RISK ASSESSMENT OF SHIPPING ACCIDENTS IN GREAT BARRIER REEF WATERS: by Maurice K. James, Department of Civil and Systems Engineering, James Cook University of North Queensland

ABSTRACT

The concepts, motivation and limitations of the objective assessment of risk are discussed, with reference to the problem of planning a response to marine spills of dangerous chemicals in the Great Barrier Reef region. The role to be played by an assessment of the probabilities and geographical distribution of shipping accidents is outlined. A method is discussed, based on the Monte Carlo simulation of fault-trees, for the estimation of these probabilities.

# 1. INTRODUCTION

The emerging discipline of risk analysis is motivated by the belief that an objective quantitative assessment of risk is a necessary input to the processes of project design, project evaluation, and planning for response to system failures (e.g. accidents) with undesirable consequences (such as spills of hazardous materials in coastal waters).

In project design and evaluation, risk analysis is concerned with the problem of risk reduction, and the achievement of a level of 'acceptable' risk. In planning response to system failure, one objective is to minimize the undesirable consequences of that failure. The nature and level of preparedness for that response should be consistent with the nature, level and distribution of risk associated with the particular system or activity involved.

## 1.1 Definition of Risk

The problem of risk is centred on people and their fears of loss or injury (Clark, 1979). 'Risk' is a loosely defined term which has at least two characteristics - the probability of an event, and its associated magnitude or severity (Pearce, 1981; Less, 1981; Dunster and Vinck, 1979). Everyday perceptions of hazards usually involve a qualitative combination of these two characteristics, so that risk is perceived as a composite entity with a general dimension ranging from negligible to severe.

The 'objective' assessment of risk is the process of estimating the probabilities and (physical) consequences of events, often by extrapolation from the frequencies of past occurrences of the event itself. Less tangible is the process of risk 'appraisal' in which the 'severity' of the consequences is evaluated. In most cases this evaluation cannot be carried out within the involvement of human values and emotions (Lee, 1981; Pearce, 1981).

