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Risk management of LPG transport activities in Hong Kong

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Abstract

This paper gives a background to risk management of liquefied petroleum gas (LPG) transport activities, with special regard to the activities taking place in Hong Kong. In particular, it looks at the recent activities undertaken by the Government of the Hong Kong Special Administrative Region (SAR); the recent risk assessment of LPG transport in the Territory, the measures developed to minimise the risks (including risk management improvements) and the risk management activities undertaken by the Government and the operators.

Keywords: Liquefied petroleum gas; Transport activities; Hong Kong

1. Introduction

Until recently, the Government's risk management focus has primarily been on the controlling of risks from fixed installations. Their risk management programme (for LPG) started in the 1980s with the Tsing Yi oil and LPG terminals risk assessments. Their efforts, along with those of the operators, have reduced off-site risks from the LPG facilities and improved site risk/safety management.

LPG is imported by ship into five terminals on Tsing Yi island, and is distributed throughout Hong Kong in cylinders and bulk road tankers. The Government has been aware of LPG transport risks for some years. In particular the 1989 Tsing Yi Risk Re-assessment Study by Technica ([1]; now DNV) highlighted the relatively high risk levels to some residential areas along the road tanker routes on Tsing Yi Island.

With this in mind, considerable effort was put into ensuring that LPG road tankers are constructed to the highest possible standards. A large number of specific engineering requirements were implemented to minimise the possibility and consequences of poten-

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tial accidents [2]. Following on, it was considered that the potential for further risk reduction by improved road tankers design was limited, and the Government turned its attention to the risks from all the LPG activities (ships, tankers, cylinder wagons, routing options, safety management, etc.).

2. Accidents

LPG transport accidents have occurred in Hong Kong and elsewhere in the world and these have contributed to increased awareness of the risks from transport activities. The most significant LPG accident in Hong Kong occurred on a cylinder vehicle, luckily there were no fatalities (Tuen Mun, 30th September 1992). The kerosene being moved with the LPG (which at that time was legal) was believed to have been deliberately ignited. The subsequent fire caused about 20 LPG cylinders to rupture resulting in fireballs up to 20 storeys high.

2.1. Fixed installation vs. transport risk

In order to understand the importance of risks from dangerous goods (DG) transport activities comparison with fixed installations is made. Fatalities from DG transport activities are compared to those from DG fixed installations in a paper by Glickman et al. [3]. This found that historically risks from transport and fixed installations are similar (see Fig. 1); therefore, it is concluded that the different risk sources need equal focus.

3. Risk management

Before discussing LPG transport risk, it is useful to review the risk management process and the risk management activities already undertaken by the Government.

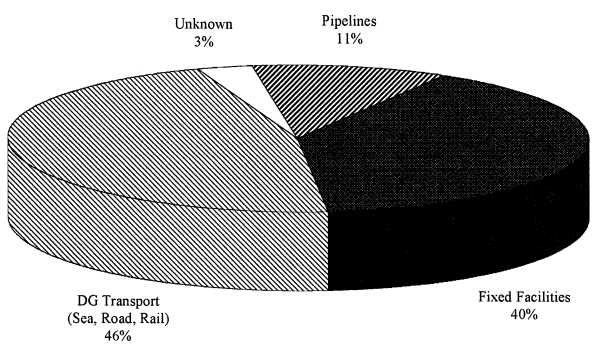

Fig. 1. Cause of major industrial accidents by source (1945 to 1986).

3.1. Risk management process

No single management function can be regarded as right or wrong, but management models from authoritative sources generally contain similar ideas (for example, see [4,5]). In 1991, the UK HSE [6] issued their core safety management document: Successful Health and Safety Management (HS (G) 65) which follows these ideas. This is referred to in most other HSE guidelines as a basis for ongoing safety management. The HSE uses the functions and the inter-relationship shown in Fig. 2.

The Centre for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineering (AIChE) ''Guidelines for Technical Management of Chemical Process Safety'' describes risk/safety management systems in terms of four basic functions ([7]; see Fig. 3). Without these management functions, the CCPS guidelines conclude that only a limited impact will be made on process risk.

3.2. Hong Kong risk management

The Government has used risk assessment techniques to assist managing DG risks in Hong Kong for many years. In 1989, they commissioned the first DG transport risk assessment to study chlorine transport. Recommendations from previous studies have been implemented reducing major hazard risks to the Hong Kong public, hence aiding the Government to manage Potentially Hazardous Installations (PHIs) and DG transport risks.

