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Collision Avoidance at Sea and on a Marine Radar Simulator Using Automatic Encounter Detection Techniques

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A thesis submitted to the Council for National Academic Awards in partial fulfilment of the requirements for the Degree of Doctor of Philosophy.

The research programme was completed at the Polytechnic of North London sponsored by the Science and Engineering Research Council in collaboration with the Department of Trade and Industry.

Declaration

No part of this thesis has been submitted for any other degree at any other institution.

While registered as a candidate for the degree of Doctor of Philosophy the author has not been a registered candidate for another award of the CNAA nor of a University.

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Abstract

Considerable interest has recently been shown in the field of marine traffic engineering. Real life data sources made available for maritime studies are often expensive and inconvenient to collect. The marine radar simulator presents the researcher with a relatively inexpensive and readily available source of navigational data. With the improvement of remote vessel traffic monitoring systems the potential for inexpensive real life data analysis is enhanced.

The work of this study has been to allow the analysis of data archived from the Channel Navigation Information Service Automatic Data Processing system (CNIS ADP) installed at St. Margarets Bay Dover using contemporary digital computer graphical facilities, and to compare mariners' behaviour in a real life and simulator collison avoidance situation. For this comparison certain navigational situations known as encounters have been automatically detected using an extension of the Range to Domain Over Range Rate (RDRR) method (Colley et al 1983), referred to as the RDRR+ technique. A statistical comparison has been completed using non parametric techniques.

Collision Avoidance at Sea and on a Marine Radar Simulator Using Automatic Encounter Detection Techniques.

Contents

Chapter One

Review of Previous Work and Project Definition

(1.1.0) Introduction

In this introductory chapter a thorough description of the problem is given in the context of previous work. In essence the project consists of five major sub-study areas, each detailed in separate chapters.

The first sub-area deals with the collection of real life data and the transfer of these data, recorded using computer techniques, onto the main frame computer at the Polytechnic of North London. After transfer these data are examined using contemporary computer graphics facilities, with the development of the necessary graphically interactive software forming the second area of study. As part of the analysis of these data a technique is required which automatically detects specific navigational situations known as encounters. The development of this technique, known as the RDRR+ method, forms a large section of the work and is the third study area. When investigating mariners' behaviour in certain situations the required real life data is quite often scarce. The marine radar simulator presents the researcher with a relatively cheap and readily available source of behavioural data. The fourth area of study deals with the collection of data from a marine radar simulator. The final section is concerned with the comparison of results obtained from the simulator and the real life data software package.

By way of introduction a brief background to maritime research is given followed by details of different research work investigated over recent years which are relevant to this study. These include the distinction between mathematical and simulation models, previous methods used to collect real life navigational data and studies investigating the validity of using a marine radar simulator as a data source representative of real life behaviour. Examples are given of studies using these different data sources and in particular studies which have quantified areas around a given vessel operating within a traffic system. The concept of an encounter is discussed with a view to develop the automatic encounter detection technique.

(1.2.0) Background to Maritime Research.

In general legislation is passed so as to protect members of a community. Laws concerning a particular subject are sometimes passed because dangers and potential threats have been recognised. A recent example of this is the introduction of the compulsory wearing of car seat belts. For this to be introduced there had to be evidence that a large number of injuries in road traffic accidents are a result of passengers being thrown forward from their seats and that if the passengers had been wearing seat belts the number of resulting injuries could be reduced.

In the past recognition of the potential threat and dangers of shipping collisions has been slow. In the 1830s the number of seamen lost due to shipwreck per year was 900. In the so called 'Black January' of 1843, 240 ships were wrecked, and 500 lives were lost within a three week period. The situation reached a critical state by the 1870s when almost 2000 seamen were lost annually.

From 1868 Thomas Grey as head of the Maritime Department took the lead in the development of merchant shipping legislation. By the end of the century the political interest which followed the public interest resulted in the internationally agreed 'Rules for preventing Collision at Sea'. The new legislation was aimed at improving standards of ship construction, preventing ships from sailing in dangerously overloaded conditions (pioneered by Samuel Plimsoll), and raising levels of ship crew competency. As a result of these actions the situation improved and public interest in safety diminished.

It was the loss of the 'Titanic' with 1489 people drowned result of passengers being thrown forward from their seats and that if the passengers had been wearing seat belts the number of resulting injuries could be reduced.

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It was the loss of the 'Titanic' with 1489 people drowned that prompted the first international conference on safety at sea in the winter of 1913-14. There was a second conference in 1929 and a third in 1948 which established the 'Intergovernmental Maritime Consultative Organisation' (IMCO) which has been succeeded by the 'International Maritime Organisation' (IMO). After the war the main area of pressure for improvements in collision avoidance at sea was professionally generated. This gave rise to revisions of the 'International Collision Regulations' at conferences in 1948 (new rules implemented in 1954), 1960 (1965), and in 1972 (1977). Another important development was the introduction of traffic separation schemes.

After the 'Andrea Doria', 'Stockholm' collision in 1956 a number of French, Belgiun and Spanish navigators proposed various schemes for traffic separation. In 1961 British, French and West German Institutes of Navigation combined to form the first working group to establish a plan for the Dover Strait. The plan was implemented through IMCO in 1967.

A succession of accidents, mainly to tankers such as the 'Torrey Canyon' in 1967, has focussed attention on new risks. This most recent interest has been a result of public environmental concern. The collision between the 'Pacific Glory' and the 'Allegro' in 1970 south of the Isle of Wight in which an estimated 600-610 Tonnes of oil was spilt (O'Raithaille and Wiedemann 1980) and caught fire, first alerted the public to the possible hazards in the Channel. On 11th January 1971 the 'Texaco Carribean' and the 'Paracas' were involved in a collision in the Dover Strait followed the next day by the 'Brandenburg' hitting the wreck and sinking and the 'Nikki' again hitting the wreck a month later. These events shocked the public.

The current interest shown in Marine Traffic Research was probably prompted by the disasters in the late 60s and early 70s. This interest has developed so that today the application of current analytical techniques and new technologies has created a discipline which may be considered a branch of Operational Research. The area of work is called 'Marine Traffic Engineering' in many parts of the world or simply 'Marine Traffic Studies'.

The current investigation into maritime vessel behaviour may be divided into two main areas; the investigation into vessel traffic systems and the analysis of individual vessel behaviour. Clearly these two interest categories are interrelated and this is shown in Figure 1.1.

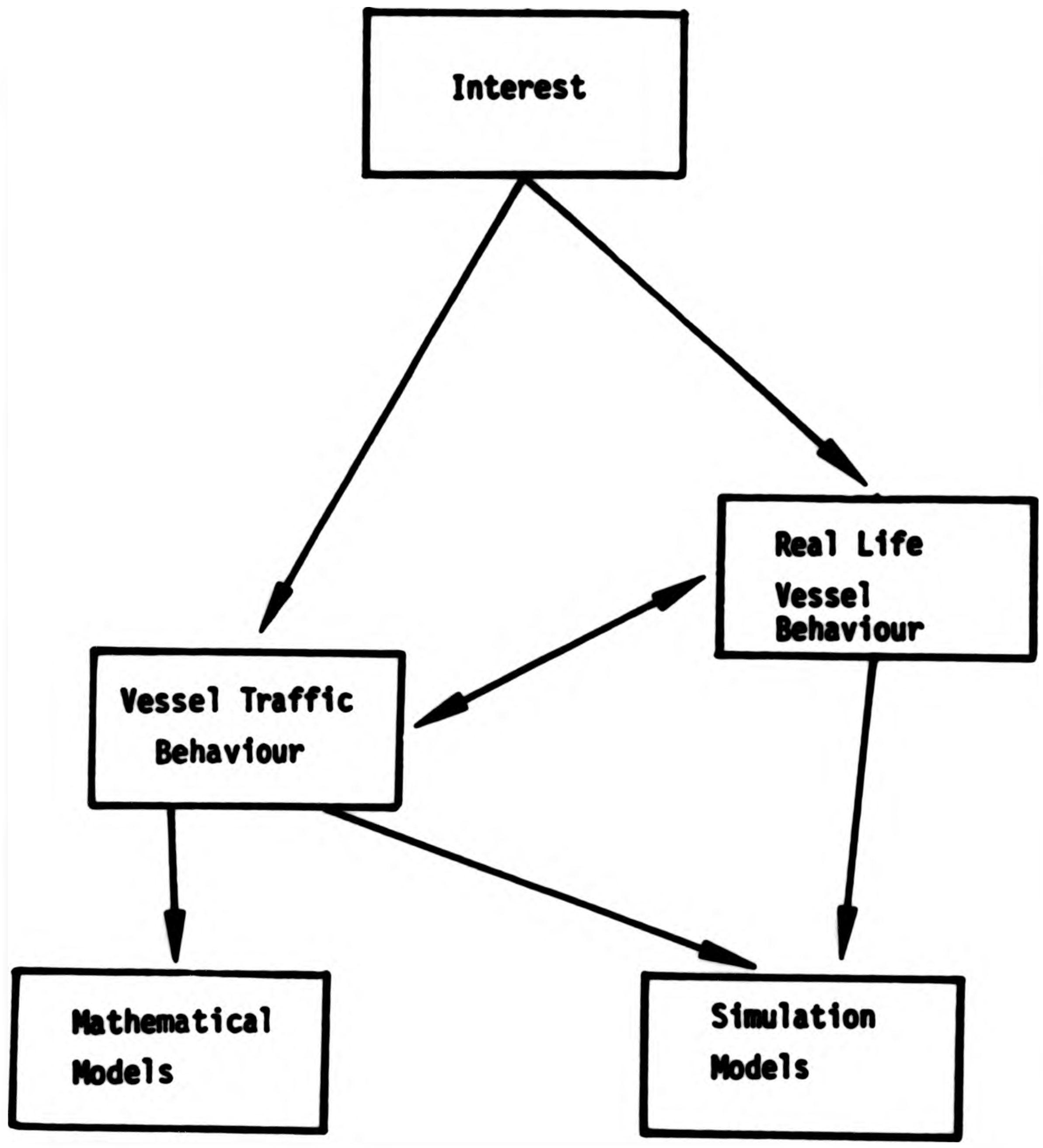

Figure 1.1 . Interest Sub-Categories Shown in Maritime Traffic.

(1.3.0) Mathematical and Simulation Models.

