THE TRANSPORT OF HAZARDOUS GOODS : AN APPROACH TO IDENTIFYING AND APPORTIONING COSTS

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ABSTRACT: *The transportation of hazardous goods poses a potential threat to the health and safety of people, property and the environment. This imposes costs in several ways: the costs in terms of loss of life, injury and property and environmental damage of hazardous incidents and the cost of clean up etc.; the costs of exposure to risk, including loss of amenity, stress, and related health effects (these costs are often reflected in property value effects); and, the additional direct transport costs of measures to reduce risk such as use of particular routes, vehicle and vessel/packaging design requirements, load limits etc. As transportation of hazardous goods is essential, the aim should be to find an optimal position where societal and individual risk levels are acceptable but controls are not excessive.*

The approach adopted in this area by the New South Wales Department of Environment and Planning is the use of Quantified Risk Analysis, the quantified estimation of levels of risk. The risk levels derived can be assessed against acceptable risk criteria and the need for action to reduce risk or to control development or designate transport routes be determined. The results can also be used for comparisons between alternative routes to determine least risk routes or between alternative safety measures for cost effectiveness assessment.

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1. Introduction

The handling storage and distribution of hazardous goods, such as petroleum products, liquified petroleum gases, chlorine gas, pesticides chemicals/petrochemicals and radioactive materials, inevitably involves the potential for incidents which may result in death or injury to people, property damage or damage to the bio-physical environment through the effects of fire, explosion or toxicity. Although the potential for such incidents is generally low, nevertheless the risk exists and cannot be totally eliminated.

There has been a growing awareness in government, industry and the community at large of the potential for incidents involving such materials in process, in storage or while being transported. This growth in awareness has been given particular impetus by incidents around the world, obvious examples being the Bhopal and Chernobyl disasters.

A policy response is required to address both the real risks associated with hazardous materials and the heightened awareness and perception of hazard, the latter often expressed as active opposition to existing or proposed developments. Specifically what is required is a rational basis for determining the level and types of restrictions, regulations and controls which should be exercised so that necessary or desirable activities can be carried out without unduly compromising public and environmental safety.

The hazard from hazardous industries is a function not just of the materials handled and associated engineering and technical controls but also of the location of the activities handling the materials. The location of the activities in relation to people, property and particular environmental features determines the potential consequences of any hazardous incident. The potential for severe consequences lies largely in the effects outside the immediate plant or storage site or in the effects on areas along transport routes. It is now well recognised that there are limitations to hazards control in technicological and economic terms. Land use/environmental planning should be considered as an integral part of the overall control process. The central question, as recognised widely overseas is a matter of land use safety and environmental safety planning and not one of engineering standards in isolation.

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The comments made above are particularly applicable to dangerous goods transportation systems. Fixed installations are more amenable to locational, organisational and operational hazard controls. Transportation systems are dynamic systems with additional external variables (e.g. drivers, traffic conditions, etc..) difficult to bring into one overall control system. Dangerous goods route planning becomes particularly relevant in this regard. This paper outlines the approach and methodology adopted by the New South Wales Department of Environment and Planning in this area with particular emphasis on transportation matters.

2. The Costs of Handling Hazardous Materials

The potential for fire, explosions or releases to the environment of hazardous materials in process, storage or while being transported imposes costs in several ways, which can be termed incident costs, risk exposure costs and costs of safety measures.

i) Incident Costs

These are the costs of actual incidents in terms of loss of life, injury to people and property and environmental damage and the cost of control and clean up etc. These costs are potentially very large particularly where large populations or sensitive environments are exposed or where highly toxic materials are concerned. Toxic releases in particular could result in large numbers of people being killed or injured as in Bhopal or severe environmental damage as occurred in the Sandoz fire where the Rhine was heavily contaminated with pesticides. The incidence of these costs varies with the case but by no means all of such costs borne by the industry or transporter, especially where costs which are difficult to translate into dollar values such as effects on the bio-physical environment are concerned. Some of the more conventionally accepted costs which can be covered to an extent by financial compensation are reflected through insurance payments but not all such costs are covered and in practice these costs are often borne by private individuals or the public sector.

ii) Risk Exposure Costs

These are the less tangible costs of exposure to the risk of such incidents such as loss of residential amenity, stress (and related health effects) and the effects on residential property values. The extent of these effects depends largely on perception. Where incidents have occurred or new developments have been publicised, then perception is heightened and stress, loss of amenity and property value effects accentuated. The magnitude and incidence of these costs is very difficult to determine.

iii) Costs of Safety Measures

Measures designed to reduce the likelihood or severity of incidents such as locational and design requirements and, in the case of transportation, requirements to use particular routes, vehicle and (pressure) vessel or packaging design requirements, load limits etc. impose costs. These costs would normally be directly borne as additional operating costs and built-in to pricing structures.

The safety measure costs can be seen as internalised costs which would otherwise be borne as incident and risk costs. Importantly, however, control measures can also reduce total costs if the costs of these measures are less than incident and risk costs. The objective should be to set control measures at a level where this is clearly true. As the brief comments above show, however, the determination of the appropriate point where the benefit of safety and risk reduction measures outweigh the costs cannot be simply determined as there is no easy monetary measures of the value of the benefits. A surrogate measure must therefore be used.

