Ping Street	0.0070	0.0240	0.0240	0.0072	0.0072	0.0072
On Sum Street	0.0076	0.0262	0.0262	0.0078	0.0078	0.0078
Tate's Cairn Highway	0.0047	0.0298	0.0298	0.0051	0.0051	0.0051
A Kung Kok Shan Road	0.0165	0.0347	0.0347	0.0165	0.0165	0.0165
A Kung Kok Street	0.0083	0.0270	0.0270	0.0085	0.0085	0.0085
Mui Tsz Lam Road	0.0125	0.0501	0.0501	0.0130	0.0130	0.0130
Shek Mun Interchange	0.0071	0.0376	0.0376	0.0076	0.0076	0.0076
Shek Mun Interchange	0.0071	0.0376	0.0376	0.0076	0.0076	0.0076
Ma On Shan Line	0.0003	0.0700	0.0700	0.0022	0.0022	0.0022