After the early PHI studies, the Coordinating Committee on Land-use Planning and Control relating to Potentially Hazardous Installations (CCPHI) was set up to coordinate the Government's risk management policy and actions with regard to the PHIs including:

- Updating information on the number and locations of PHIs in Hong Kong.
- Endorsement of risk reports for new PHIs and developments in the vicinity of PHIs.

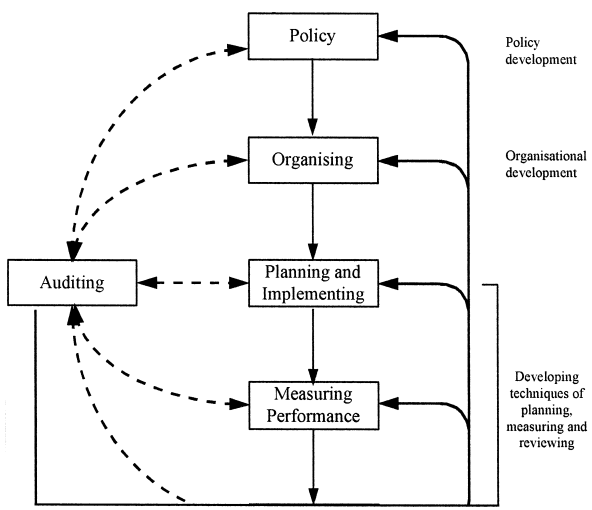

Fig. 2. Key elements of successful health and safety/risk management.

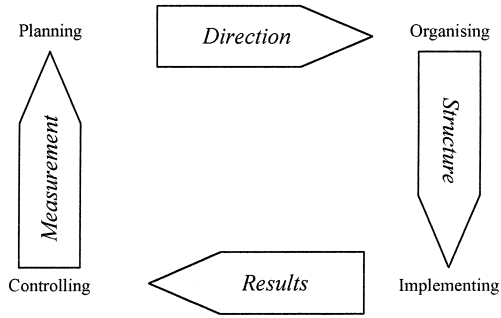

Fig. 3. Functions of a management system ([7]).

- Special approval of application for developments within PHI Consultation Zones.
- Monitoring development pressures in areas with the best attributes for future PHIs.

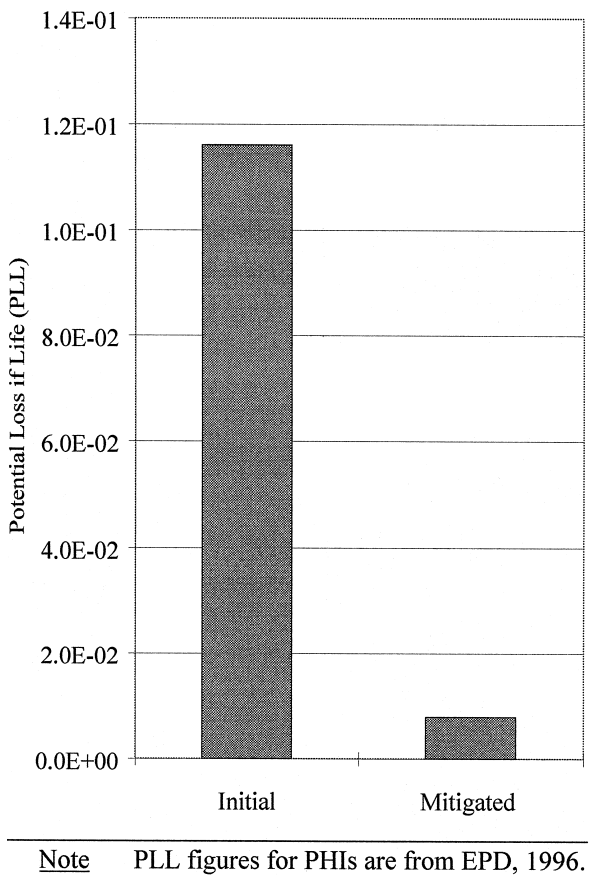

Fig. 4. Risk reduction (PLL) for oil and lpg terminals (ref. 1989–1995 QRAs).