In order to investigate vessel traffic behaviour researchers have modelled complete vessel traffic systems and two/multi ship encounters. Ship models in tanks have previously been developed at the National Maritime Institute for testing ship manoeuvring capabilities, but this work is not relevant for this study.

[The National Maritime Institute (NMI), previously part of the National Physical Laboratory (NPL), after privitisation was known as NMI Ltd. and has now become British Marine Technology (BMT).]

A model of marine traffic behaviour may be one of two distinct types;

i) Mathematical or Theoretical and

ii) Simulation.

Once these models have been postulated their validity is tested against real life data. Mathematical models of marine traffic flows do not take account of manoeuvring actions in collision avoidance situations.

(1.3.1) Mathematical Models.

Current research interest has shifted from open sea simulations (two ship encounters) to traffic systems (routeing of vessels in restricted waterways). Much of the early work was pioneered by Calvert (1960,61) and Hollingdale (1961) of the Royal Aircraft Establishment. This early work examined two vessels in a defined potentially dangerous situation, an encounter, attempting to formulate a logical method for their behaviour. Following IMCO recommendations of 1967 for a traffic separation scheme in the Dover Strait sea area, Draper and Bennett (1972) of the Departments of Industry and Trade constructed a mathematical model of the area in order to predict in a given sea area the number of times vessels would be expected to come within a specified distance of each other, defined as the encounter rate. Barratt (1973) (National Physical Laboratory) went on to make an analytical study of encounter rates.

The National Maritime Institute have since published work on mathematical models. Lewison (1977) formulated a model intended to predict the number of these defined encounters if no collision avoidance action were taken. Gill (1977) modelled a vessel manoeuvring by means of a non-linear model. Curtis (1977) prescribed a theoretical model of a ship overtaking based on collision time and minimum safe overtaking distance.

Holmes (1979) defines the indirect distance separation as the total distance between two vessels via their closest point of approach. Using real life data and data collected from a marine radar simulator, empirical statistical models were constructed using least squares regression. These models predict critical values for the indirect distance separation at the point where a collision avoidance manoeuvre is expected.

<u>(1.3.2) Simulation Models.</u>

Mathematical models used to model complete traffic systems cannot do not usually. take into account individual collision avoidance manoeuvres. Lewison's model (1977) for example can only model systems when no collision avoidance action is taken.

With the advent of cheaper and more readily accessible digital computer technology the idea of modelling ship behaviour is moving from the system simulation of the mathematical models to the system and vessel simulations using computer models.

The most recent of these studies has been undertaken by Colley et al (1984) and is based on determining the time at which a manoeuvre is expected to be made according to the developed Range to Domain over Range Rate (RDRR) method. Using this method Colley et al have managed successfully to simulate an area of the south west bound lane of the Dover Strait separation scheme.

This simulation has many advantages over the mathematical models. By modelling individual two ship and multi-ship collision avoidance situations, complete systems may be modelled for given flow rates and traffic densities. Alterations to systems may easily be programmed into the simulation giving clear indication of the resulting effect. This effect may be monitored by setting up a series of gate counts or by using improved computer graphical facilities to allow visual representation.

Prior to this simulation Davis (1981) simulated two and three ship encounters based on determining the distance separation of two vessels at which a collision avoidance manoeuvre should be considered. This model was validated by comparisons with real life data.

Earlier models were suggested by Batkin (1976), Degré and Lefèvre (1978), Spaargaren and Tresfon (1978) and, Van der Tak and Spaans (1977).

(1.4.0) Real Life Data Collections

Real life survey data is required to investigate vessel behaviour or validate the use of a mathematical or computer simulated model. Although questionnaire methods present the researcher with an easy, relatively inexpensive method for data collection, the results can be unreliable. The methods available for collecting real life data have up until now been time consuming, expensive and have required the use of specialised equipment. These methods have involved a photographic record being made of particular radar displays.

The National Physical Laboratory made a continuous photographic record of the traffic in the Dover Strait between 1971 and 1982.

These data were collected to investigate incidents such as collisions, strandings and the contravening of marine traffic rules. The collection has been made by filming a 3cm. (wavelength) radar display with an offset range of 16 miles, based on H.M. Coastguard station at St.Margarets Bay. This has been done using a 16mm. cine camera exposing one frame every minute. The films are then stored as records, which can be projected at a later date in order to plot ships tracks or count the number of ships operating in a given sea area etc. These data have been used by Barratt (1973,1977) and Lewison (1977) for comparison with mathematical models.

These collected data have also been used for the compilation of general statistics concerning the area, such as traffic density, or the number of rogue vessels. Some of the data were made available to Batkin (1976) in order to investigate the performance of a developed computer simulation model.

Both Goodwin and Kemp have in the past made a number of surveys on board the MV 'Sir John Cass', chiefly in the southern North Sea centred on the Sunk Lightvessel. The method used in the surveys was to photograph a 3cm radar display every 3 minutes for as long as possible (usually 8-12 hours). The radar display was set to a 12 mile range to cover a reasonable sea area but with adequate discrimination between echoes. These data were used by Goodwin (1975) for a statistical study of ship domains. Goodwin and Kemp (1977) have also used the data to examine route structures in the southern North Sea. This method was used for economic reasons but is clearly outmoded with the advent of new data processing technologies.

Various marine surveys have been carried out in Japan principally by Fujii (1977). Fujii and Tanaka (1971) also describe a method called a programmed radar photograph where six frames of 35mm film are exposed every minute by an electronically controlled camera. Photographs are then produced showing the wake lines of ships, omitting some of the shots to give the direction of them. These data have been used by Fujii and Tanaka to investigate traffic capacity, accidents and suggested forms of traffic control.

All these above methods have involved the recording of a radar display by some photographic means. These methods have proved to be reliable and are now regarded as an 'accurate' representation of vessel traffic data. However these methods are both time consuming and expensive. Time can be lost whilst the data is being processed.

With the innovation of automatic tracking systems, in particular in the Dover Strait sea area, the possibilty of direct data access has been made possible.

Along similar lines, Spaargaren and Tresfon (1978) used data collected from an automatic radar plotter in the Hook of Holland. These plotters are used by the Netherlands Waterways Authority in the approaches to the Hook of Holland. Data were collected over a period of 1100 hours at 15 second intervals. After a preliminary analysis by means of a playback monitor the data were extensively processed so as to eliminate the effects of the deficiencies in the automatic tracking system of the plotter and to match the recorded tracks with the noted names of the vessels.

An investigation into the performance of the plotter revealed that the frequency of tracking error was quite high. These were mostly caused by the seduction of signals for vessels close together or vessels near to stationary objects. Kalman filtering and smoothing provided a method for improving the raw data, taking account of the characteristics of the tracks including both estimates of variances inherent in the system and measurement errors. The improved data set was used to establish average figures for traffic density, course and speed distributions and the number of anchored ships as well as the number of collision avoidance actions taken. Some of these data were made available to Goodwin (1978) for her study of marine encounter rates in different sea areas using a 'marine index of orderliness' (a weighted count of predicted and actual conflicts existing at a given current time) to give an overall measure of traffic behaviour.

The use of an automatic radar plotter was considered uneconomical for data collection by Spaargaren and Tresfon. The problems encountered were in part due to a large number of pilotage vessels and ships at anchor in the Hook of Holland, which may not be the case in other study areas. Holmes (1979) plotted vessel progress directly from the radar screen which although cumbersome was considerably cheaper.

The Channel Navigation Information Service monitors vessels progress in the Dover Strait sea area by means of an automatic radar tracking system, full details are given in chapter two. Position and velocity data are archived onto margnetic tape on request by H.M.Coastguard. Both the position and velocity of each tracked vessel is recorded at minute intervals. Since the traffic is monitored as part of the CNIS coverage, it is relatively inexpensive and routine to collect huge amounts of data. These magnetic tapes have up until now never been utilised to their full potential. By copying some of these tapes to the main frame computer at the Polytechnic of North London, identifying file structure and developing advanced computer software which utilises current computer graphical technology facilities, the work of this study allows the archived data to be analysed. Many facilities have been built into this software package one of which allows the application of devised mathematical techniques to identify specific navigational situations. Behavioural parameters can and have now been measured using this package. With these measurements future and previously developed mathematical and simulation models may be investigated.

Facilities which the software package offers are limited only by imagination, but as is the case with many new technologies the most successful are the facilities which are most practical.

(1.5.0) Comparison of Data Collection Methods

Navigational data may be collected in three different ways;

i) the observation of marine traffic in the field,

ii) the completion of questionnaires by mariners, and

iii) by using a marine simulator.

Ideally when investigating vessel traffic behaviour a researcher would work with real life survey data. These data can be collected using visual survey methods, radar traffic survey methods or the direct recording of vessel positions tracked automatically by computer.

Direct plotting from a radar display has in the past been used by City of London Polytechnic researchers when the traffic density has been low. This method can be supplemented by direct visual methods when there is a need to identify vessel class. This method has been used by the Netherlands Pilots Association for collecting data off the Hook of Holland.

Photographing the radar display is a method which can deal with the recording of positional data when the traffic density is high. This method is relatively expensive, requiring specialised equipment and the processing of film. In the past photographing the radar display has been the standard form in which data have been collected at the Coast Guard station at St. Margaret's Bay, Dover. More recently, continuous video recordings of radar displays have been made allowing instant 'playback' facilities.

The automatic recording of radar information by computer has the great advantage that large amounts of data may be handled both quickly and economically. Once the initial programming difficulties are overcome, subsequent data collections become routine. By comparison, real life data collections made from vessels require a full crew. Weather conditions are never guaranteed and valuable time may be lost because of poor conditions. The positioning of the survey vessel may itself influence other vessels and a biased survey may result. A sample which is statistically large enough requires observations over a period of time to represent a variety of conditions, again this is expensive and impractical. Surveys conducted from the air overcome the problem of the survey vessel influencing the behaviour of other vessels, but are expensive and consequently rare. The National Physical Laboratory when conducting the Dungeness survey, Marine Traffic in the Dover Strait (1971), used three Beaver aircraft to identify vessels. The aircraft also have advantage of greater speed and manoeuvrability than ships. The reader is referred to Holmes and Kemp (1979) for a greater discussion on data collection method comparisons.