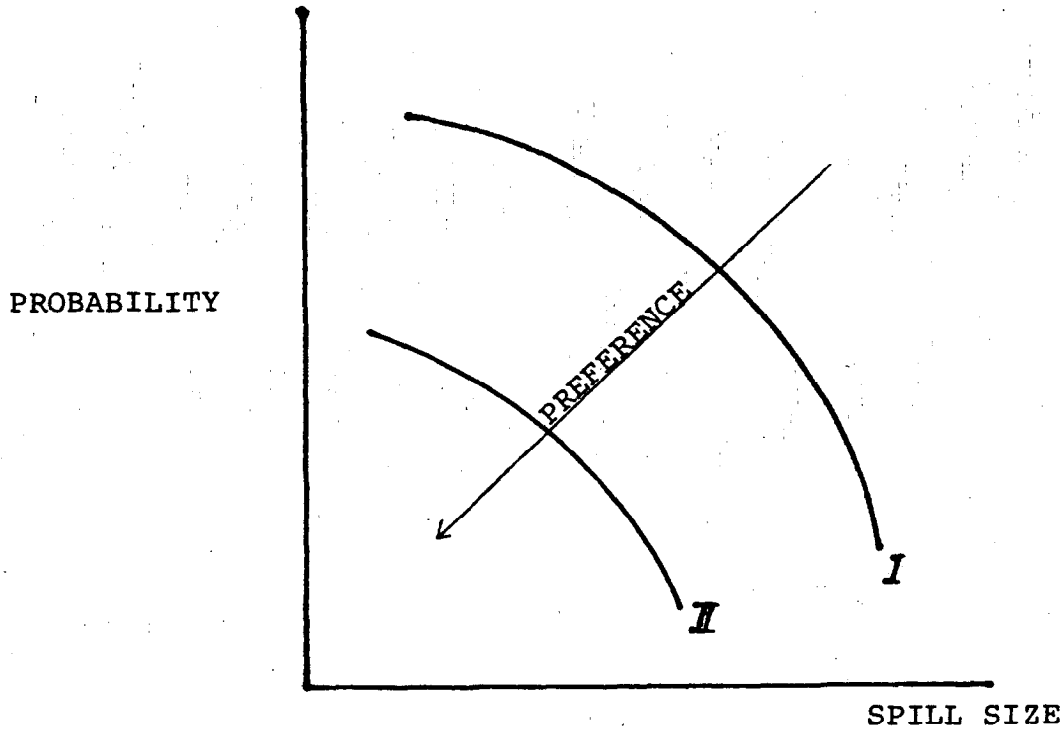


Figure 1
RISK PREFERENCE CURVES

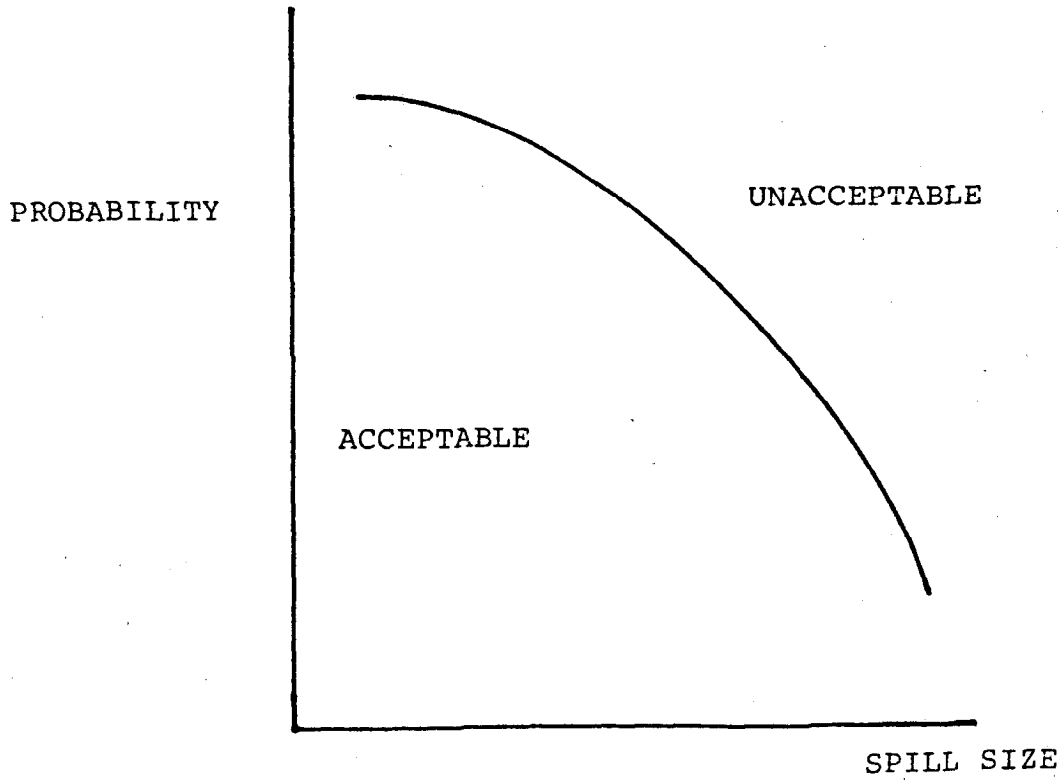


Figure 2
FARMER CURVE - LIMIT OF ACCEPTABLE RISK

The value of objective risk assessment as a direct input to decision-making at the highest level can therefore be seriously diminished in situations where these less tangible issues are important (especially, for example, when danger to life is involved).

## 1.2 Risk Assessment and the Concept of 'Acceptable' Risk

The risks accepted by people show a wide range of types and probabilities which can be discussed in terms of risk preference curves (Pearce, 1981). For example, points on curve 1 in Figure 1 represent combinations of probability and spill size which an individual perceives as equally acceptable. Points on curve II are also equally acceptable, but are perceived to be more acceptable than points on curve 1. The Farmer Curve (Henley and Kumamoto, 1981, p.13) is then defined as the preference curve which divides all possible combinations into disjoint sets of acceptable and unacceptable combinations (Figure 2). A limiting curve of this kind, representing the minimum level of acceptable risk, is used by the UKAEA as a guide for design of new plants and for assessing the safety of existing plants.

Direct applications of the simple approach based on a limiting Farmer curve has been strongly criticized for a number of reasons. For example, individual preference curves need somehow to be aggregated to form societal preference functions, a procedure which may not, in fact, be logically possible (Pearce, 1981). Secondly, the position of a particular combination on the (probability, consequence) plane of Figures 1 and 2 implies little concerning the desirability of the project since it involves no comparison between benefits and costs.

Pearce (1981) argues that the "concept of an 'acceptable' risk is without proper meaning unless benefits are known", and suggests that the costs implied by the necessity to accept risk should be treated as an additional component in a thorough cost-benefit analysis. Dunster and Vinck (1979) suggest that risk be divided into three classes:

(1) unacceptable: risk is too high whatever the benefit to society;

(2) potentially acceptable: benefits might justify therisk could be further reduced at 'reasonable' cost;

(3) acceptable: benefits justify the risk,and the level of risk has been reduced to the point where further reduction would cause a decrease in net benefit.

## 2. RESPONSE TO HAZARD

In planning the response to an event such as the spill of a hazardous chemical in the GBR region, the system under consideration (Figure 3) can be subdivided into two parts:

- the marine transportation system;
- the response mechanism

### 2.1 Benefits and Costs

Operation of the transportation system generates benefits which can mainly be measured fairly readily in monetary terms. It also implies costs, one of which is associated with the risk of damage to the reef system by accidental or deliberate spills of dangerous chemicals.

The response to this hazard operates in a number of ways:

- by taking steps to reduce the probability of spill events (e.g. by regulating traffic; by providing navigational aids, etc.);
- by action, in the event of a spill, to minimize the severity of the consequences (e.g. by containment; by removal; by dispersal etc.);
- by establishing scientific monitoring activities so that understanding of environmental impacts can be improved.

Thus while the response mechanism involves establishment, maintenance and operating costs, it should also generate benefits in terms of reduction of risk (in both dimensions) and improved assessment of future risks.