Members of the CCPHI came from several different Government departments. The CCPHI ensures that risk assessments are undertaken at an appropriate time and that the risk mitigation measures recommended are implemented.

The completed risk assessments have helped to significantly reduce the risks from PHIs [8,9]. Fig. 4 shows how the risk levels for the 5 oil/LPG terminal PHIs have fallen over the last 10 years due to the Government's risk management programme.

The Government and operators have been responding and improving standards in accordance with new international codes and practices, and their learning from near miss incidents and accidents in Hong Kong and worldwide. Previously, however, transport risk studies in Hong Kong have been undertaken on an ''ad hoc'' basis when specific concerns have arisen. PHI risk studies are undertaken on a systematic basis with control and coordination through CCPHI. The current transport risk studies were commissioned based on the realisation that the risks to the general public from DG transport activities could be as great as, or greater than, those from PHIs.

4. Risk assessment of LPG transport risk

With the recognition of the relative importance of DG transport risks, and knowing the special features of Hong Kong (high density population, narrow streets, etc.) the Government decided to undertake the first step of the risk management process for DG transport, i.e. to examine the risks to identify appropriate control measures and actions that might be necessary. LPG was the first DG to be studied, the work was managed by EMSD with assistance of steering group members from other Government Departments. DNV Technica was commissioned to carry out the study.

4.1. Objectives

The primary objectives of the study were to:

- Estimate the risks of LPG transport accidents.
- Develop risk guidelines for assessing in LPG transport risk levels in Hong Kong.
- Assess the risks using the guidelines, and identify if risk reduction is necessary.
- Identify the main contributors to the risk and suggest practical risk reduction measures.
- Evaluate the effects of the risk reduction measures using cost-benefit analysis to show their effectiveness in reducing the risks to as low as reasonably practicable (ALARP).

4.2. Scope of the study

The project's scope was to study: present (1995) and future (2006) cases for LPG road and marine transport within the land and sea boundaries of Hong Kong. The study included:

- LPG in bulk marine tankers.

- LPG transport in road tankers from the terminals to the bulk stores.
- LPG cylinder transport by road from the terminals to specified locations in each district.
- LPG cylinders carried by barge from the terminal to their destination.

The people covered were residents, road users, harbour users and other third-parties not involved in the LPG operations.

4.3. Approach

The approach followed the ''classical'' risk assessment methodology which is well established in Hong Kong for PHI risk assessments (see Fig. 5). It included:

- Development of the methodology.
- System definition (data collection).
- Reviews of the LPG terminal operators transport SMS.
- Hazard identification, including an incident review, SWIFT and FMEA structured hazard identification, and incident case development.
- Frequency estimation using historic data and fault trees.
- Consequence and impact modelling, including use of Computational Fluid Dynamics (CFD) as well as standard models such as PHAST.
- Development of criteria and assessment of risk results.

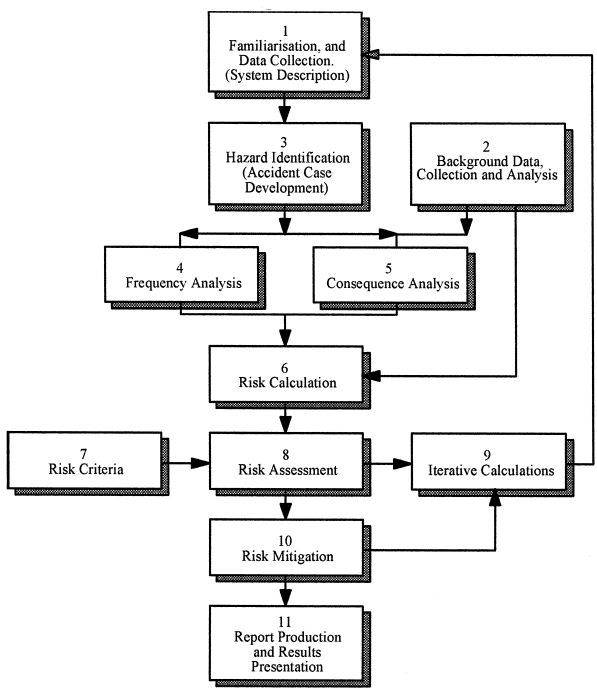

Fig. 5. QRA flow diagram.