Information on how a mariner behaves may be collected using questionnaire techniques as does Davis (1981). This provides a relatively cheap and easy method. It is also the least representative of the methods discussed. The questionnaire is conducted outside the operational situation when the mariner is more relaxed and certainly has more time to consider the situation than he would otherwise have on the bridge of a vessel. If a questionnaire is conducted as part of a debriefing session the mariner quite often feels he has to reply with 'text book' answers and fails to report on what action he actually took. The questionnaire is useful for collecting data for preliminary data analysis but lacks the depth and accuracy for more detailed studies.

Mariners' behavioural data can and indeed is often obtained from a marine radar simulator.The simulator presents the researcher with a relatively cheap, quick and easy to use tool for collecting behavioural data (Goodwin 1975). Simulation is controlled by a central computer, and is generally of a set, pre-programmed pattern (i.e. the program does not model vessel traffic behaviour). The reactions and actions taken by the operator are recorded for later analysis. The simulator allows the researcher to repeat scenarios on different subjects, allowing variation in behaviour to be explained by both subject and scenario rather than by scenario alone. The main disadvantage of using the simulator as a data source for research is that it is removed from the real life situation and may not accurately represent mariners behaviour.

(1.5.1) Simulator Data

It is assumed that the mariner will behave in a similar manner on a simulator as he does in the real life situation. Some work has been done to try and validate the use of the radar simulator as a research tool, (Goodwin 1975, Holmes 1979, Curtis and Barratt 1981), but further comparison between real life survey and radar simulator data has been limited by the availability of real life data.

Curtis and Barratt (1981) compare the passing track separation of overtaking vessels using real life and simulator data sets so as to validate the use of the simulator. Simulator experiments were devised so that subjects were presented with initial track separation at the start of an experiment and from the results the distributions of passing track separations were constructed. These distributions were compared with distributions obtained from the real life data. The study was conducted at the former National Maritime Institute of the Department of Industry where there existed an extensive data bank of mariners' responses at sea in the form of time lapse photographic records of radar displays which give ships' manoeuvres in the Dover Strait.

In order to compare results from the two data sets Curtis and Barratt transform the simulator data set to achieve comparable passing track distributions.

For a uniformly distributed traffic flow about a vessel referred to as 'own ship', the distribution of passing track shown in Figure 1.2 is expected.

The dotted line is the expected distribution in the absence of the 'own ship'. The presence of the 'own ship' displaces the vessels that would normally pass close to it. The real life and simulator data sets were from different vessel distributions. A transformation was performed so that a direct comparison of passing track distributions could be made. In the Dover Strait the distribution of ships across the traffic lanes is not uniform. This transformation was performed on the simulator data set and effectively obtained the predicted distribution of passing track separations for the non-uniform distribution of ships across the lanes in the Dover Strait. Curtis and Barratt introduced the following notation:

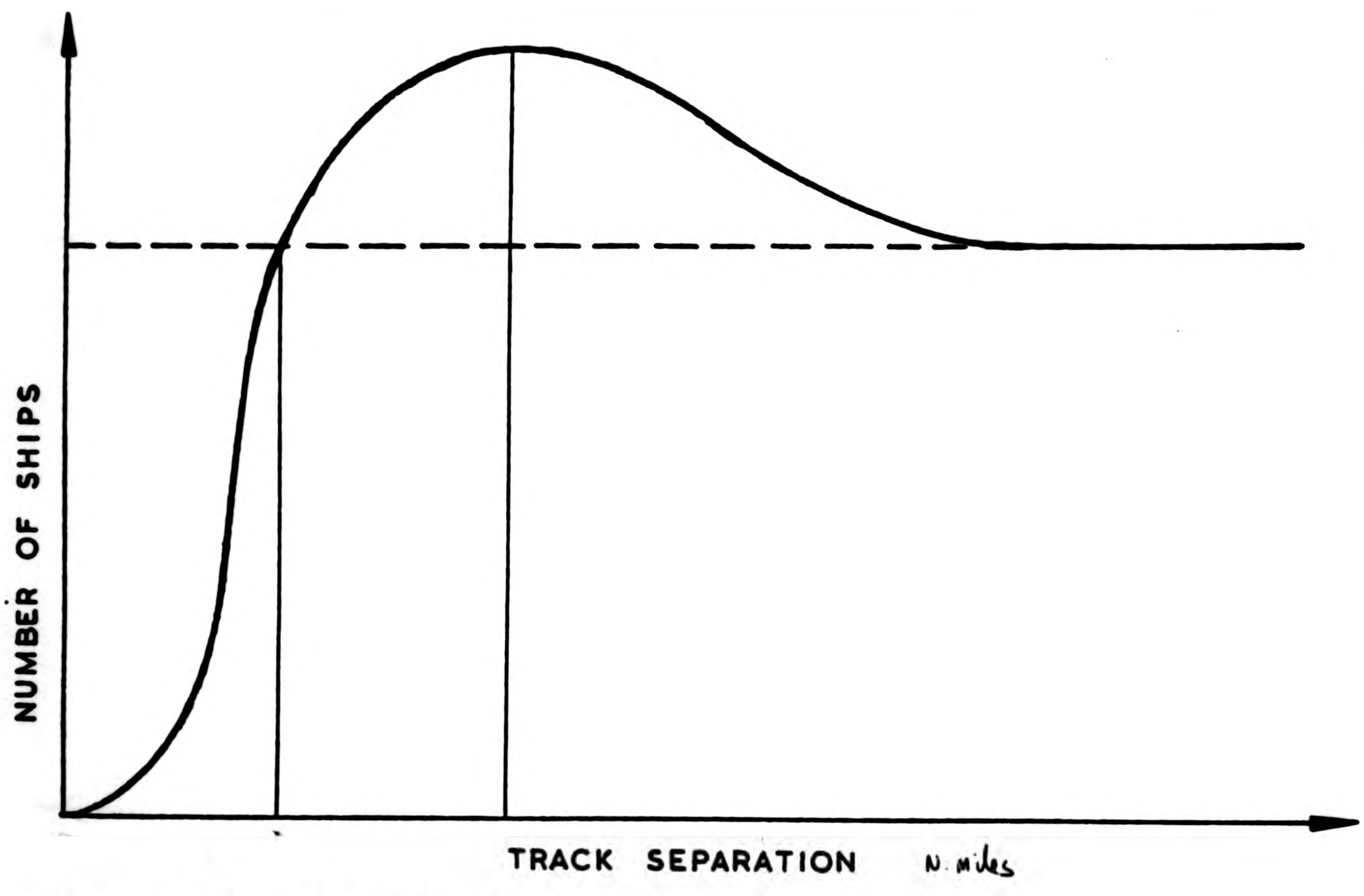

Figure 1.2 Distribution of Passing Track.

$S(x)$	Traffic flow density of ships crossing a lane.
V_a	Average speed of overtaken ships in the lane.
V_b	Average speed of overtaking ships in the lane.
$I(z)$	Density of ships with initial track separation z.
$P(z,x)$	Passing density at x for the particular traffic flow.
$E(x)$	Predicted passing density at x for the particular traffic flow.

The approximate expression for the density of ships approaching to overtake a ship in two strips with lane densities S(1) and S(2) a distance z apart given by,

$$I = \frac{V_h - V_a}{V_a} \; S(1)\, S(2)$$

This gives after integration the total density of ships with initial track separations z apart for all strips in the lane,

$$I(z) = \frac{\int_0^{\infty} \frac{V_h - V_a}{V_a} S(x)\, S(x+z)\, dx}{\int_0^{\infty} S(x)\, dx}$$

By applying the theorem of total probability Curtis and

Barratt obtain an expression for E(x).

$$E(x) = \int_0^{\infty} P(x,z)\, I(z)\, dz$$

$$x, z \in \mathbb{R}$$

$$x, z \geq 0$$

By graphically comparing the distributions of E(x) for real life and simulator data sets the study reported no reason to doubt the validity of the radar simulator, that is that mariners at sea can be expected to respond in a similar manner as subjects conducting simulator tests, given unrestricted sea room.

Curtis (1980) in a study into the minimum safe overtaking distance concludes that a mathematical model can be suitably applied to mariners behaviour on a marine radar simulator, ie. that a mariner, on a simulator, behaves in an expected manner.

Goodwin (1975) found no evidence to suggest a difference in behaviour following the comparison of calculated domain sizes for simulator and real life data sets. The study was by no means extensive but lead Holmes (1979) to conduct a number of statistical techniques on both real life and simulator data. Following the application of a stepwise discriminant procedure (see Kendall 1975) on the different simulator exercise types it was found that open sea exercises are apparently different from restricted waterway exercises but that the discrimination between Dover Strait and Gibraltar Strait exercises is poor. Following principal component analysis (see Chatfield and Collins 1983) the original measured variables could be reduced by eliminating or combining those that were highly correlated. For restricted waterway data five components were considered to be significant, each of which are linear components of measured parameters. By application of a forward stepwise regression technique a linear prediction equation was estimated for each of the defined dependent variables, namely, Indirect Distance apart defined as the total distance separation of own ship and target ship via the point of intersection of the two courses, Own ship time and distance from the intersection of the two courses, the difference between own ship and target ship speeds and the expected time until domain infringement (see section 1.6.0 for domain definition). For the restricted waterway exercises the following regression equation was considered to be the most useful,

$$\text{IND-DIST} = 0.63 + 0.19(\text{TS-TIME}) + 0.21(\text{TS-SPEED}) - 0.03\,(\text{EXPERIENCE})$$

Where the TS-SPEED and TS-TIME are the target ship speed (knots) and the time from the intersection of courses (minutes) respectively and EXPERIENCE is the mariners sea experience measured in years.

This equation differed from the 'best fit' equation obtained from the real life data set. This difference in the prediction equations was acknowledged but not examined, and as such does not give clear enough evidence to refute or validate the use of a simulator. The main finding of Holmes' study relevant to this study is that mariners can be expected to respond in a similar manner in restricted waterway exercises, and that the variable defined as the indirect distance separation is highlighted as an important variable.

It has been one of the aims of this study to compare mariners behaviour in a collision avoidance situation in real life and on a radar simulator by utilising the resource of CNIS ADP data. With this investigation greater confidence may be given to results arrived at after using simulator data sets for analysis. Even if no validation can be offered, greater knowledge of how the mariner behaves in the training situation would have been gained.