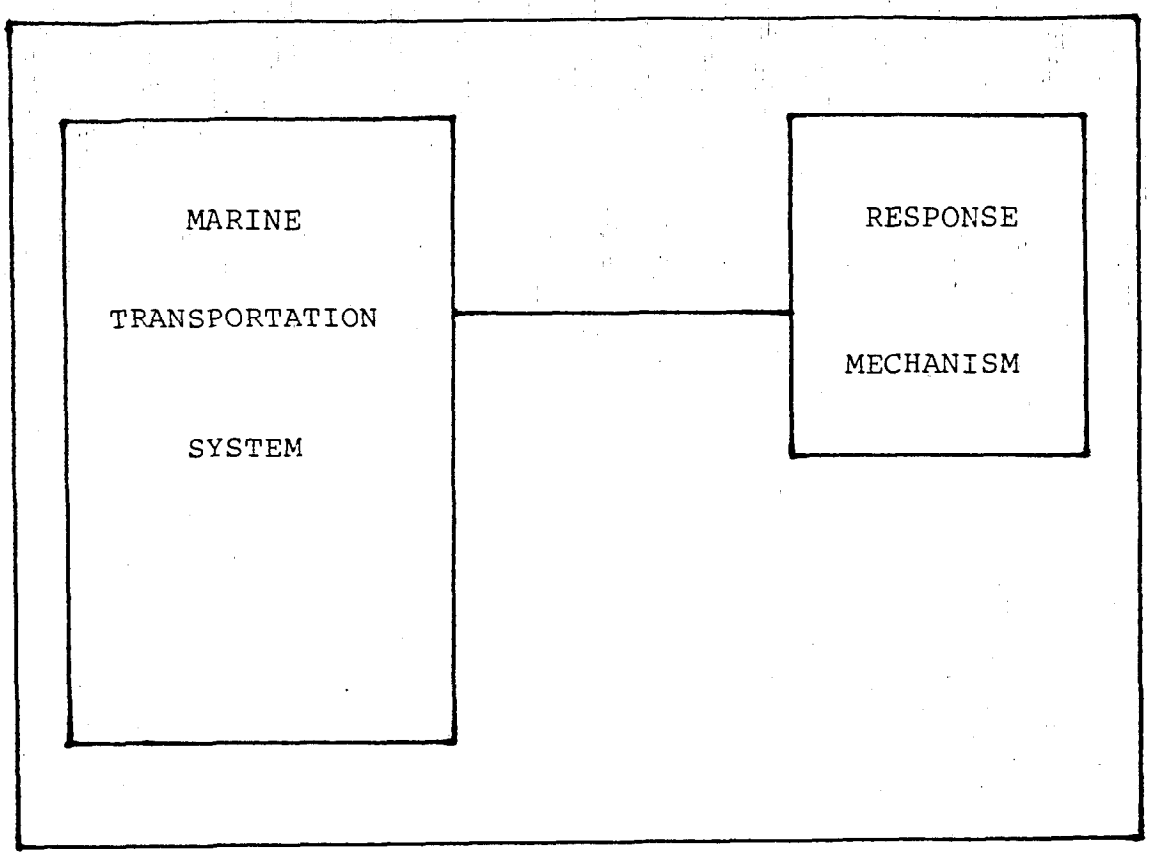


Figure 3

Total system considered in Planning for Response

## 2.2 The Role of Objective Risk Assessment

Figure 4 illustrates the role which might be played by objective risk assessment in the development of a planned response. It also illustrates the scope of current research by the author. The scheme is iterative.

In the first iteration, the likely occurrences of accidents under existing traffic management systems, and the likely consequences under the existing response mechanism (e.g. the National Plan) are estimated. These consequences are appraised and possible improvements in the response mechanism are determined. The iterations would then be repeated until no further improvement in net benefits could be made.

Current research is concerned with estimating the probability of shipping accidents (collisions and groundings) in Great Barrier Reef waters, and the distribution of that risk over the region; that is, the relative likelihoods of accidents at different locations. This will result in risk distribution maps as illustrated in Figure 5 (preliminary results only).

Later, these accident statistics will be used to determine the probabilistic geographical distribution of spills to provide input to:

(1) Spill trajectory models for the determination of impact zones
(2) Logistic analyses to plan the location and mobilization of materials, equipment and personnel for both protective and scientific responses (e.g. Charnes et al, 1979).
(3) Reliability analyses of the response mechanism, so that different response plans can be evaluated.

## 3. ASSESSMENT METHOD

Objective risk assessment involves estimating the probabilities of future events on the basis of statistical data from past events. This may be purely statistical, based on the frequency of past occurrences of the event itself. Alternatively, it may employ an aggregation of the probabilities of the chain of events which lead to the accident (Lee, 1981). The latter may be the only rational approach when there are virtually no past records (as applies for shipping accidents in GBR waters).

### 3.1 Shipping Accident Statistics

Very few serious shipping accidents have been recorded in GBR waters. Consequently there is no statistical base which could be used to estimate probabilities of accidents.

Several major compilations and analyses of shipping accident data have been made for other parts of the world (e.g. Drager, 1980; Grimes, 1972). Grimes has analysed data for 10 years' shipping operations in N.W. European waters and has fitted probability distributions to the accident occurrences. Drager reports on a very comprehensive analysis of casual factors reported for approximately 3000 shipping accidents in Norwegian waters.

The extent to which analyses such as that of Grimes can be used to assess risks in Australian waters is very dubious. It involves an extrapolation in both time and space which would be extremely difficult to justify. In addition it could hardly be used to help achieve the objective of a probabilistic geographical distribution of risk in the region.