- Production of risk results and risk assessment.
- Developed risk reduction measures and cost benefit analysis (CBA).
- Developed options for the consideration by the Hong Kong Government.

4.4. Accidents

A survey and analysis of Hong Kong and worldwide LPG road and marine transport accidents. From the survey it was noted that:

- *LPG road tankers* were responsible for most LPG transport releases and fatalities.
- There are few reports of leaks from *LPG cylinder wagons*, (probably under-reported).
- Cylinder transport tends to cause relatively frequent but comparatively minor accidents.
- There are many reported incidents with *LPG ships*, including one collision in Hong Kong waters, but very few actual releases of LPG, (except during transfer).
- No accident reports are available for the type of *LPG barges* used in Hong Kong.
- There have been several incidents involving DGs on large ocean-going Ro-Ro ferries; similar accidents might be expected on small *DG ferries* as used in Hong Kong.

In order to show the relevance of previous accidents to modern vehicles in Hong Kong, a formal accident review was conducted on 20 LPG releases from road tankers and cylinder vehicles. The conclusions from this review for *tankers* were:

- The single-tank design of Hong Kong tankers eliminates the accident potential from non-standard vehicles such as that involved in the Bangkok accident (24th September 1990).
- The Hong Kong rigid tanker chassis design reduces the chance of overturn accidents.
- The recessed pressure relief valve on Hong Kong tankers reduces the chance of leakage caused by low overhead clearance and in rollover accidents.
- Hong Kong's use of a driver and helper reduces the chance of accidents due to fatigue, etc.
- The location of delivery pipework at the side of the tanker reduces vulnerability to rear-end collisions, but its integrity in side-on collisions or rollovers is then critical.
- The isolation of delivery pipework from the tank is critical in assessing the likelihood of continuous liquid leaks.
- Hong Kong tankers are typical with regard to leaking in high-speed impacts with objects such as bridge supports, (considered as a likely major accident scenario).
- Hong Kong tanker passive fire protection reduces vulnerability to BLEVE events.

The conclusions from this review exercise for *cylinder wagons* were:

- The prohibition of joint conveyance of LPG and kerosene will, if enforced correctly, reduce the frequency of fires leading to BLEVEs.
- Some LPG vehicle routes in Hong Kong cross light rail transit tracks at level crossings, which have been the causes of catastrophic failures in other countries.

This type of review exercise, evaluating the warnings from DG accidents abroad, was proposed as an on-going risk management technique for use by Government and industry.

4.5. Transport risk model

The Transport Risk Model (TRM) was created to generate the risk results for the project in the required format. It has the following components, used in the LPG risk calculations:

- **Frequency model** — combines the frequencies of each failure case (per vehicle km year) with the route data (route sections, lengths, and numbers of vehicles/vessels per year), to determine the annual frequencies for each failure case on each route section.
- **Population model** — represents the population distribution for representative route sections. This included consideration of people on the road, pavements, inside and outside buildings, building sizes and ventilation types and in vessels on the harbour.
- **LPG consequence and impact model** — calculates consequence zones in 3-dimensions for each outcome (fireball, flash fire, VCE, etc.) appropriate to each failure case. It superimposes the outcome consequence zone on each population case, and calculates the number of fatalities and the individual risk transect contribution. It then determines the fatality rate, FN curve and individual risk transect for each failure case and population case combination, for unit release frequency.
- **Risk summation model** — combines the frequency and impact results to generate risk results, PLL, FN curve and individual risk transect, for each route section, considering the vehicles using the route section, and their failure cases. The societal risk results were summed to give the network totals, or a breakdown by vehicle type or failure case.

4.6. Forms of presentation for risk results

Results were presented as risk contours and risk transects (Individual Risks) and FN curves and potential loss of life (PLL) rates (Societal Risks). PLL is the estimated average number of fatalities per year.

4.7. Proposed interim criteria

The study developed Risk Guidelines against which to judge the acceptability of the risks, hence helping to ensure LPG transport risks are controlled according to an agreed decision-making framework.

UK has risk guidelines for the import of DGs but these apply to within port areas only. The Netherlands uses criteria to aid their management of DG transport risks. The Australian states use individual risk criteria to judge acceptability, but use societal risk (PLL) to aid routing decisions. No risk guidelines existed in Hong Kong for DG transport.