Marine simulator data have been presented in the form of computer plots obtained from exercises undertaken by subjects at the City of London Polytechnic. A software package has been developed to analyse ~~graphically~~ the radar simulator data supporting much the same facilities as the Dover Strait data software package.

(1.6.0) Vessel Behaviour Investigations

Much of the real life investigation into vessel behaviour has centred around the question of identifying areas and distances around a given ship.

This need to quantify distances from a vessel operating in a system is particularly useful when modelling vessel traffic systems. Distance identification helps to determine both the points and the nature of a decision a mariner might be expected to make.

The first attempts to identify distance from a central ship were proposed by Fujii and Tanaka (1971). It is now a well accepted concept that there exists an area about a ship which a mariner wishes to keep clear of other vessels. Such an area is known as the ship's domain. Fujii and Tanaka descibed a theoretical potential field around a vessel which causes a repulsive force for approaching vessels and a weak attractive force for distant vessels. This so defined repulsive force causes an avoiding motion and gives rise to a vessel free or low density area about a given vessel. This area of low density is known as the effective domain of a particular vessel. The effective domain size was found by Fujii and Tanaka working in Japanese waters to be ellipsoidal in shape and a function of length of the vessel for the specified water way. Thus by using a mean ship length value for a specified shipping area, and calculating the effective domain size, the shipping capacity of that waterway was estimated.

Goodwin (1975) from data collected from the Sunk Light Vessel in the southern North Sea and from a marine radar simulator, suggested that the domain of a ship was dependent on the density of shipping in a given sea area for different classes of vessels. The form of the domain could theoretically be considered as comprising of three sectors as shown in Figure 1.3. Each sector corresponding to the give way, stand on and overtaking areas respectively as defined by the Collision Regulations (1972). The sector referred to as the giveway area having the greatest weighting, and the overtaking sector having the smallest weighting.

If no domain were present it would be expected that there would be a uniform ambient distribution of vessels around a given ship, assuming a uniform distribution of vessels.

Goodwin defined the domain radius as the distance X_A indicated in Figure 1.4, such that for all $X < X_A$ the number of ship points is less than would have been expected given no ship domain present. Fujii and Tanaka defined their domain boundary as the distance from the central ship at

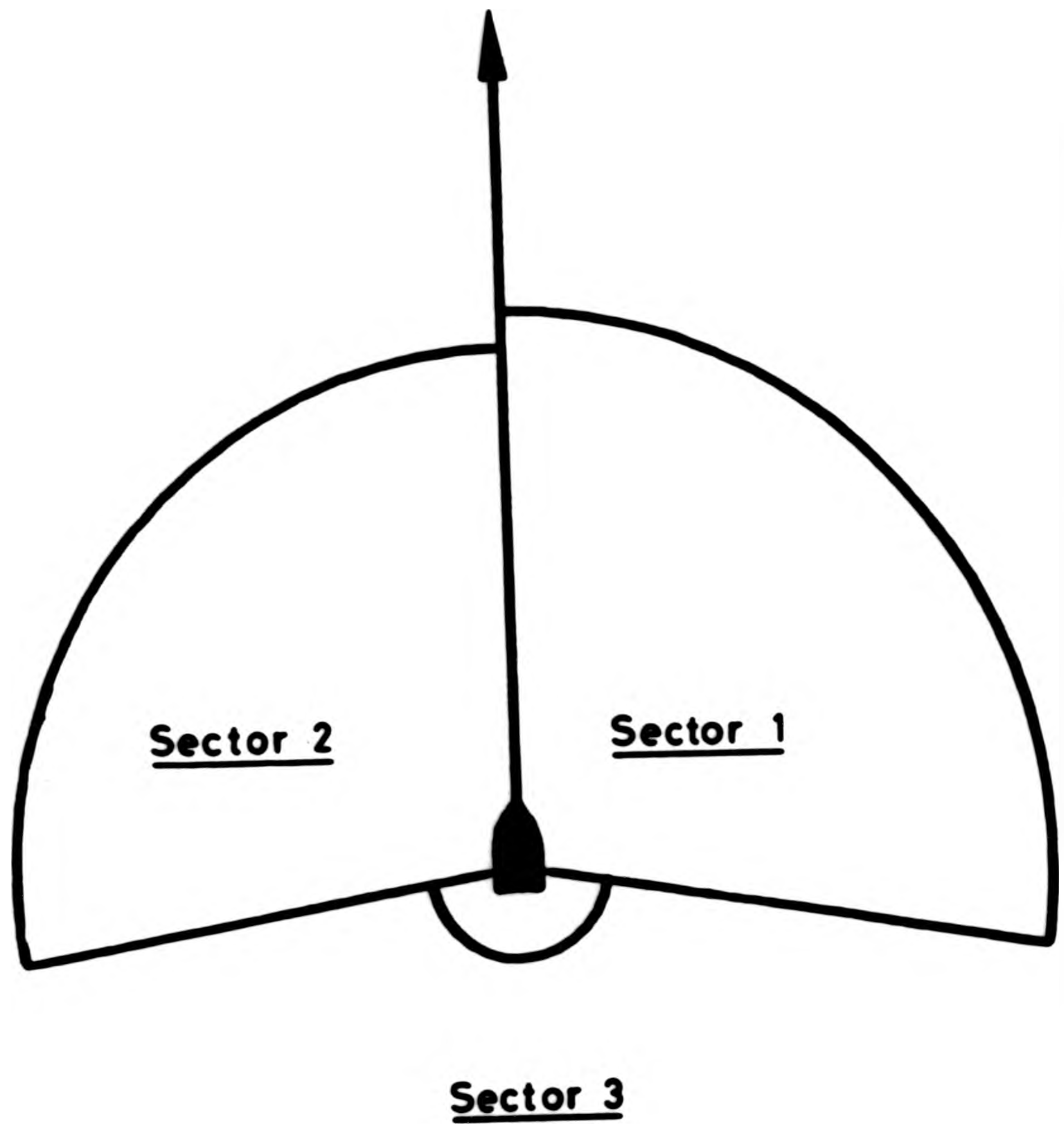

Figure 1.3 Goodwin's Domain.

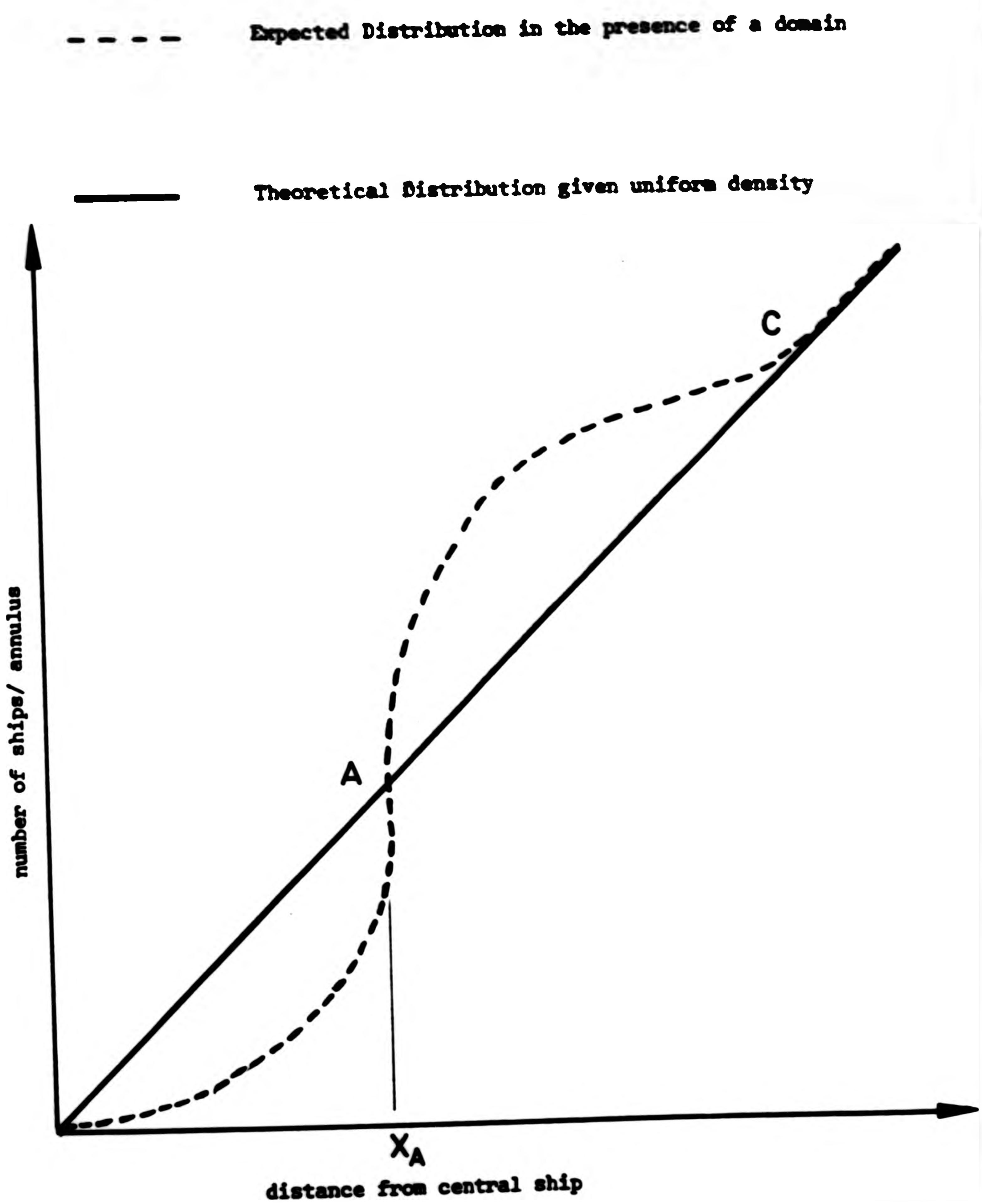

Figure 1.4. Calculating the Domain radius

which the density around it is maximised. Goodwin's criticism of this definition was that for practical purposes this is an over conservative estimate as ships would be willing to accept smaller distances without causing too many problems. Also that the kurtosis of typical curves is such that the maximum is not well defined in open waters and this problem compounded if the data are noisy. Goodwin smoothed the Data using a straight forward three point moving average. The line of uniform density was also drawn by locating point 'C' (see Figure 1.4). Once point 'C' is reached the total number of ship points observed in the area defined by $X < X_C$ will equal the total number of ship points in the area expected with uniform density. Therefore once point 'C' is located the line of uniform density can be drawn in and the domain radius read off. Along similar lines Coldwell (1984) working in the Humber Seaway investigated and quantified ship domains.