3. Control Measures

Historically the approach to hazard control and safety measures has been a technical one of setting engineering standards and design specifications together with support measures such as hazard placarding for hazardous industry plant or transport vehicles. These measures have a legitimate role to play, generally however they have been developed and applied in isolation from considerations of cumulative impact or the nature of the uses of affected lands. They have generally not been determined on any systematic rational basis relating them to the appropriateness of the level of safety provided. Such measures in isolation therefore, have been largely unrelated to the question of the level of costs and who bears these costs. The application of such measures has generally also been on an across the board basis and there has been little scope for flexibility to meet particular circumstances.

4. Approach Adopted by the New South Wales Department of Environment and Planning

The Major Hazards Policy Unit of the N.S.W. Department of Environment and Planning has adopted an alternative approach to these issues which provides a systematic and rational basis for determining the appropriate level of control measures, provides an effective basis for determining the distribution of residual risk costs and can be flexible to meet specific cases and circumstances. It also provides a sound basis for determining the most cost effective measures.

The approach is based on the concept of acceptable risk, and the methodology of hazard analysis and quantified risk assessment.

The acceptable risk concept is that all activities involve a degree of risk, either voluntary or imposed, and that people clearly demonstrate that some level of risk is acceptable in return for benefits. The classic example of this is the choice to use motor vehicles : there is clearly a significant and well known risk of death or injury but people judge that taking this risk is justified by the benefits of such use.

The basic methodology of hazards analysis and quantitive risk assessment is illustrated in Figure 1 Basic Methodology. Four elements are involved : hazard identification, consequence analysis, probability (or frequency) estimation and quantified risk assessment.

Hazard identification involves the identification of the materials handled and their properties such as flammability, toxicity and volatility and possible incidents.

Consequence analysis is the estimation of consequences of possible incidents in terms of the physical effects such as heat flux, explosion overpressure and toxic concentrations at various points and the impact of those physical effects on receptors such as residents and sensitive environments. Probability or frequency estimation is the estimation both of the likelihood of incident occurring and the likelihood of particular outcome if those events occur. For example in the case of a toxic gas storage, information on probability of such things as vessel failure or pipe failure, frequencies of various wind and stability conditions and the probability of fatality or injury from given concentrations is necessary.

The consequence and probability estimations are combined to give a quantified risk result. Addition of all results gives the cumulative risk for any given point of a particular effect. The most common expression is in terms of human fatality risk usually on an annual basis. Without loss of validity the results can be expressed in other terms such as levels of injury, property damage or environmental damage.

Human fatality risk results are commonly expressed in two forms, individual risk and societal risk. Individual risk is the risk of death of a person at a particular point from the source. Societal risk is the risks of a number of fatalities occurring. The societal risk concept is based on the premise that society is more concerned with incidents which kill a larger number of people than incidents which kill smaller numbers.

The quantified risk result can be used for comparative purpoes or judged against adopted acceptable risk criteria. There can be debate as to any adopted acceptable risk criteria but such debate does not invalidate the approach.

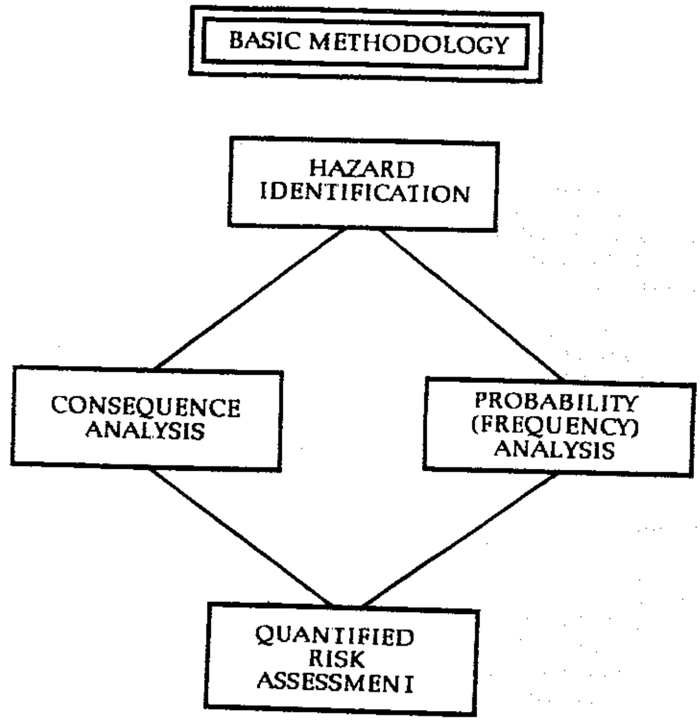

BASIC METHODOLOGY
HAZARD IDENTIFICATION
CONSEQUENCE ANALYSIS
PROBABILITY (FREQUENCY) ANALYSIS
QUANTIFIED RISK ASSESSMENT

Figure 1

5. Application

The Unit applies the approach in four areas. The assessment of new development proposals, the assessment of risk in areas with existing or new concentrations of hazardous industries, the development of guidelines for activities where direct involvement by the Department in development consent is not appropriate, and in transportation studies. In the case of hazardous industry, the Department applies a seven stage approval process for the industrial hazard aspects. The process is shown in Figure 2 Land Use Safety Requirements. As will be noted, the process does not stop at the Environmental Impact Assessment development application stage, but continues, through conditions attached to consent, to address the safety of the plant or operation as a whole through the final design, construction and operational phases - the latter through requirements for annual hazard auditing to ensure that initial operating safety standards are maintained. The impacts of transportation associated with proposals are fully considered in this process.