It should be noted that the criteria used in the study were ‘‘proposed interim criteria’’. The Government is still reviewing and developing DG transport risk criteria. A decision on whether or not to formally adopt a criteria and what it should be is yet to be made.

4.7.1. Individual risk criteria

For individual risk, the fatality risk level of 10^{-5}/year was the proposed criteria for the limit of acceptability. This limit is for a person's exposure to the risks for a year.

4.7.2. Societal risk criteria

The societal risk criteria were developed based on the PHI criteria and the number of sites to which LPG is delivered. Fig. 6 presents the criteria used. The study's report [10,11] discusses their development.

4.8. Results — current case (1995)

4.8.1. Individual risks

The peak individual risk occurs on the road routes from the oil terminals where the LPG cylinder wagons and tanker traffic are the greatest, and on the marine route for the bulk tanker import to Tsing Yi. It is found that the individual risk for a person who is continuously exposed to the risk contour only exceeds 10^{-5}/year for a few routes, and that the 10^{-5}/year risk contour never extends into an area where people will be present for extended periods (e.g. residential areas and shops). The LPG transport was judged to be acceptable in terms of the individual risks it poses.

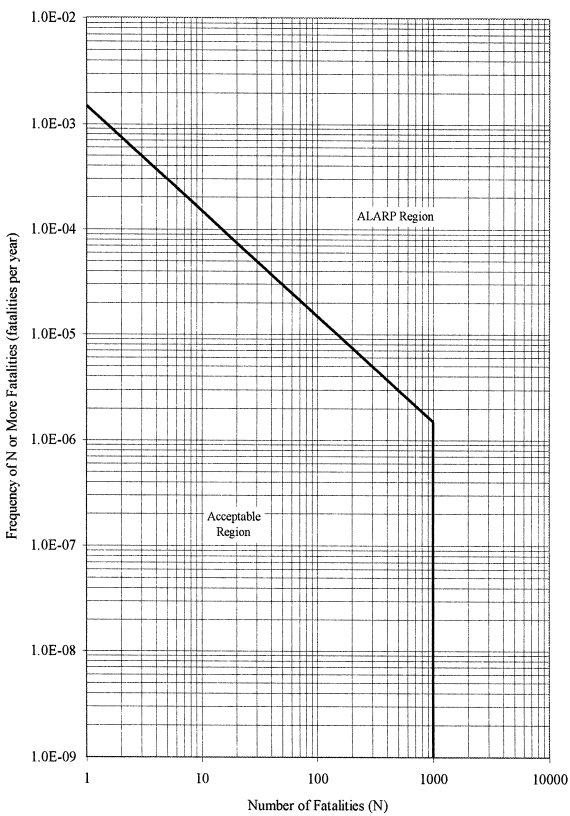

Fig. 6. Proposed interim risk criteria for LPG transport in Hong Kong.

4.8.2. Societal risks

The FN curve for the transport of LPG in Hong Kong, for the current case (1995), is shown in Fig. 7. By comparison with the interim criteria it can be seen that the societal risks for the current case lie in the ALARP region. The study, therefore, proceeded to identify possible risk reduction measures and to assess their cost effectiveness, in order to demonstrate ALARP (see Figs. 8–10).

From the societal risk results, it is found for the LPG transport activities that:

- The estimated frequency of fatal accidents is once every 300 years.
- The PLL is 0.094/year (i.e. the estimated average number of fatalities per year is 0.094, which may be considered equivalent to one fatality every 11 years).
- The average numbers of fatalities for a fatal accident is estimated as 28.
- Road transport has a PLL of 0.086/year and contributes most (~90%) of the societal risk.
- The PLL for the marine transport is 0.0083/year.
- For the road risk 90% is from tankers and 10% is from cylinder wagons.
- Major catastrophic failures of the tankers produce ~2/3 of the road PLL. This is due to the severe consequences of these events. (These incidents make up only 3% of all the incidents modelled).