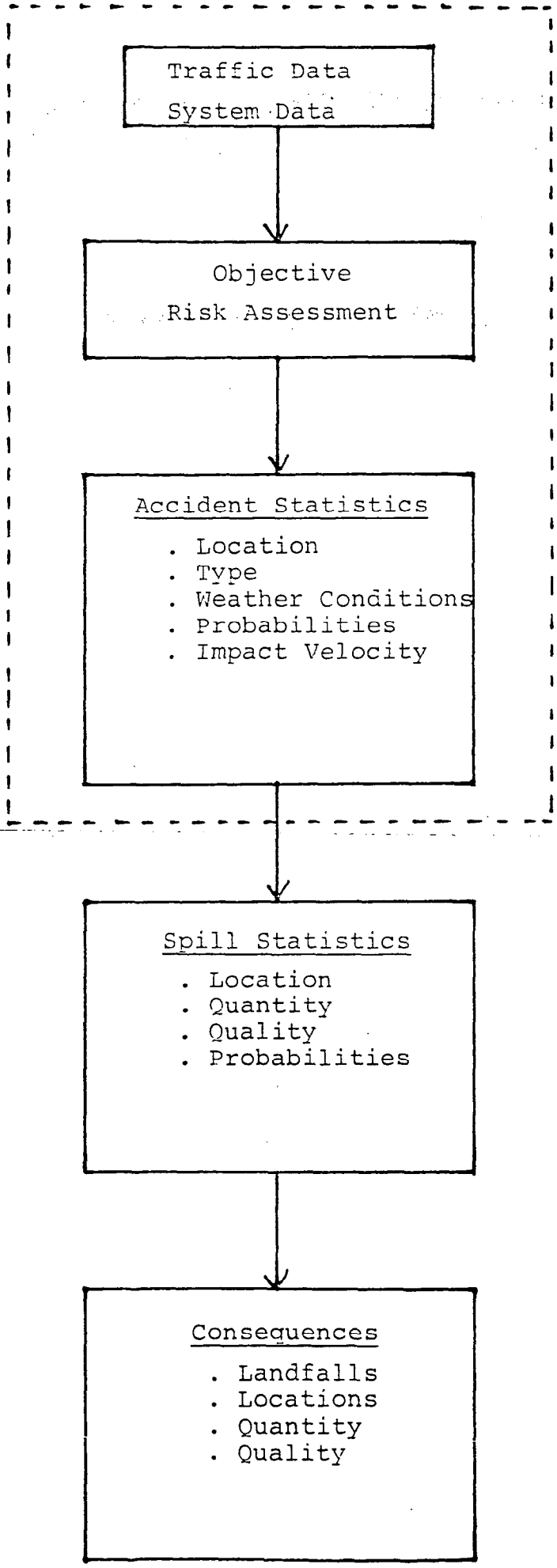


Figure 4(a)

Objective Risk Assessment

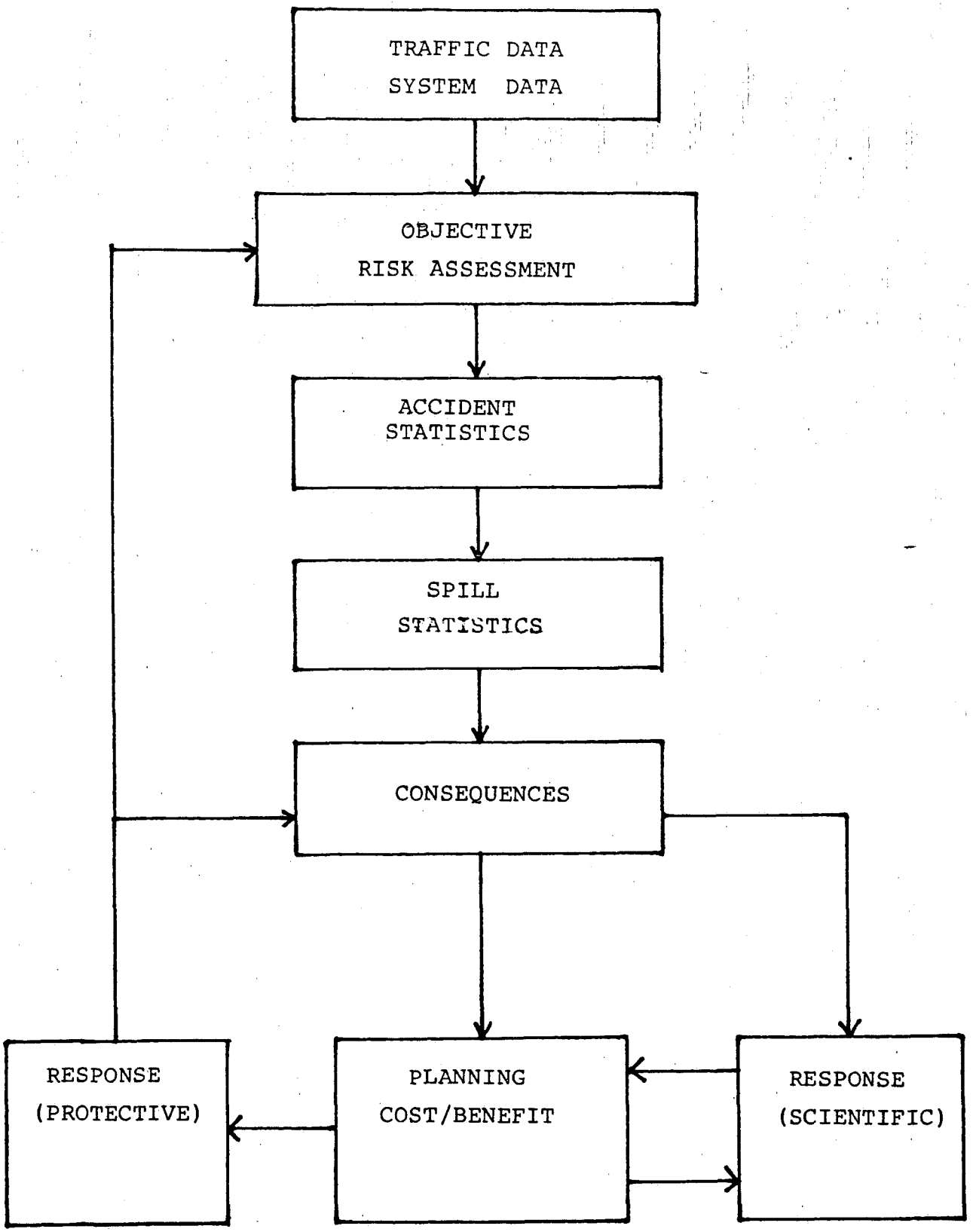


Figure 4(b)