The area studies such as those carried out for the Botany/Randwick Industrial Complex and Port Botany (10) and the Kurnell area (12) also have a transport component with the integration into the studies and their recommendations of the results of complementary transportation studies.

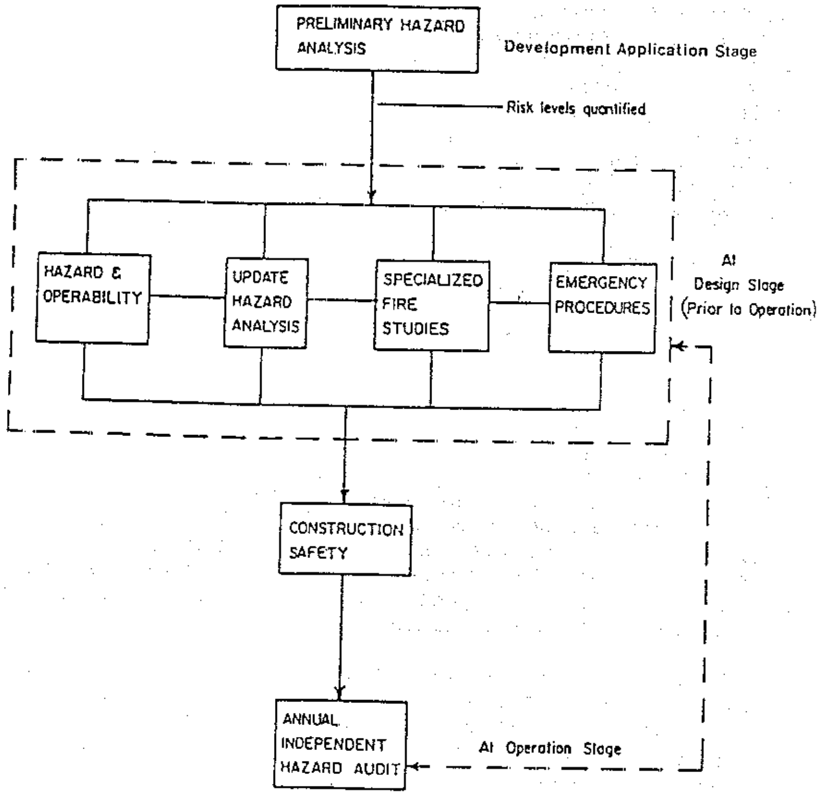
Applications of Quantified Risk Analysis in assessing Land Use Safety Implications for potentially hazardous installations such as chemical/petro-chemical complexes and related storage facilities are well established. The application to transport raises challenges due to the dynamic nature and the extent to which factors outside the control of the particular operation are involved. The transport studies are particularly important however as it is often during transportation that the risk of incidents is at its highest level and where control or containment is at its most difficult.

The Department has development techniques to overcome these problems and study results have been used for the development of policy measures covering such things as route designation, packaging and containment of loads, load limitations and road contribution calculations.

The following section of the paper briefly outlines some examples of the applications of the approach to transport issues.

6. Risk Assessment of Dangerous Goods Routes

In March 1980, the N.S.W. Department of Environment and Planning initiated an investigation into the risk to people living in or around the Botany/Randwick Industrial Complex. The investigation which led to the assessment study was initiated by the Department in response to concern expressed by community groups and local councils.



LAND USE SAFETY REQUIREMENTS FOR HAZARDOUS INSTALLATIONS

Figure 2

The Botany/Randwick industrial complex and Port Botany comprises the largest area of industrial land in the Sydney Region. Integrated into some 600 hectares of industrial zoned land are major petro chemical and petroleum storage facilities responsible for storing or processing over 450,000 tonnes of flammable liquids and gases, and over 22,000 tonnes of toxic or highly reactive materials.

In that context the main objectives of the Department's assessment study were :

- to examine whether public safety, property or normal community activity are at risk from industrial operations in the Botany/Randwick Industrial Complex and Port Botany;
- if such risks are found, to quantify the hazard impact and identify the major contributing causes; and
- outline and prioritize cost effective measures to ensure reasonable and acceptable levels of public, property and community safety.

It is the Department's experience that Quantified Risk Assessment offers the most cost effective means in fact the only means by which technical, economic and land use safety issues can be assessed.

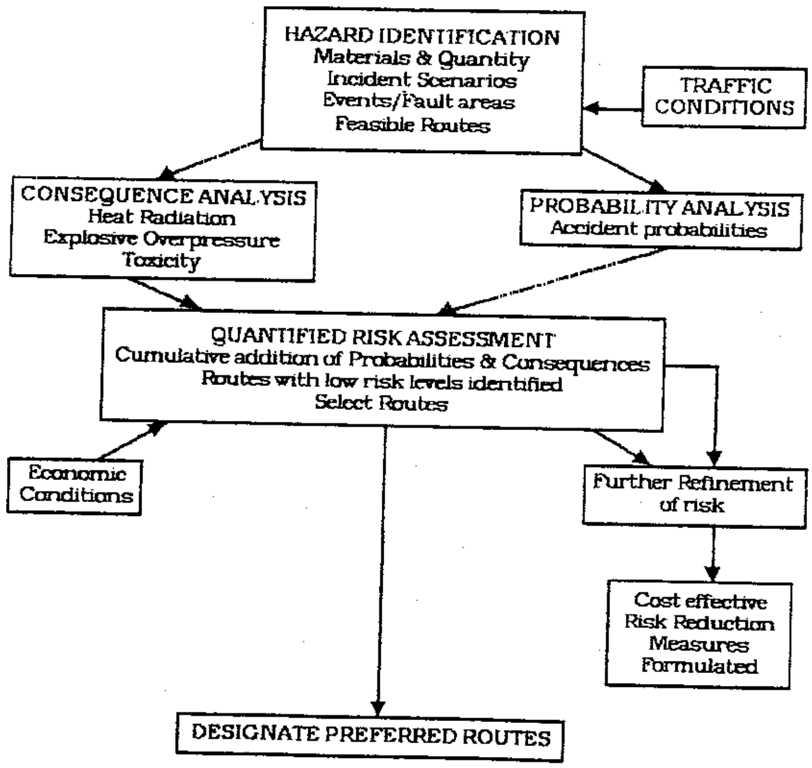
Once assessed and the major risk contributors identified, risk reduction options can be formulated.