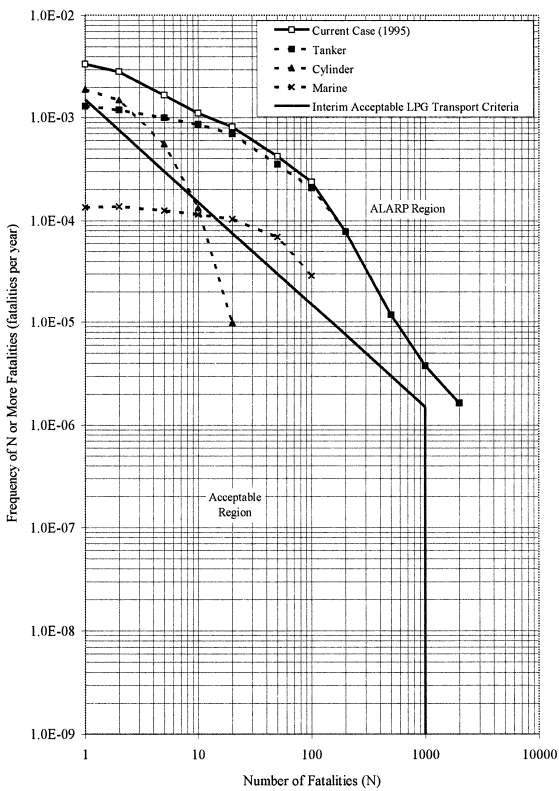

Fig. 7. FN curve for the transport of LPG.

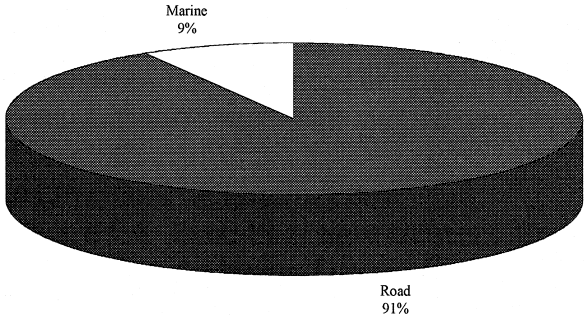

Fig. 8. Total PLL slpit between road and marine transport.

- About 2/3 of the incidents modelled are releases from cylinders on LPG wagons.
- The fault tree analysis shows the dominant cause of catastrophic tanker failures to be collision accidents.
- DG ferries (48%) and bulk LPG marine tanker movements (45% import and 7% China trade) are the main contributors to the marine risk.

4.9. Results — future cases (2006)

The future case (2006) is very similar to the current case (1995). Predictions are that the LPG trade will remain constant, so the only changes (an increase in PLL by 0.1%) relates to population changes.

Changes in the LPG market could effect the future LPG risks, for example the introduction to Hong Kong of LPG powered taxis alone could double LPG usage.

4.10. Developing risk reduction measures

Meetings were held with Government personnel and operators to identify possible practical risk reduction measures. The meetings considered, in a structured manner, each part of the relevant transport operation. They identified ways to reduce risk by:

- Elimination/avoidance (often referred to as termination of the risk).
- Reduce the frequency of occurrence/likelihood (often referred to as treatment).

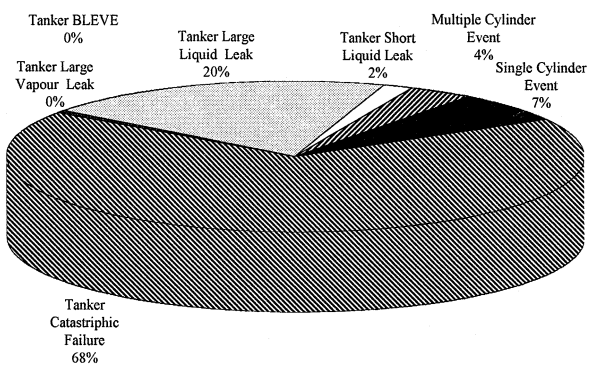

Fig. 9. Breakdown of the road PLL by incident case.

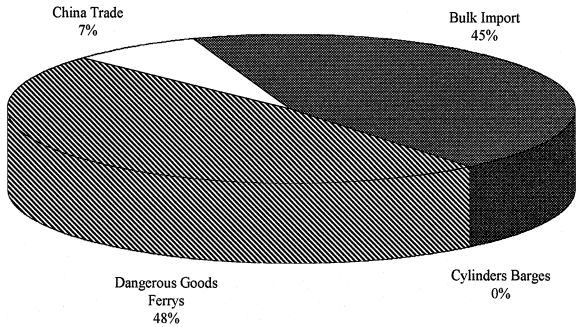

Fig. 10. Breakdown of the marine PLL by type of vessel.