Davis et al (1980) followed one of Goodwin's suggestions that a discontinuous domain boundary would be unsuitable for modelling on a digital computer. Davis therefore developed an algorithm which smoothed the Goodwin domain so that it was circular. The method placed the central ship in an offcentred circle in such a way that the original weightings were preserved, as shown in Figure 1.5.

The arena of a ship may be considered as an area about a

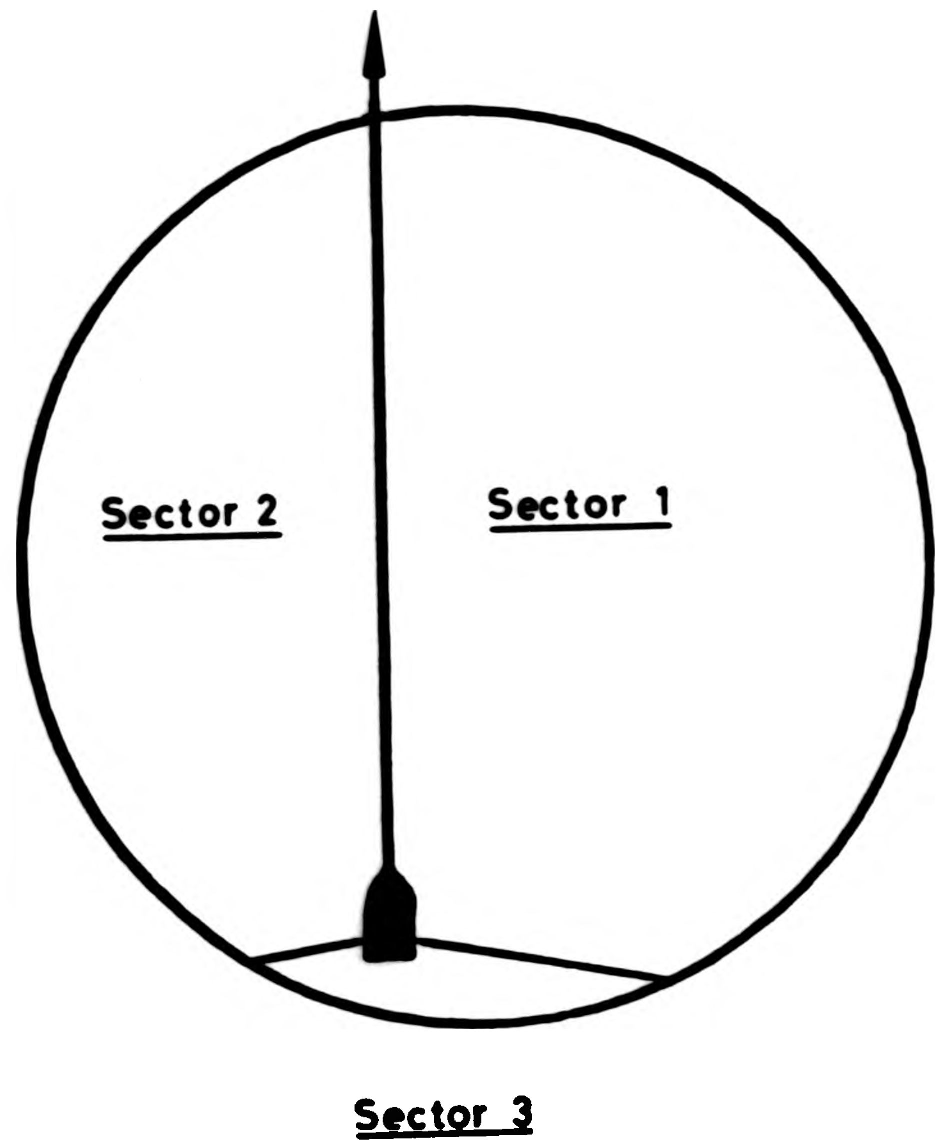

Figure 1.5. Davis' Domain.

ship which when infringed causes a mariner to take avoiding action. The arena may be regarded as a sort of 'playing area'. Davis used a circular arena which again placed the central ship offcentre. Davis used both this domain and arena to model two ship encounters.

Colley et al (1983) pointed out that Davis' use of a circular arena to identify the point at which a mariner would manoeuvre is unsuitable. By identifying the point of manoeuvre by using a method purely based on distance from domain, Davis' arena does not take into account the relative velocity of the two (or more) vessels. This apparent flaw is evident if we consider a trivial situation in which we have two vessels equidistant from the central ship and in the same relative position to it such that they encroach the central ship's arena. If one of these vessels is travelling with large velocity and the other with a small velocity then both vessels would, using Davis' arena, have to be manoeuvred for. Clearly the two ships do not pose the same degree of threat as each other. Indeed an encroaching vessel may not represent a threat at all. Davis' arena definition does not take into account that although a ship may infringe the distance arena of another vessel we need to consider the rate at which the vessels are approaching each other to determine whether or not a manoeuvre is required.

Colley et al (1983) considered new concepts and looked at air traffic control theory. They defined the ratio referred to as the Range to Domain over Range Rate (RDRR) as;

$$\frac{R - D}{\dot{R}}$$

where range to the target is R, the domain radius is D and $\dot{R}$ is the range rate of the two vessels, i.e. the differentiation of R w.r.t time.

The RDRR is a measure of time (distance / speed), and the arena is said to be infringed if the RDRR is less than some predetermined value say, T_C . The value of T_C is dependent upon the class of the central vessel and the sea area it is operating in. This arena definition allows the model to cope with all types of encounter (crossing, overtaking and meeting).

Colley has since used this model to simulate on a digital computer ships progress in the Dover Strait and validates the model by comparing ship distributions through gates set up by the Varne light vessel.

The principal use of the ship domain has been for vessel traffic simulation models, estimating exposure to risk and modelling traffic flow patterns, though it has also been used to examine the safety and positioning of off shore structures.

Van der Tak and Spaans' model was developed to simulate traffic flows in the approaches to Rotterdam and the area around Texel and Terschelling lightships. The model incorporated the idea of a ship domain as a basis of a risk criteria. The domain was defined as: On every relative bearing ϕ from own ship there is a distance $R(\phi)$ to the other ship or object at which the situation of own ship is considered to represent a certain degree of danger. The area within the contour connecting all points of equal danger is called the ship domain.

The domain is ellipsoid in shape and the size depends on the assigned danger class which is determined by size and cargo, accounting for manoeuvrability, qualification of the navigator, psychological factors, reaction time and the environment.

Since collisions are relatively rare occurences and vessel traffic systems are constantly amended, in order to make a risk assessment the collision statistics can be supplemented by the observed number of close quarter situations over a given time period. The ship domain can be used as a basis for encounter rates. Indeed Van der Tak and Spaans' model has also been used to estimate encounter rates.

(1.7.0) Encounter Detection

The problem of analysing the data archived from the CNIS ADP system has already been outlined in this chapter. An investigation into the archiving system and the problems relating to the reading of the magnetic tapes along with software design details are all given in later chapters.

When analysing these data it has been necessary to pick out specific navigational situations. These situations known as encounters involve some degree of collision avoidance consideration. A technique is required to detect these encounters automatically and so save much laborious work and time of the researcher. Once these encounters have been detected references to them may be stored in a computer data base. In order to develop this technique, which is described fully in chapter four, a complete understanding of what constitutes an encounter is required.

With these encounters detected and by utilising the facilities built into the computer software package, direct comparison beween mariners' behaviour in the real life and radar simulator situations has been made possible.

(1.7.1)Encounters

An introductory encounter definition may be, a situation involving two or more vessels which can be considered to be of high collision risk relative to a non-encounter situation.

Encounter definitions are generally formalised relevant to a study. Barratt (1977) describes an encounter as a near miss that 'but for the grace of god could well have been.......'. Coldwell (1984) considers an encounter to be the next best thing to a collision. In work such as James (1986) no formal encounter definition is given and the reader can only deduce that an encounter is said to mean a potentially dangerous situation. Encounter definitions such as Barratt's and Coldwell's infer that an encounter has a high absolute probability of leading to a collision. The definition adopted for this study makes no inferences about the associated probability, but does state that an encounter involves at least collision avoidance consideration and on many occasions a collision avoidance manoeuvre.

Most encounter definitions reviewed are based purely on distance criteria. These take the general pattern that;
an encounter between two or more vessels is said to have occurred when two or more vessels have passed within a specified minimum distance of each other. This specified

minimum distance is referred to as the encounter distance (ED). This encounter distance may be a function of the class of vessel characterised by variables such as maximum speed, manoeuvrability and stopping distance, as well as the sea area in which the encounter occurs, or a combination of these.

Lewison (1978) and Barratt (1973) use an encounter distance of 0.5 n.m. to pick out encounters. The use of this almost arbitrarily chosen value for ED has the advantage that it is easy to program on a digital computer although it does not account for differences in either vessel characteristics or sea areas. As described earlier in this chapter, Goodwin (1975) following work by Fujii and Tanaka (1971), defines a ship domain as the area around a ship which the mariner wishes to keep free of other vessels. An encroachment of the domain could be considered to be an encounter. The domain can be defined for a given class of vessel and sea area, and as such is more detailed than both Lewison's and Barratt's encounter criteria.

Coldwell (1984) defines an encounter to be the encroachment of the ship domain and uses this definition in a study of traffic flows in the Humber Seaway. The number of encounters over a given time period was found to be heavily dependent on the sea area (correlation coefficient, r = 0.5).

Batkin (1976) developed a simulation model built specifically to model the main North East bound lane of the Dover Strait traffic separation scheme. The model was based upon the theoretical construction of a 'risk triangle', and was used to simulate both crossing and overtaking encounters. According to this model overtaking encounters are determined by monitoring the vessels distance separation and comparing calculated values against a predetermined critical value. For crossing encounters Batkin defines a miss distance as the difference between distances from the expected intersection of courses, which is calculated from bearing and speed data. This miss distance is compared with critical values for the CPA defined for class of vessel. If the miss distance is deemed critical then a collision avoidance manoeuvre is modelled with the angle of manoeuvre determined by the encounter characteristics. This uses basically distance based criteria for encounter determination.