These same conclusions were reached in consideration and assessment of appropriate transport routes for the carriage of hazardous materials, moreover these techniques can apply to any dynamic transport system. Specifically three main considerations ought to be accounted for in the formulation of a truck route system for the carriage of hazardous materials, they are:

- cumulative traffic implications including level of service of existing roads, intersection capacity, accident rates and traffic volume;
- safety and land use impacts as a result of Quantified Risk Assessment;
- economic distribution considerations including operator's requirements for practical transportation economies.

In this regard the N.S.W. Department of Environment and Planning has developed specialised hazard analysis techniques which fully account for the considerations outlined above. The steps involved in application of these techniques are described schematically in figure 3, Dynamic Transport Risk.

Figure 3 **DYNAMIC TRANSPORT RISK**



Examples of the application of these techniques to transport implemented by the Department include "The Kurnell Transportation Study", N.S.W. Department of Environment and Planning, 1986, (12) and "Dangerous Goods Truck Routes in the Surrounds of Port Botany", N.S.W. Department of Environment and Planning, (Unpublished). (13)

It should be noted that the main purpose of the Port Botany study was not to determine risk levels along each route but rather to compare the safety implications of each route as an input into the overall route selection process and then rank the routes in terms of relative risks.

On that basis a mathematical derivation for selecting preferred routes (suitable for computer simulation) is detailed in Appendix A, Route Comparison.

The method adopted could be further refined to evaluate the risk more accurately along a particular route, as in the case for the Kurnell Transportation Study where such accurancy was required to pinpoint major risk contributors and formulate priorities for road upgrading works.

7. Computer Simulation and Hazard Analysis

The hazard analysis techniques, developed by the Department for selecting preferred routes for the transportation of dangerous goods tankers are ideally suited to simulation by computer. In this section the simulation model developed for the Port Botany Study is generally described. For ease of explanation we have described the Port Botany model as schematically represented in Figure 3, Dynamic Transport Risk. More detail is given using transportation of petrol tankers as a worked example, (see Appendix B, Petrol Tanker Analysis).

7.1 Hazard Identification

(i) Feasible routes

It was considered appropriate that all arterial/sub-arterial routes in the study area (as defined by the Sydney Road Hierarchy Plan) which provide relatively convenient access between Port Botany and the major roads external to the study area, were potential dangerous goods truck routes. This was also scrutinized by responses from 24 companies/operators within Port Botany associated with the production, storage and transport of dangerous goods. Responses covered areas relevant to:

- weekly movements and total number of vehicles carrying dangerous goods;
- type of vehicle and class of dangerous goods transported (i.e. material and quantity);

- transport routes presently used by type of vehicle and the reasons for travelling these routes;
- transport operational costs;
- accident history since 1975;
- safety precautions which are currently and/or planned for the transport of dangerous goods.

Analysis of responses showed a total of 210 vehicles transporting dangerous goods arrived at Port Botany on an average week. During the same period, some 1535 vehicles transported dangerous goods away from Port Botany. Of these, about 65 percent carried flammable liquid (e.g. petrol) whilst only 6.5 percent of vehicles carried liquified flammable gas (e.g. LPG).

In all, dangerous goods truck movements represented approximately 9.3% of all truck movements and 0.08% of all vehicle movements.

(ii) <u>Incident Scenarios</u>

Analysis of vehicle type, materials and quantity transported led to a number of simplifying and conservative assumptions.

Firstly, all materials were broadly classified into 3 groups or representative loads. By representative load it was assumed that the physical and chemical properties of petrol are typical for all flammable liquids, that LP Gas is typical for all liquified flammable gases and chlorine typical of all toxic gases. It should be noted that the carriage of petrol, LP Gas and chlorine in any case represents more than 88% of all dangerous goods movements in the surrounds of Port Botany.

Secondly, only articulated rigid tankers were considered.

Finally surveys of incidents involving petrol tankers, LPG tankers and chlorine tankers were analysed to identify incident scenarios and relevant frequencies of release. These incidents were then subject to fault/event tree principles to give the event trees shown in Figures 4, 5 and 6 for petrol tanker accidents, LPG tanker accidents and chlorine tanker accidents.

Incident surveys analysed included "Severity of Transportation Accidents" (Clarke, Foley, et al., 1976) (16), "Risk Assessment of future LPG facilities in New Zealand" Liwuid Fuels Trust Board, prepared by TNO (1984), (8) and Energy, 1984), and the "California Tank Truck Accident Survey" California Highway Patrol, (1981) (2).