Planning for Response

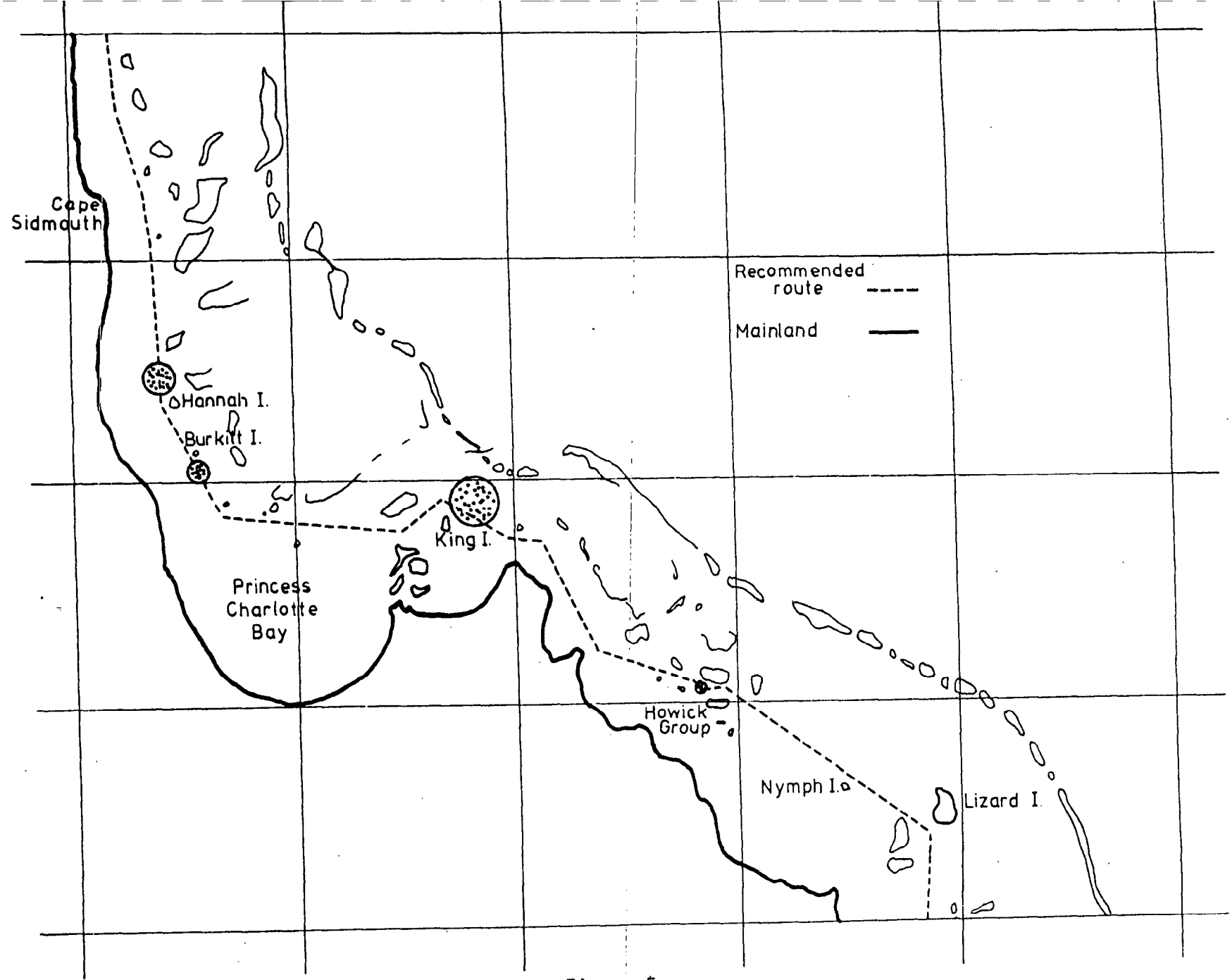


Figure 5.

Relative likelihoods of grounding incidents.

On the other hand the results of Drager's analyses could well find application in guiding a less empirical approach to risk assessment which is described below. This approach should be able to take account of both local conditions and changing navigation technology.

## 3.2 Modelling for Risk Assessment

The approach currently under development involves the mathematical modelling and computer-based simulation of the navigation of ships and of the collusion process which takes place between ships and fixed obstacles such as reefs, offshore structures, etc. The approach is illustrated in Figure 6.

The model allows important casual factors to be taken explicitly into account, such as: environmental conditions (e.g. poor visibility); mechanical conditions (e.g. steering failure); human error (e.g. positioning errors, mismanoeuvres, navigation errors). The stochastic nature of casual events is also explicity recognised and simulated by the Monte Carlo technique based on the generation of random variables within the computer program.