Degre and Lefevre's model (1978) uses encroachment of the ship domain for encounter determination in the Dover Strait. The model was developed to evaluate encounter situations in the Dover Strait and uses an overtaking domain radius of 0.3 n.miles and a circle of radius 0.65 n.miles with eccentricity 0.15 n.miles ahead of the ship for crossing encounters. Similarly Spaargaren and Tresfon (1978) model encounters by comparisons of expected CPA against predetermined domain sizes. An encounter is considered to exist if the vessels are within a specified range of each other or if the time taken to achieve this critically valued CPA is less than a specified value. The model determines the encounter type and hence the domain size by considering the relative bearing of the target vessel, and as such does not take into account the direction of approach. A standard domain is used with different radii for the starboard, port and astern sectors, multiplied by a scaling factor depending on the target ship's type.

In Van der Tak and Spaans' simulation model the encroachment of the domain, whose definition is outlined earlier, is the chosen criteria for an encounter. The domain size is again calculated from the relative bearing of target vessels. Using the developed model the average number of encounters for specified conditions was estimated in order to determine a maritime risk criterion.

The need to be able to count the number of encounters in a given area over a stated time period, the encounter rate, has been generated mainly from the need for some sort of quantitative assessment of how well a particular sea area is functioning with respect to safety. With this assessment the nature of any possible amendments to the system may be determined. For example if such a system existed where there were a considerably large number of meeting encounters then it might be suggested that the introduction of a traffic separation scheme is required. Using the encounter rate, and in this case the meeting encounter rate, an assessment as to the effectiveness of any amendments could be made. Ideally collision statistics should be used for this quantitative assessment. This however, is not an effective method. Collisions are generally speaking rare events and in order to obtain a statistically large enough sample of collision data a large time period needs to be considered. Over such a time span factors other than the amendments to the traffic system may have contributed to a reduction in the collision rate. These factors may be improved radar facilities, more comprehensive radio information coverage or the introduction of new technology providing more sophisticated navigational aids. It is therefore unsuitable to use collision statistics to evaluate the effectiveness of traffic system amendments.

A recent study in this area has been the COST 301 project, Glansdorp et al (1985). One of the aims of this particular study has been to carry out research to improve the safety of navigation and to reduce the risks of pollution connected with marine traffic. This involved the assessment of potential benefits from shore based marine traffic systems (VTS) to the safety and efficiency of traffic in European waters. Specifically the COST 301 Working Group 2 was responsible for the quantitative assessment of risk to vessels, which uses a Problem Area Identifier (PAI) to estimate the effectiveness of VTS, at various levels, in reducing collision and stranding rates. Data were collected using questionnaires which were subsequently compared with historical survey data. Encounter rates were measured using domain infringements as the criteria for an encounter being registered.

Barratt (1986) whilst investigating distances from a given vessel defines the following six conceptual distances which are supposed to be useful in Vessel Traffic System (VTS) operations.

(i) Tactical Decision Distance (TDD):
The distance apart at which a specific vessel in a defined encounter situation can be expected to take action in a situation which requires a collision avoidance manoeuvre.

(ii) Strategic Decision Distance (SDD):
A safe value of distance at Closest Point of Approach (DCPA) which is acceptable to both ship and VTS operator so that collision avoidance manoeuvres will be infrequent and the available space is used efficiently.

(iii) Minimum Separation Standard (MSS):
The least DCPA which could properly be allowed between

passing ships taking account of all relevant circumstances including hydrodynamic and human factors.

(iv) Tactical Separation Standard (TSS):

A safe value of DCPA which is acceptable to the navigator of a ship as the aim of a collision avoidance manoeuvre.

(v) Strategic Separation Standard (SSS):

A distance apart, such that collision avoidance manoeuvres will only rarely be made at a greater distance.

(vi) Minimum Decision Distance (MDD):

The least distance between conflicting ships at which a collision avoidance manoeuvre can lead to ships passing at at least MSS, as viewed from one of the conflicting ships.

The TDD, SSS and MDD ignore any need for a time consideration when investigating the decision point for a possible collision avoidance manoeuvre. This idea of using time based criteria for decision points for mariners as opposed to methods based on purely distance is fully discussed in Chapter Four. The SDD, TSS and MSS all concern values for a minimum value for the distance at the Closest Point of Approach, though the SSS is considered from the VTS operator as well as the individual ship's position.

Draper and Bennett (1972) whilst working with the Operational Research Unit at the Department of Trade and Industry (DTI) developed a mathematical model to estimate encounter rates between ships in a limited area of sea and applied the model to the Dover Strait sea area. This work was particularly important as at this time the Marine Traffic Division at DTI were assessing possible routeing schemes in the Dover Strait. Draper and Bennett describe a collision as the result of two events. The first being an encounter which exists when two ships approach to within a specified short distance of each other (0.5 n.m.). The second event being when an encounter becomes a collision. A probability may then be multiplied by the encounter rate to obtain the collision rate, though Draper and Bennett point out that this probability is dependent on many factors (encounter distance, relative orientation of the two ships, manoeuvrability, visibility.......) and that the study of all these factors is too complex to ~~adequately estimate~~ estimate adequately the probability of an encounter leading to a collision. The mathematical model finally developed includes four main input parameters:

i) the mean speed of ships,

ii) the proportions of traffic travelling in opposite directions,

iii) the variation of speed from ship to ship, and

iv) ship density.

It was found that if the flow rate is held constant, so that as the mean number of ships increases, their mean speed decreases correspondingly, then encounter rate is directly proportional to density. If however, the mean speed is assumed constant, so that the flow increases with density, then the expected encounter rate increases as the square of the mean number of ships in the area.

A potential encounter is said to exist when two or more vessels are proceeding along courses which would lead to an encounter if no manoeuvres were effected.

The potential encounter rate can be used to assess the exposure to risk of collision for both real life data and mathematical or computer simulation models. The set of encounters is obviously contained in the set of potential encounters though not all potential encounters necessarily lead to encounters.

Coldwell (1984) found that for a restricted waterway (Humber Seaway) 78% of potential encounters result in actual encounters.

Lewison (1978) uses these definitions for potential encounters and (actual) encounters to estimate the probability that a given situation will result in a collision.

Potential Encounter—— P1⟶ Encounter—— P2⟶ Collision

A collision is described as the conclusion of a two stage process. The probability P1 is calculated from traffic flow patterns and the joint probability P1P2 is calculated from Dover Strait data 1967-76. The assumption here of independence of the two events, a potential encounter leading to an encounter and an encounter leading to a collision is unproven. Goodwin et al (1982) doubt whether the number of collisions is proportionate to the number of potential encounters since navigators may compensate for increased workloads by increased care and attention, whilst low work loads may induce lack of vigilance and decreased watchkeeping. This is criticism of the assumed relationship between potential encounters and encounters.

The conclusion that the number of collisions in a sea area is in some way dependent upon the associated encounter rate is disputed. The relationship is difficult to prove as again the occurrence of a collision in a particular area is rare, though Lewison (1978) after comparing encounter rates and collision figures states that meeting encounters are more likely to lead to a collision than overtaking ones, but only significantly so in poor visibility conditions which are now less common. These findings were in agreement with results from major work in this area of study by Cockcroft (1978, 1982).

This idea that some encounters are potentially more dangerous compared with others led Goodwin (1978) to produce a weighted encounter index known as the Marine Index of Orderliness which was based on concepts originally applied in air traffic studies. This index takes into account potential encounters and is a measure of time exposed to risk. Lewison (1980) developed another risk index, the Fog and Collision Risk Index based on the probability of collisions per million potential encounters, with the Encounter Distance (ED) equal to 0.5 n.miles.

It was Cockcroft (1978, 1982) who developed the idea that some encounters were potentially more dangerous than others. Following studies of collision statistics it was found that although the incidence of collision had not significantly changed over the period from 1950 to 1980, the pattern of accident had. A regional redistribution and a decrease in the number of collisions occurring in restricted visibility and those associated with meeting encounters was found. Some of these findings were attributed to the improvement and implementation of separation schemes.

When assessing the risk a vessel is exposed to, measurements of safety are required. Goodwin et al (1982) following a study which investigated the routeing of vessels around the Sunk Light Vessel three types of encounter are defined. These encounter types are namely the meeting, crossing and overtaking encounter.

Given that an encounter exists, then if the two vessels involved are on the same route and travelling in the same direction the situation is an overtaking encounter. If the two vessels are travelling along the same route but in opposite directions, then the situation is a meeting encounter. Finally, if the two vessels are travelling along different routes with a crossing angle of ϕ between the routes, then the situation is known as a crossing encounter.

For Goodwin et al's study an encounter was registered if the Closest Point of Approach (CPA) was less or equal to 0.45 n.miles between any two vessels. This value was chosen as the mean domain size for the area and was later weighted according to encounter type to represent different degrees of danger. These definitions for encounter types are now well accepted and have been used in the most recent studies including Colley et al (1983).

Goodwin et al (1982) have since developed the concept of a hard core domain. The hard core domain is distinguished from the ordinary domain in that it defines an area around a ship which, if encroached upon signals when danger actually threatens rather than alerts to a general awareness of danger. The hard core domain, which can be regarded as an encounter area, is, as is the domain, more detailed in its description of areas around a vessel. This followed on from earlier work by Fujii.

Overall it is unproven that encounter rates are a good indication of collision rates for a specified sea area. Nevertheless the need to estimate or measure the encounter rate is great. Despite the inability to prove the relationship between encounters and collisions, it is well accepted that the aim of any traffic system must be to reduce as far as possible the encounter rate so as to increase the level of safety and to reduce the risk that vessel traffic is exposed to.

The analysis of encounters also permits the development of more sophisticated and true to real life simulation models.

The method for encounter detection developed for this study extends the described RDRR method, and is fully explained in Chapter Four.

(1.8.0) Summary

In this introductory chapter a comprehensive background to the study has been given. This background has explained methods for data collection and subsequent investigations into marine vessel traffic behaviour. Some mathematical and simulation models have been outlined as relevant examples of previous work in this field.

The need for real life data is heavily stressed as devised models' performance may be investigated with real life comparisons. For this study new sources of data have been made available from the CNIS ADP system which is fully described in the second chapter. The problem of presenting these data in an easy to utilise manner has been briefly outlined and forms a major part of the study.