7.2 <u>Probability Analysis</u>

Information on road accidents are compiled by the Traffic Authority of New South Wales. The number of truck accidents per annum for each route segment was obtained from the Traffic

FIGURE 4. EVENT TREE FOR PETROL TANKER ACCIDENT

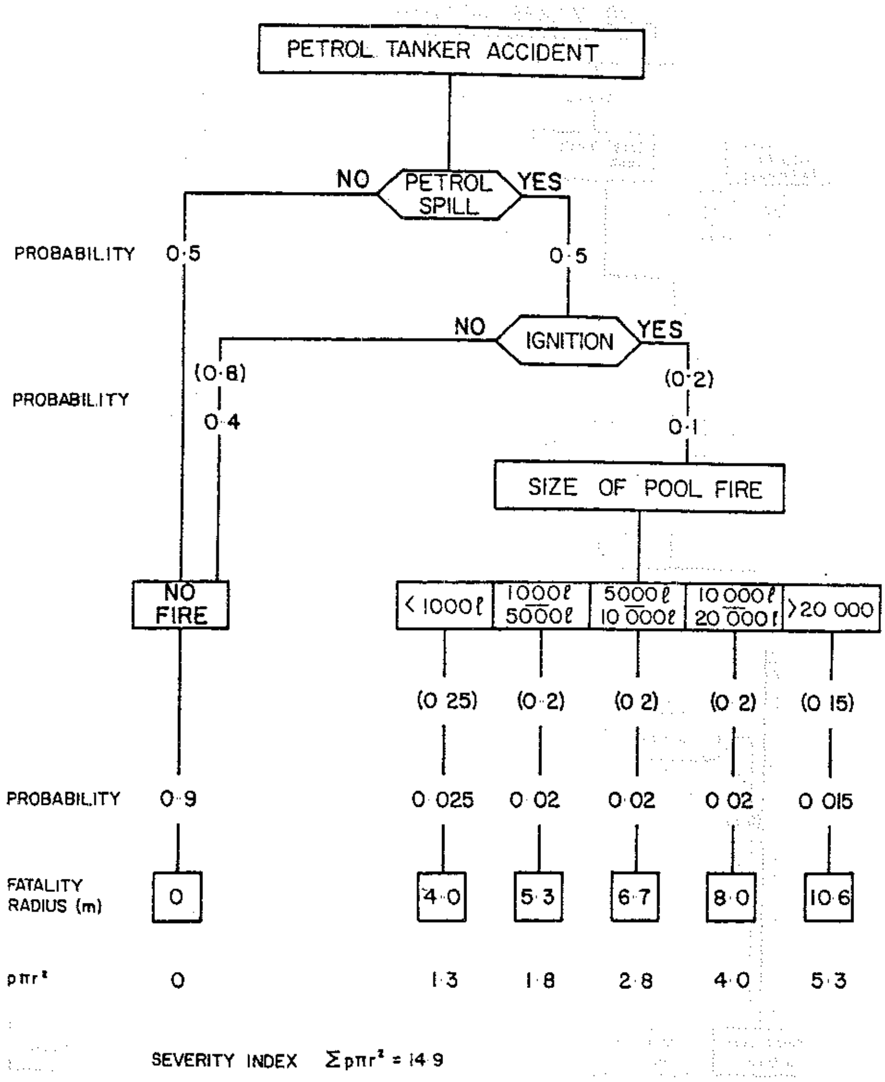
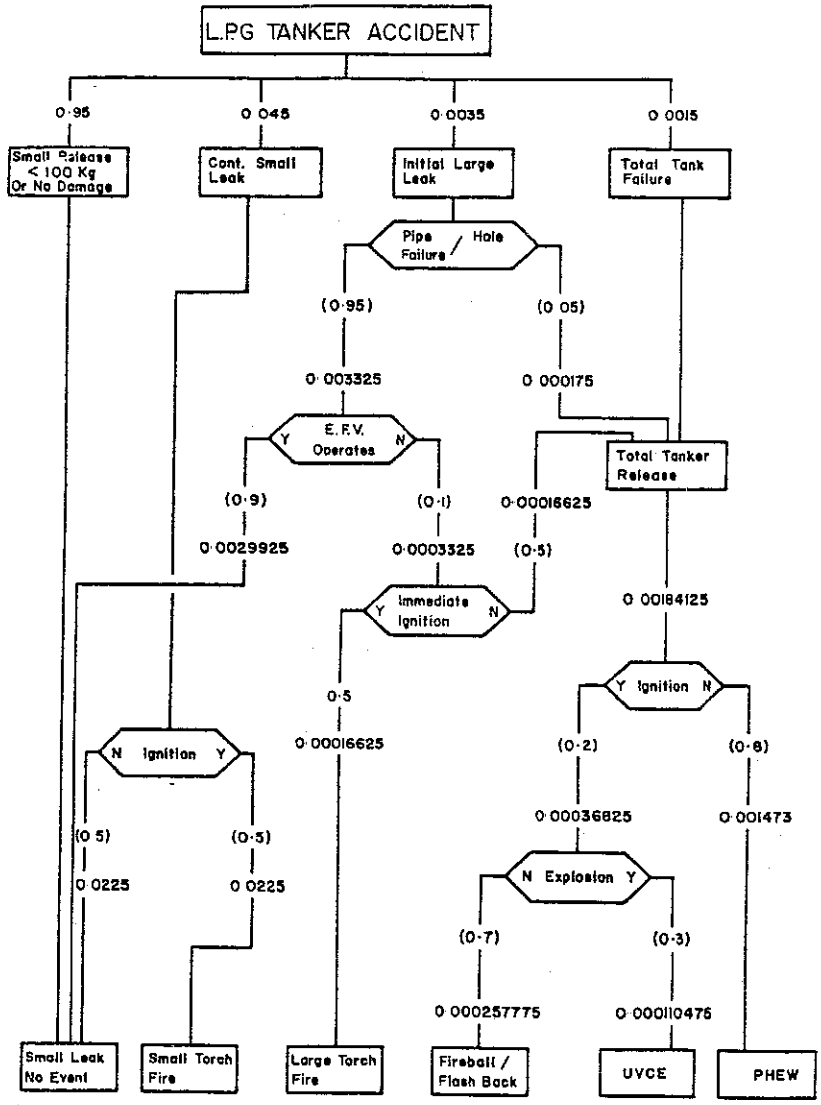