The advantage of this approach is that very many years' shipping experience can be simulated and a large number of potential accident situations analysed so that valid statistical estimates of probabilities can be made.

### 3.2.1 Navigation Model

The study region for the current project is shown in Figure 7. Details of the region, including water depths, the location of reefs and navigational aids, are stored in digitized form in the computer. The position of a ship at any time is also stored.

Ships are navigated through sequences of target points at which course changes are made (Figure 8). Depending on external conditions (e.g. wind, current, visibility) and the reliability of steering gear and compass, the actual course made good can differ significantly from that desired, and this stochastic effect is modelled.

In the simulation, navigation is represented by a sequence of events and state changes such as: course changes, course corrections, weather changes, gear failures, encounters with other vessels. At each event, the position of the ship is updated, and the time at which the next event will occur is randomly determined.

### 3.2.2 The Encounter Model

If, during operation of the navigation model, two ships come within some specified distance of each other, or a ship comes within some specified distance of a reef, the outcome of this encounter is determined by the encounter model.

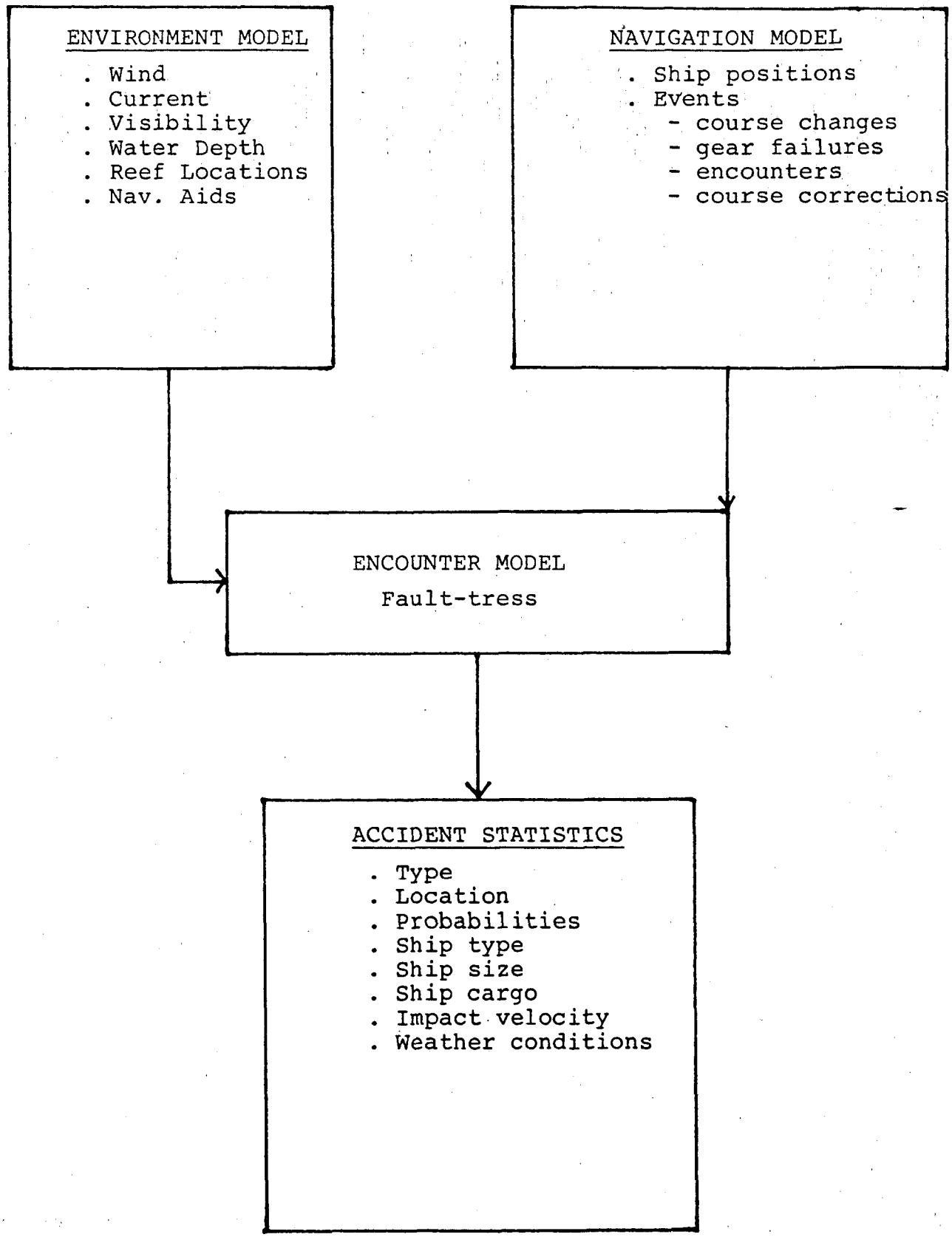


Figure 6

Model Structure

The outcome depends in a complex way on the interaction of a (possibly large) set of casual factors. Conceptually, the model is based on the method of fault-tree analysis first developed in the early 1960's for the U.S. Air Force (Henley and Kumamoto, 1981). A simple example is illustrated in Figure 9. The accident appears as the top event and is linked to more basic fault events by various logic gates. The idea is that an accident occurs when one or more basic failures occur, enabling a casual path which leads to the accident. If the top event can be traced back to basic failures whose probabilities are known, then the probability of the top event can be readily computed.