A much used source of navigational data has been the marine radar simulator. Some applications have been pinpointed, stressing the need to validate its use as a research tool. Previous validation studies have been descibed. With the availability of new sources of real life data for this study, a direct comparison to test the validity of using a simulator has been made possible. A section of the study has been devoted to this investigation.

So that the comparison can be made certain navigational situations known as encounters need to be detected. A comprehensive review of previous encounter definitions and applications has been given in this chapter with a view to developing an automatic encounter detection technique which is descibed and tested in chapter four.

The work then can be seen as comprising five main overlapping components. Firstly, the transferring of real life data from the CNIS ADP system to the main frame computer at the Polytechnic of North London. The second component is the development of graphically interactive software to analyse these data. The development of an automatic encounter detection technique forms the third component with the fourth and fifth components being the analysis of simulator data and the direct comparison of these data with the real life CNIS ADP data.

Chapter Two

Real Life Data Capture

(2.1.0) Introduction

The Dover Strait has long been recognised as a potentially hazardous sea area for mariners. On average some 300 vessels a day pass through the Straits with up to an additional 300 ferry and hovercraft crossing daily during peak periods (Dare and Lewison 1980).

The narrowness of the waterway, the restriction to traffic caused by shallows and sandbanks all contribute to the potential danger.

By the mid 60s the number of serious collisions and strandings had reached 15-20 per year. This was considered too high an incident rate. With the increase of cargo carrying capacity and the modern threat to the environment posed by Very Large Crude Carriers (VLCC) action was taken to improve safety in the area.

As a measure to reduce this incident rate the International Maritime Consultative Organisation (IMCO) adopted a traffic separation scheme in the Straits in 1967. The scheme has since been amended but is essentially the same. North East bound vessels proceed on the French side of the Channel whilst South West bound vessels proceed on the English side.

Crossing vessels are required to cross as close as possible at right angles to the system whilst vessels entering the system other than at its begin and end points are required to do so at as shallow an angle as possible, which is rather similar to the scheme by which a car joins a motorway.

The introduction of the scheme was associated with a marked decrease in the number of incidents whilst still leaving scope for improvements. It was agreed in 1971 by the United Kingdom and France to set up a joint organisation to provide continuous surveillance of the Dover Strait and its approaches. The aims of the project were to monitor vessels within the system and to provide, by radio telephone, information of navigational value to ships in the area. In the United Kingdom radar was installed at H.M. Coastguard station at St. Margarets Bay, near Dover, and a preliminary surveillance and information service came into operation in July 1972. This Dover Strait Information Service (DSIS) was located with and manned by H.M. Coastguard. This is because in the United Kingdom H.M. Coastguard has the responsibility for organising Search and Rescue (SAR), and for providing information on the local coastlines, hazards and other features of vital interest to mariners.

Following the success of the DSIS the Department of Trade carried out a feasibility study on the possible extension of the service by the application of computer processing techniques (Barfield and McAuley 1973). This study lead to the creation of the Channel Navigation Information Service (CNIS) in 1979 with its computerised processing of information.

In this chapter a description of this computerised system is given along with details on how relevant data are transferred from the CNIS system to the main frame computer system at the Polytechnic of North London.

(2.2.0) CNIS Automatic Data Processing System.

With the development of the Channel Navigation Information Service and improved facilities for greater safety in the Dover Strait area there was a need for an improved monitoring system of vessels operating within the traffic separation scheme.

The use of coastal radar for surveillance was adopted in 1978 after a detailed study carried out by outside consultants in co-operation with the Operational Research Unit of the Departments of Trade and Industry. This adoption coincided with the move of H.M. Coastguard to its purpose built operations centre at Langdon Battery. The systems area of coverage is shown in Figure 2.1.

The Automatic Data Processing System is operated from the operations centre at Langdon Battery and provides monitoring facilities for the Dover Strait area. The system allows the automatic detection of vessels entering the Strait and tracks the vessel progress through (or across) the separation scheme. The computer system accepts information directly from two radar positions, one at Dungeness the other at St. Margarets Bay, which can be supplemented by VHF radio direction finding signals or by information entered manually by H.M. Coastguard.

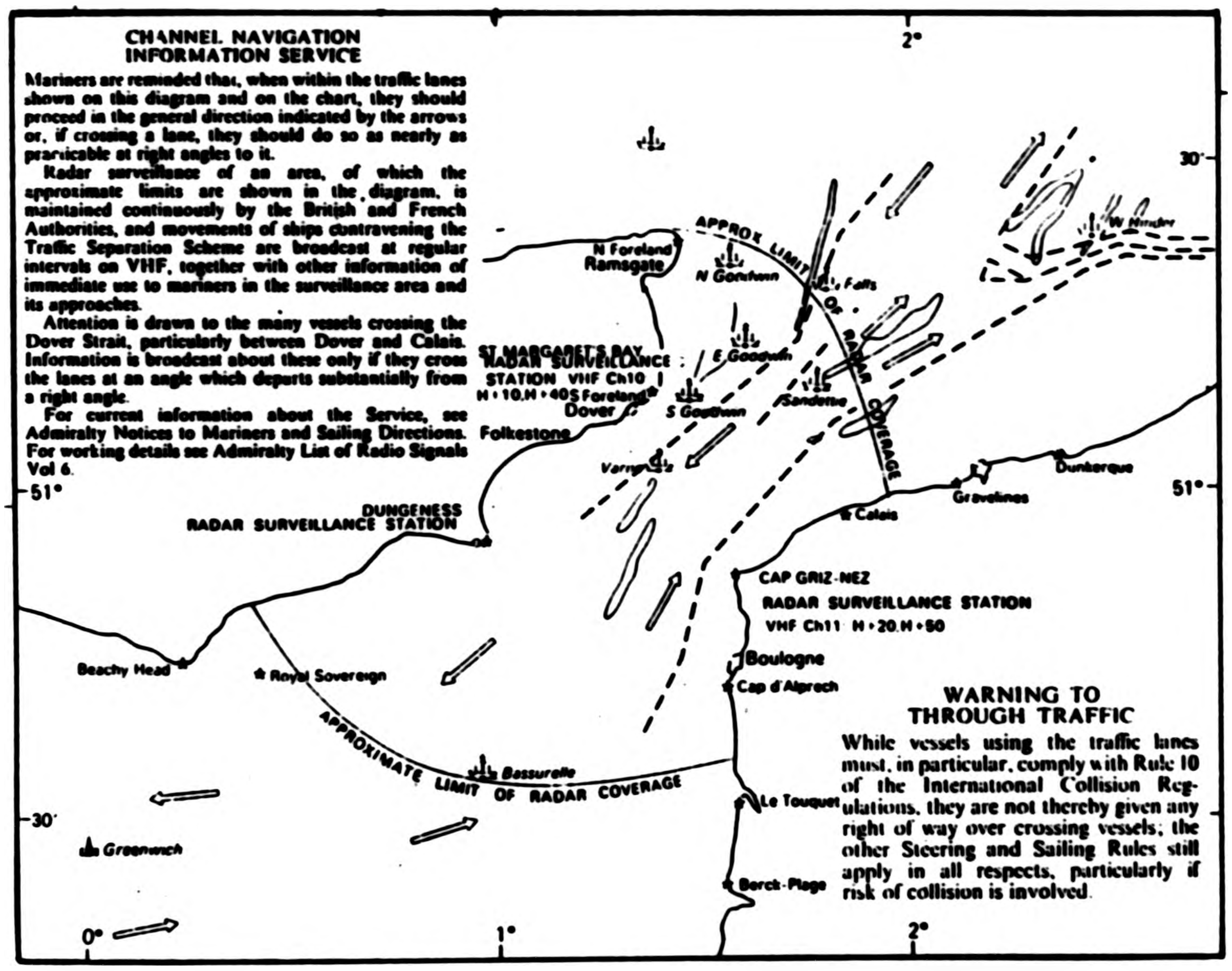

Figure 2.1. Coverage of the CNIS ADP system.

The data processing is undertaken by two integrated computer sub-systems, which are duplicated for reliability. One of these sub-systems is responsible for the receiving of radar signals and the automatic tracking of upto 256 (2^8) targets which can be acquired remotely or manually. Each new acquisition is given a unique identifier known as the External Track Number (ETN) which is in the range of 0-999.

Following the acquisition of each target the position and velocity are continually recorded and positions are plotted at minute intervals. The velocity estimation is based upon target positions since the last plot. Additionally the position of 192 waymarks, buoys, lightvessels and the like are also monitored.

The computer hardware of the Autotrack system is based on a network of some 34 microprocessors. The second integrated computer sub-system is the Information system, a data storage and processing system connected by two-way data links to the autotrack system. The logical layout of the hardware system is shown in Figure 2.2.

Operationally the operator is presented both with a raw and a synthetic radar display. The synthetic display includes coastline, waymarks, and vessel traffic separation scheme

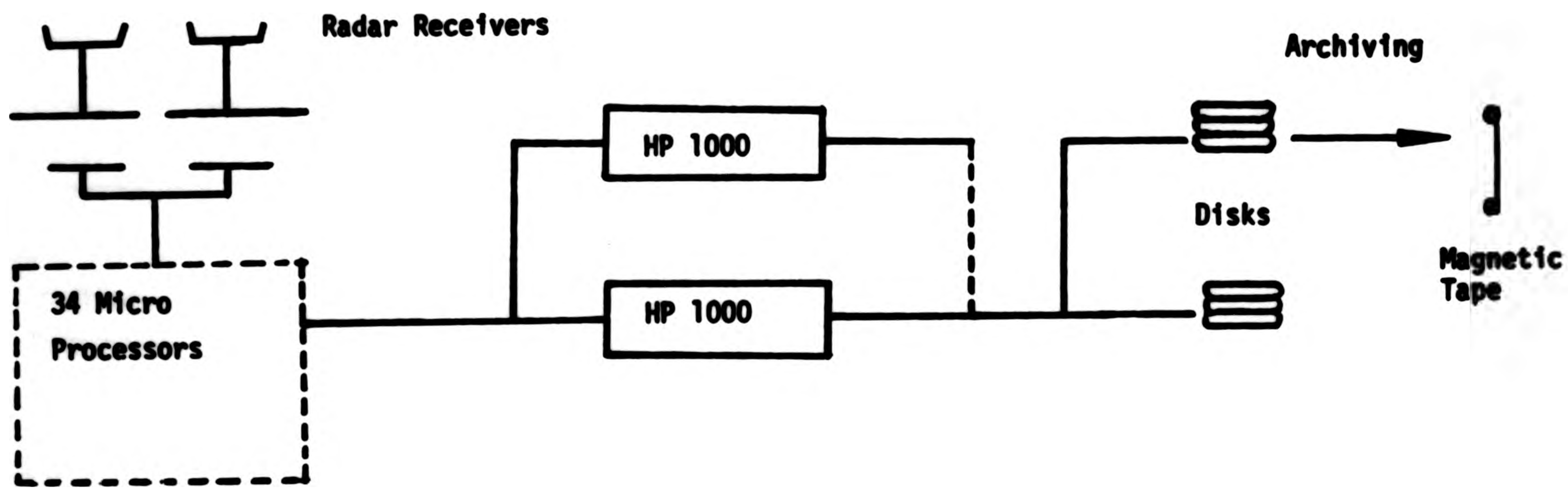

Figure 2.2 .Computer Logical Layout.

representation. The vessel ETN's are displayed by the current vessel position and vessels may be identified directly using the VHF/DF system. Situations of particular interest may be enlarged and a hard copy obtained.