FIGURE 5. EVENT TREE FOR LPG TANKER ACCIDENT



Probability	0·9754925	0 0225	0 00016625	0 000257775	0·000110475	0 001473
Fatality Radius (m)	0	12 2	63	60	75	0
$\rho\pi r^2$	0	10·5	2·1	2·9	2 0	0

SEVERITY INDEX $\Sigma \rho\pi r^2$ = 17 5

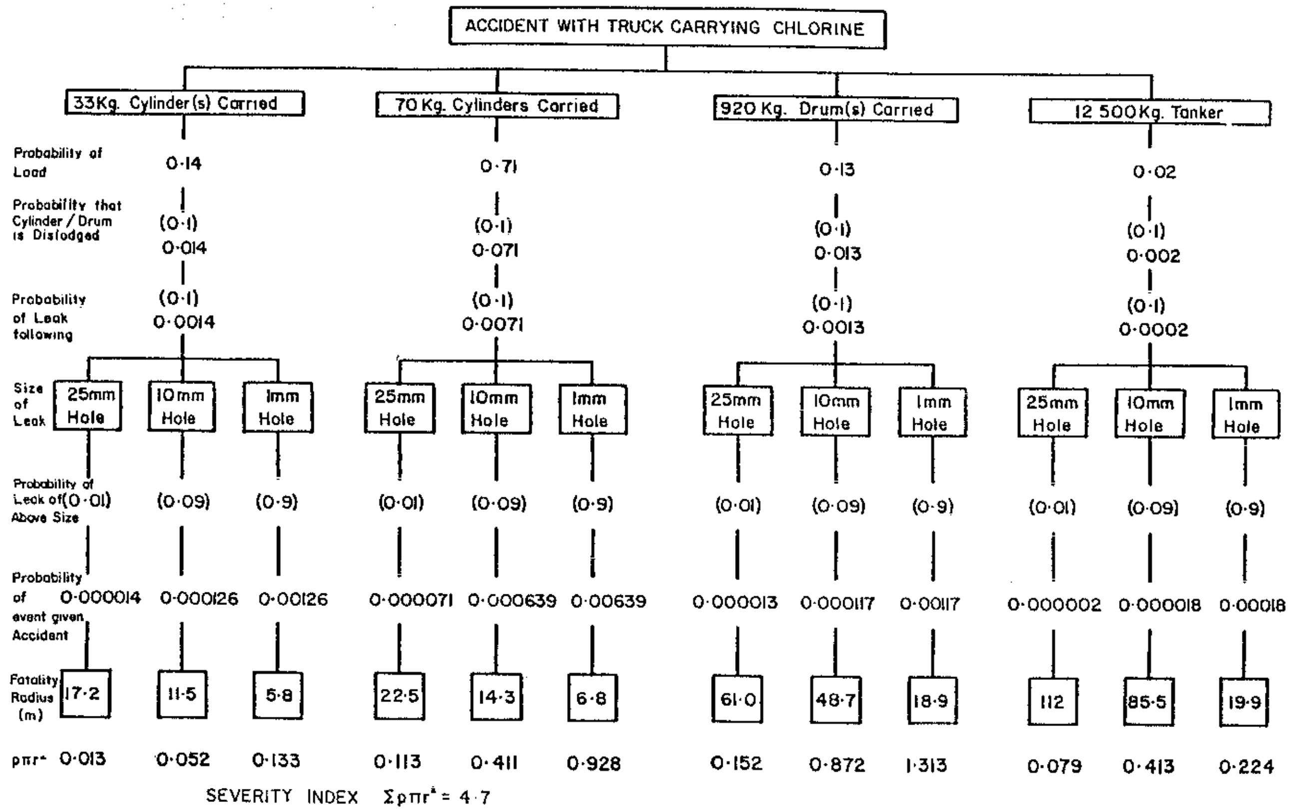


Figure 6 EVENT TREE FOR ACCIDENT WITH TRUCK CARRYING CHLORINE

Authority for the years 1979 to 1985 inclusive and the mean number per annum determined. Where the route sub-segments were shorter than the segment for which accidents were recorded and number of accidents was scaled allowing for traffic density and sub-segment length.

The total number of trucks passing along a route segment in any year may be estimated from the average annual daily traffic $(AADT_i)$ and the ratio of trucks to total traffic (TTT_i)

$$\text{Number of trucks/annum} = (TTT)_i \times (AADT)_i \times 365$$

The probability of a truck accident (pai) for any truck passing passing segment i

$$= \frac{(TA)_i}{(TTT)_i \times (AADT)_i \times 365}$$

In the absence of detailed data $TTT_i = 0.08$ (i.e. 8% of the total traffic is trucks) has been used for all route segments and is consistent with the results of screen line surveys conducted on behalf of the Department.