The basic events may be of three types:

(1) events related to human beings (e.g. incorrect interpretation of a navigational aid);

(2) events related to hardware (e.g. failure of a gyro compass);

(3) events related to the environment (e.g. failure of visibility).

In the simulation, the determination of a failure event is achieved stochastically by Monte Carlo sampling. For example, suppose at a particular point in an encounter, a course change is required, and the steering gear is known to be 98% reliable. A uniform random number is generated in the interval (0,1). If its value falls between .98 and 1.0, then the steering gear is determined to have failed at that point.

The structure and detail of the fault tree must, of course, be consistent with the data available. This investigation is currently in train, with heavy reliance on the analytical results of the project reported on by Drager (1980).

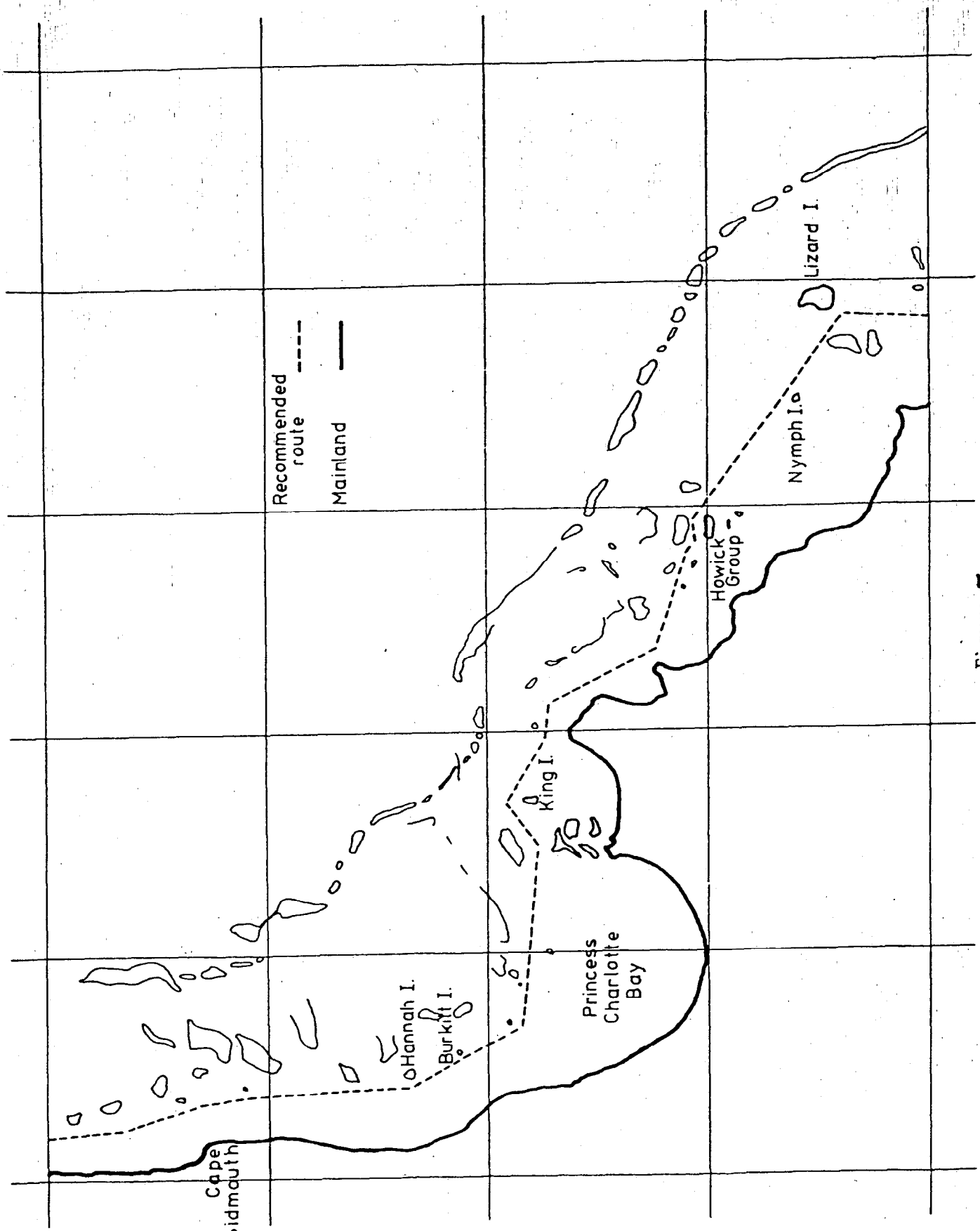


Figure 7.

Study Area.