- Reduce the consequences, initial or knock-on effects (often referred to as treatment).
- Reduce the impact of the consequence (often referred to as treatment).

If a hazard can be eliminated (i.e. terminated) while still achieving the intent of the activity, then this should be the preferred option. In risk management, it is commonly stated that risks can be terminated, treated, transferred (e.g. by insurance) or tolerated. Looking for ways in which activities can be made inherently safer, should be emphasised since it helps to control risk efficiently. The principle of inherent safety is to eliminate hazards by making activities simple, user-friendly and inherently low risk. Safer activities can be achieved by:

- Reducing the risk potential of the activity.
- Incorporating in the engineering design safety systems to control hazards (i.e. location and engineering controls).
- Establishing an effective safety management system to incorporate design, operation, maintenance and incident response (operational controls, administrative controls, etc.).
- Controlling the quality of the people who design, operate, and maintain the activity and facilities by selection, motivation and training.

These are different types of safeguards that can be incorporated to reduce risk.

4.11. Risk reduction and cost benefit

Eighteen risk reduction measures were defined in the meetings with Government personnel and the operators. Of these, the CBA found 10 to be cost-effective, (although

Table 1

No.	Risk reduction measure description
1	Improving tanker and cylinder wagon emergency response equipment to enhance intial response
2	Enhance safety management
3	Improve inventory management
4	Re-routing the LPG deliveries to avoid high risk areas
5	New ro-ro ferry routes and new road routes
6	Improve emergency response by enhancing the emergency reponse plans and undertaking emergency reponse exercises

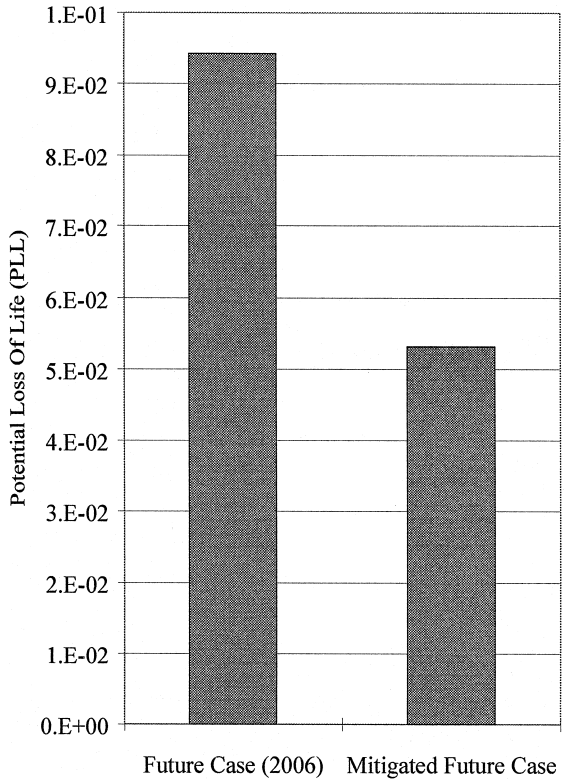

Fig. 11. PLL bar chart showing the future and mitigated future cases.

some needed to be combined). Table 1 lists the 6 cost-effective combined risk reduction measures.

If these measures are successfully implemented, then the PLL will be reduced by around 40% (see Fig. 11). The FN curve (which will still be in the ALARP region), will lie closer to the proposed interim risk criteria's acceptable line, overlapping it at the high fatality end of the curve (see Fig. 12).

5. Conclusions and outcome of study

5.1. Implementing measures

5.1.1. Safety management

The safety management audit found that the quality of the operators' safety management systems were much improved from the oil terminals studies in the 1980s. The recommendation made for further improvements were discussed with the operators and are being implemented.