These accident probabilities from the top or initiating event in each event tree model.

7.3 Consequence Analysis

The consequence of each accident scenario was estimated using well established calculation methods. Based on such estimates and the mean population densities for land use adjoining each route segment, the number of people affected by the postulated incidents could be determined.

Of course consequences may be measured for population, property or both, by the analyst specifying the level of impact. Effects of heat radiation levels are given in Table 1, Consequences of Heat Radiation. For transport planning purposes the Department adopted a level of 12.6 kW/m^2. As can be seen from the table the effect can be fatal to 30% of the outdoor population for continuous exposure.

TABLE 1 CONSEQUENCES OF HEAT RADIATION

Heat Radiation (kW/m^2	
1.2	Received from the sun at noon in summer
2.1	Minimum to cause pain after 1 minute
4.7	Will cause pain in 15-20 seconds and injury after 30 seconds exposure (at least second degree burns will occur).
12.6	. 30% chance of fatality for continuous exposure. High chance of injury. . Cause the temperature of wood to a point where it can be ignited by a naked flame after long exposure. . Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure.
23	. 100% chance of fatality for continuous exposure to people and 10% chance of fatality for instantaneous exposure. . Spontaneous ignition of wood after long exposure. . Unprotected steel will reach thermal stress temperatures to cause failure . Pressure vessel needs to be relieved or failure would occur.
35	. Cellulosic material will pilot ignite within one minute exposure. . 25% chance of fatality if people are exposed instantaneously.
60	. 100% chance of fatality for instantaneous exposure.

Similarly effect levels for explosion overpressure and toxic gas concentration can be expressed in terms of risk of fatality.

7.4 Risk Assessment

The probability and consequences of an accident were combined to give risk levels along each route segment. These were further cumulatively computed to quantify overall resultant risk levels along each route. Results were in terms of fatality frequency per million tanker movements of dangerous goods for each route being considered. Routes were compared on that basis and the ones with 'least' exposure selected as being acceptable routes.

These acceptable routes were then subject to traffic and economic analysis including:

- Average Annual Daily Traffic Volumes (N.S.W. Traffic Authority).
- Screenline intersection Counts and Field Survey.
- Travel time information.
- Physical and operational characteristics.
- Operating costs, both fixed and variable.

As part of the route selection process.

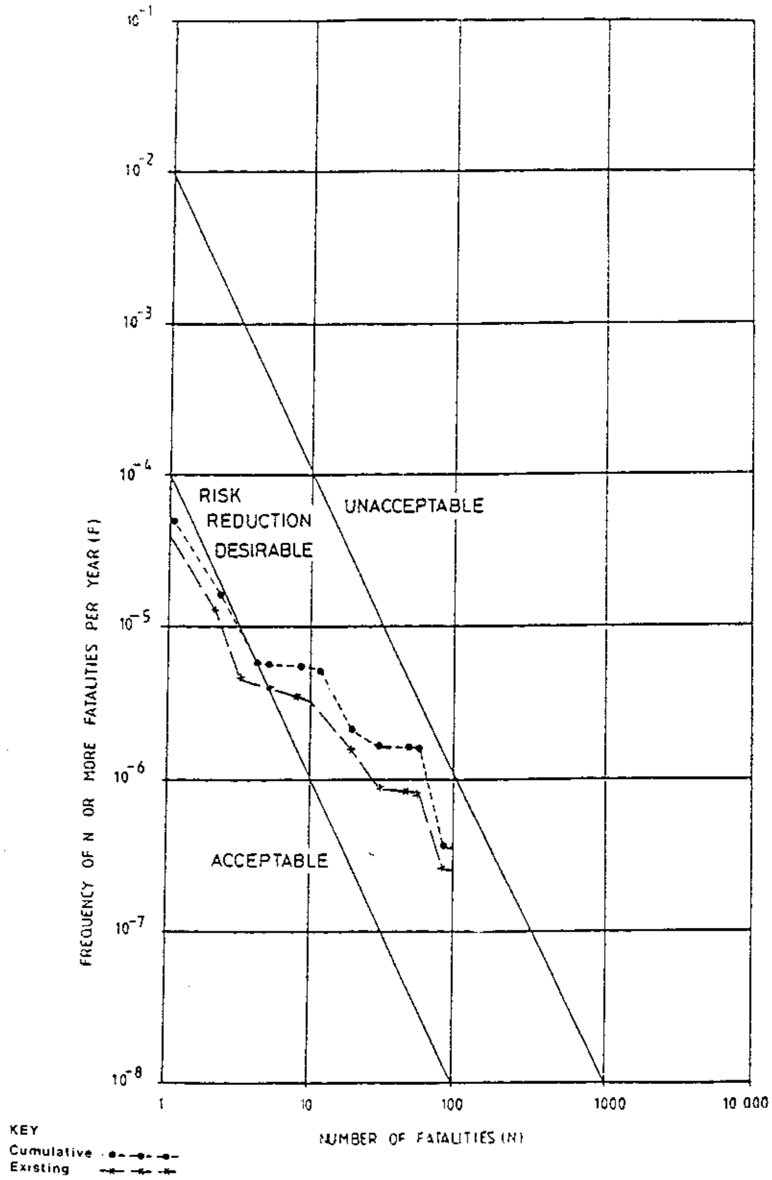
In addition to selecting preferred routes for the transportation of dangerous goods the Department can isolate the principal sources of risk using a recently acquired computer simulation package known as the SAFETI package. The package comprises a suite of over 80 individual programs for the calculation of risk levels using Quantified Hazard Analysis and Risk Assessment Techniques. The Department is one of four public authorities in the world utilizing the package to resolve land use safety conflicts through the minimization of risk levels.