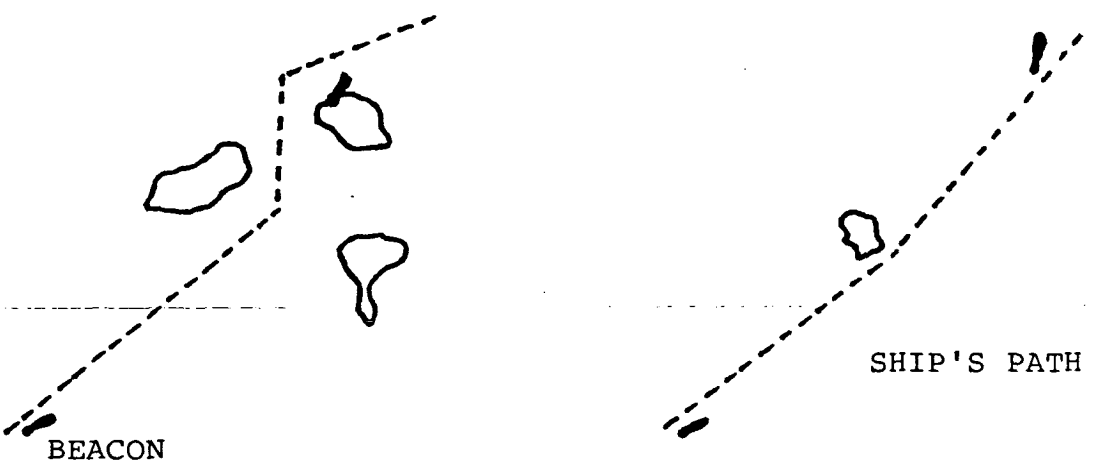


Figure 8

NAVIGATION PROCESS

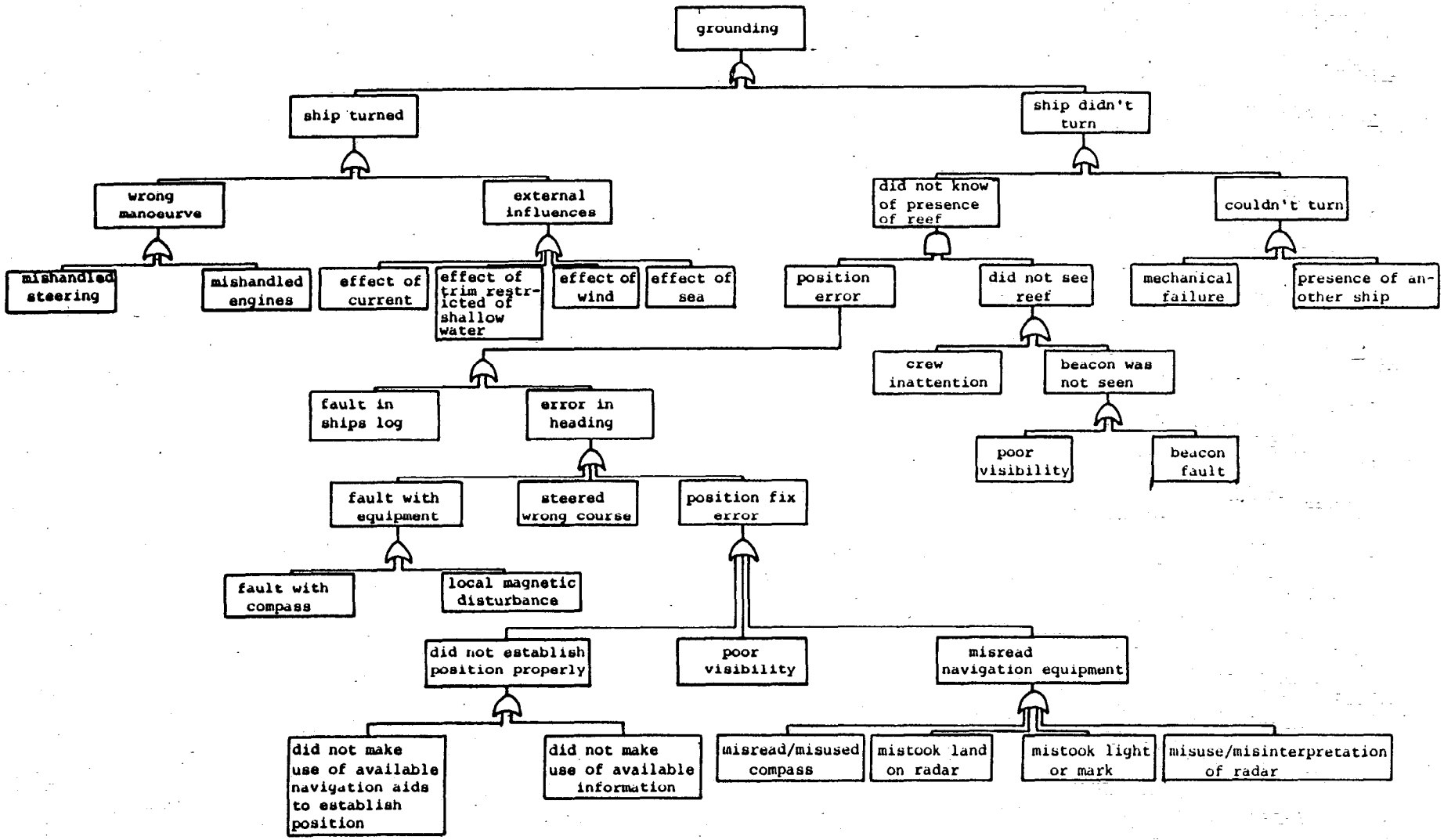


Figure 9

Fault-Tree Example

### 3.3 Validation

The risk assessment model will be generalized, in the sense that it will be readily adapted to any particular region. The methodology can only be validated by implementing and testing the model for some region for which significant historical data exist. It may be possible, at a future stage of the research program, to perform this validation task by applying the model to shipping in Norwegian waters, in collaboration with Det Norske Veritas.

## 4. CONCLUSION

Development has commenced of a method for the objective assessment of shipping risk in Great Barrier Reef waters. The method will yield an estimate of the probabilistic geographical distribution of the risk of collisions and groundings. This will complete the first phase of an overall approach to the development of a planned response to accidental spills of hazardous chemicals.

## 5. ACKNOWLEDGEMENTS

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