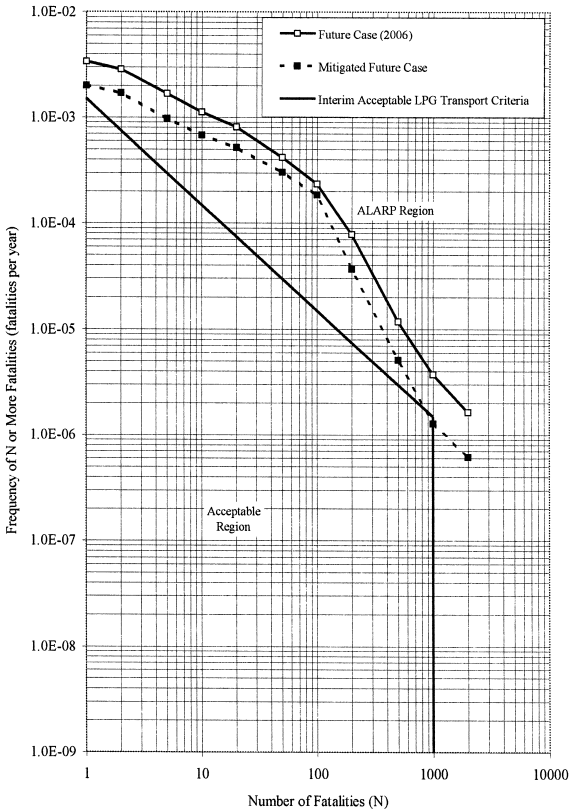

Fig. 12. FN curve for the future and mitigated future cases.

The government have taken actions to improve their own activities which include:

- Developing a plan to implement the recommendations, and implementation of the plan.
- Establishment of a procedure to check the training and experience of tanker drivers.
- A review of incident statistics and a plan to establish an incident/near miss database.

5.1.2. Re-routing of road vehicles and use of additional DG ferries

The specific measures proposed illustrate that risk reduction can be achieved by routing road tankers and cylinder wagons away from the most densely populated areas. There are plans for new roads, bridges and railways (for example the Ting Kau Bridge). Possible new alternative land routes are under review and will be used once the bridges, etc., have been brought into use. The most beneficial re-routing exercise is to shift road transport bound for Hong Kong island onto ro-ro ferries and send them there directly. There are a number of issues to be resolved, not the least of which is cost to the operators of such a dedicated service. The Government is looking at the possibility of adopting the measure when the ro-ro facilities can be made available, possibly in about 2

years' time. Also the Government is starting to identify where sensitive populations (hospitals, schools, homes for the elderly, etc.) are situated next to road tanker routes, and to see where local diversions might be beneficial.

5.1.3. Improve inventory management

Operators have accepted and implemented this recommendation and see it as a cost reduction measure. The Government is considering ways in which they can monitor effectiveness of the operator's actions.

5.1.4. Improvements to emergency response

Government have had discussions with the operators on an exercise involving an overturned road tanker. The aim is to improve the ability to transfer product from overturned vehicles. The Government, seeking ways in which this can be done effectively, is intending to have an exercise once a road tanker has been modified.

5.2. General conclusions

The results of the study were presented to, and were understood and well received by LEGCO (the Legislative council of the Government of the Hong Kong Special Administrative Region).

The risk model is now available to be used for sensitivity calculations. The Government is able to look at the effects of using new road routes, increased consumption of LPG, etc. Currently the model is being used to assess the risks if taxis and buses in Hong Kong are converted to run on LPG.

The risk criteria have been discussed within the Government and have been further developed. Their use in the study was understood and accepted by LEGCO.

Glossary

AIChE	American Institute of Chemical Engineers
ALARP	As Low As Reasonably Practicable
BLEVE	Boiling Liquid Expanding Vapour Explosion
CBA	Cost Benefit Analysis
CCPHI	Coordinating Committee on Land-use Planning and Control Relating to Potentially Hazardous Installations
CCPS	Center for Chemical Process Safety of AIChE
CFD	Computational Fluid Dynamics
DG	Dangerous Goods
DNV	Det Norske Veritas
EMSD	Electrical and Mechanical Services Department
EPD	Environmental Protection Department
FMEA	Failure Modes and Effects Analysis
FN Curve	An FN curve shows the relationship between the number of fatalities in an accident, and the cumulative frequency of accidents causing that number of fatalities or greater

HSE	Health and Safety Executive
LEGCO	Legislative Council
LPG	Liquefied petroleum gas
PHAST	Process Hazard Analysis Software Tools
PHI	Potentially Hazardous Installation
PLL	Potential Loss of Life
QRA	Quantitative Risk Assessment
SMS	Safety Management System
SWIFT	Structured What If and Checklist Technique
TRM	Transport Risk Model
UK	United Kingdom
VCE	Vapour Cloud Explosion

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