As a direct application of the package the Department has formulated risk reduction options by way of road upgradings for the Kurnell Transportation Study. Figure 7, "Kurnell Transport Safety Societal Risk Levels" depicts the risk levels for the existing dangerous goods movements and the cumulative effects of an increase in dangerous goods movements due to new developments.

8. Conclusion

This approach to finding the appropriate balance between the need for the use, storage and transport of hazardous materials and land use and environmental safety, that is determining whether costs should be borne as incident and risk costs or safety measures and who should bear them, is relatively new. The

Figure 7 KURNELL TRANSPORT SAFETY SOCIETAL RISK LEVELS



application of the approach to fixed plant and to flammable liquids and gases and materials with acute toxicity effects on people are relatively well developed. The application to transport, to non-acute toxicity and to impacts on the bio-physical environment are less well developed. The Department in applying it to these areas has developed new techniques and extended and adapted others.

While development and refinement is on-going, we have found the approach to be extremely useful and very cost effective in terms of staff resources in the hazard control process. The methodology is particularly useful for comparison of the cost effectiveness of measures and for identifying particular component contribution to risk so that measures can be applied which have the greatest effect with the least control measure costs.

The hazard and safety aspects of any decisions on transport or plant development are of course only part of the total context in which these decisions must be made and the hazard analysis and risk assessment methodology should be regarded as providing an input to the decision making process. One of the advantages of the approach is that it allows flexibility to deal with particular cases on their merits rather than applying blanket controls.

In this regard it is important not to adopt rigid risk criteria. It is also important that the concept of acceptable risk should not be twisted to suggest that low risk levels should be allowed to rise, that operations should be allowed to become less safe. A principle applied by the Department is that regardless of the level of risk shown, avoidable risk should be avoided, e.g. if a safer alternative process or material is available at reasonable cost then it should be used.

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Appendix A ROUTE COMPARISON

Each of these routes has been broken into sub-segments for which information on land use, and accident frequency, is known.

Thus if one considers the movement of a truck carrying dangerous goods along a route :

For each sub-segment i of the route there is a probability of the truck being involved in an accident p_{ai}

For each accident there are a number of possible accident scenarios (S_j) each of which may be considered to be fatal to individuals present within a radius r_j - of the accident with a probability p_{sj}.

The number of people present and affected at the scene of an accident depends on the population density ρ_i

$$= \pi r_j^2 \rho_i$$

Thus if one considers the passage of a truck through a route segment i the probability of some one being killed for scenario j is.

$$= p_{ai} \times p_{sj} \times \pi r_j^2 \rho_i$$

The probability of someone being killed from the passage of the truck along the sub-segment i is the sum of the probabilities for all possible accident scenarios

$$\text{ie} \quad \sum_j p_{ai} \, p_{sj} \, \pi r_j^2 \rho_i$$

$$= p_{ai} \rho_i \sum_j \pi r_j^2 p_{sj}$$

Now for any type of load the term $\pi r_j^2 p_{sj}$ is a constant independent of the route.

We have called this the Severity Index, SI, for the load.

Thus the probable number of fatalities from the passage of a truck carrying load L along subsegment i

$$= p_{ai} \rho_i (SI)_L$$

The probable number of fatalities from the passage of a truck carrying load L along a given route is

$$= \sum_i p_{ai} \rho_i (SI)_L$$

$$= (SI)_L \sum_i p_{ai} \rho_i$$

It is thus possible to assess the relative safety of two alternate routes by comparison of the term $\sum p_{ai} \rho_i$ for each alternative route.

Appendix B PETROL TANKER ANALYSIS

A survey of incidents involving petrol tankers reported by the Chief Inspector of Inflammable Liquids, Victoria has shown that fuel is released in 50% of the accidents and that a fire ensues in 20% of the accidents when fuel is released.

The distribution of the fuel spillage is

- 25% < 1000 litre
- 20% 1000-5000 litre
- 20% 5000-10000 litre
- 20% 10000-20000 litre
- 15% > 20000 litre

In "Severity of Transportation Accidents" it is indicated that a fuel spill of 250 US gal distributes over an area of 125 ft^2, 500 gal over 200 ft^2, and 10000 gal over 500 ft^2.

It is thus estimated that a pool fire from a 1000 litre spill will be 3m diameter, from a 1000-5000 litre 4m, 5000-10000 litre 5m, 10000-20000 litre 6m, and > 20000 litre 8m in diameter.

Further it is assumed that 100% fatalities will occur within the radius where the intensity of radiation from the fire exceeds 12.5 kW/m^2 and no fatalities will occur at lower radiation intensities. (Note that in most cases the area will be evacuated before the fire reaches full intensity and the use of lower levels of radiation eg 4.7 kW/m^3 which most people can survive, if only for a few seconds, will grossly over estimate the number of fatalities. Further information on the effects of heat radiation are summarised in TABLE 1").