The VHF direction finding receivers have been installed at South Foreland Lighthouse, near St. Margarets Bay, and at Fairlight near Hastings to enable a precise fixing of the position of any vessel transmitting VHF radio signals, and is under the remote control of the operations centre.

(2.2.1) Archiving.

The original pupose of archiving the CNIS ADP data onto magnetic tape was to permit later analysis of an operational situation or to collect statistical data of patterns of behaviour. Since it was not known at the time of designing the system how the archived tapes would be used no elaborate data processing is performed before the data are written to magnetic tape.

Basically then the archived data consist of four component files. These are referred to as :

i) VHF/DF readings;

ii) Track History files;

iii) Waymarks;

iv) Ship Name File.

Data are archived on request by H.M. Coastguard. The first record of each file is designed so that it easily identifies its respective file.

Of the four files the track history file is of great use, the ship name file is of limited use and the VHF/DF and waymark files are of little use for this project.

The data are archived from the HP1000 which is a 16-bit binary computer. Ascii code is of the 8-bit variety and files are written in both Ascii code and binary integer mixed. Records are written contiguously, some padded so as to achieve physical file structures, while others are written ignoring physical file boundaries.

(2.3.0) Other Tracking Systems.

(2.3.1) Harwich.

Shortly after the collision between the European Gateway ferry and the rail ferry Vanguard, in December 1982, Harwich Harbour Board invited Marconi electronics to design a new radar monitoring system.

The collision was not the major factor behind this request but the casualty may have been a symbolic factor in the Harbour Board's thinking that a radar system, properly applied can indirectly reduce the risk of collision.

The new system as with the CNIS ADP system is not to be used for collision avoidance in the direct sense, though some of the more advanced facilities such as predicted course and speed could tempt the operator into 'armchair sailing'.

The system provides a synthetic radar display as well as a raw display in case the operator is suspicious of the completely synthesised picture.

The system as with the Dover Strait system enhances the Harbour Board's ability to disseminate useful information to vessels.

(2.3.2) French Channel Surveillance.

The monitoring system operated by the French in the Channel, based at Cap Gris Nez, in many ways duplicates the work of the CNIS ADP system. The system is essentially part of the information service offered by the French Maritime Surveillance and Information centres and is currently being updated.

Degre and Tricaud (1984), separate the purpose of the system into four categories. These are:

i) General Surveillance of Traffic.

Traffic close to or operating in the different traffic separation schemes is monitored and vessels which transgress from the navigational rules of the road are detected.

The highly developed display unit allows the operator to view a synthetic radar display incorporating coastline, buoys and traffic separation scheme. The positions of all vessels operating in or close to the system are displayed with a track history of fixed length three positions (i.e. the current position along with the previous two recorded positions are displayed). On request a label may be displayed by each vessel indicating heading and speed following the course of any vessel to be extrapolated from a given sailing time. Various telemetric/azimuthal measures may be made using a rotating ball cursor.

ii) Traffic Police for Rogue Vessels.

When rogue vessels have been detected, vessels nearby are warned and attempts are made to identify the offending vessel with the help of traffic police so that legal action may be taken.

iii) <u>Special Tracking of Some Types of Vessel.</u>

Following the Amoco-Cadiz disaster in 1978 the French authorities created procedures called MAREP and SURNAV whereby vessels carrying hazardous cargo indicate their positions when entering a separation scheme or French territorial waters.

It is the task of the operators to collect the information and to monitor the vessels' progress after distinguishing the vessels from others on the display.

iv) <u>Information.</u>

The information provided using the radar tracking is basically of two types;

Information bulletins are transmitted every half hour. This information reports on the state of beacons, temporary obstacles and the presence of rogues.

The second information service consists of personal messages addressed to a vessel which has been identified. The messages may indicate immediate obstacles, appropriate assistance if the vessel is in difficulty, and information concerning regulations if a vessel is in danger of transgression. An example of this radar display is given in Figure 2.3.

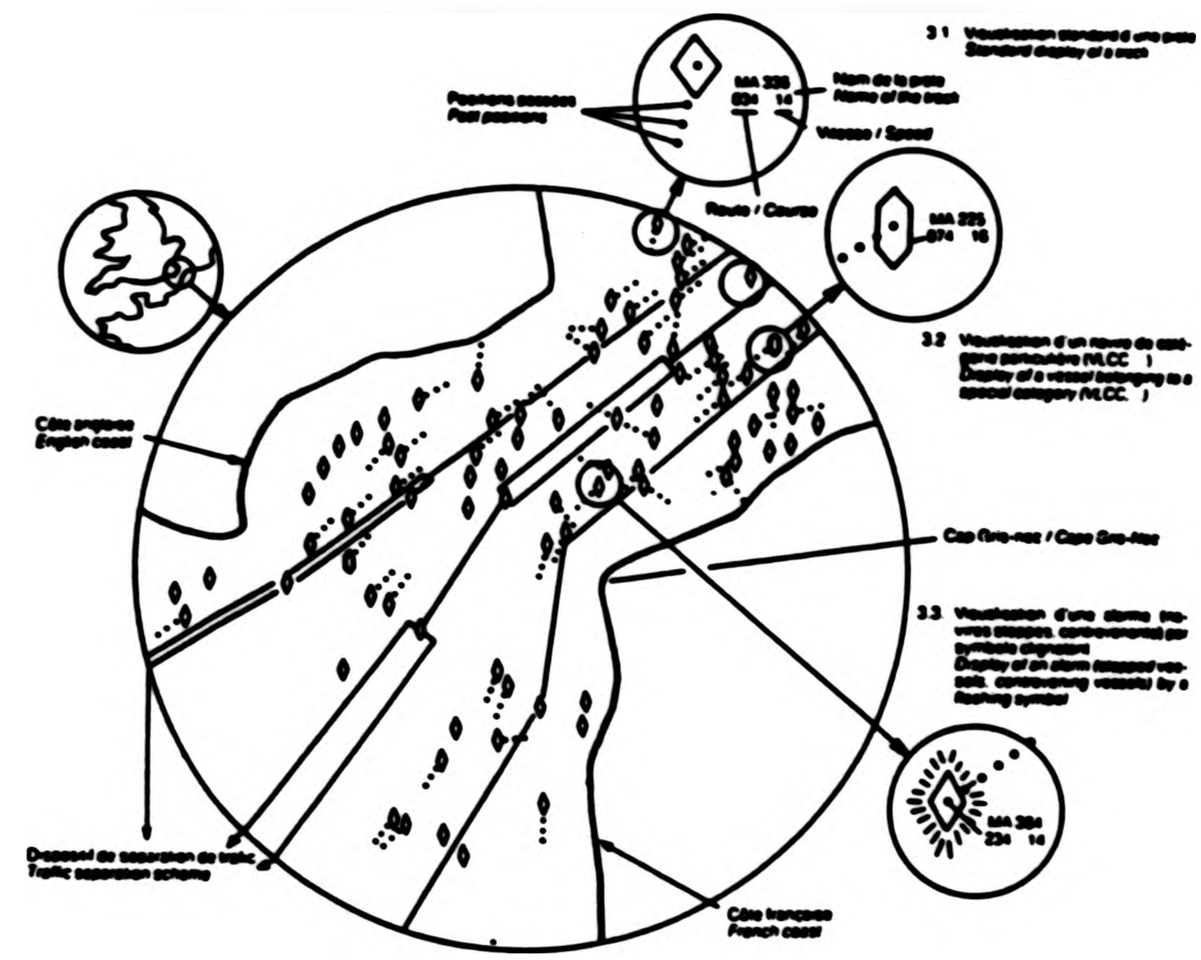

Figure 2.3 French surveillance system synthetic display.

As with the CNIS system data may be archived for subsequent statistical investigation.

It is proposed that the system for the tracking of ships with hazardous cargoes is to incorporate the automatic detection of vessels transgressing the organisation rules of the separation scheme, ships stopped in the traffic channels, ships making high amplitude manoeuvres, and rogues.

Traffic statistics presently collected manually will be measured using the tracking system. These statistics include traffic volumes of different traffic lanes, rogue vessels as a function of their situation, the number of oil tankers identified and announced by MAREP and SURNAV systems, and the number of broken down vessels.

In terms of aiding collision avoidance Degre and Tricaud state that 'navigators keep their responsibilty of collision avoidance manoeuvres and that the shore-based centre intervenes only in order to warn navigators of a conflict that they would not have forseen or to put these navigators in communication with each other so that they can adopt co-ordinated avoidance manoeuvres'.

All these radar tracking systems operated by the Coastguard, Harbour Board or Maritime Authority currently are information services. There is an obvious temptation to build into the computer systems a whole host of sophisticated facilities which would aim to duplicate or substitute tasks which many believe should only be carried out on the bridge of a ship.

There are also many other systems in the world, especially in Japan. The EEC COST 301 project is looking at the whole area of Vessel Traffic Systems (VTS) and will publish extensive details on all existing systems along with recommendations for the future.

In terms of computer technology the systems described here are not the most advanced. These systems however, allow operators to collect a higher quality of information and consequently provide a more effective information service for vessels operating in a restricted waterway. Vessel masters may choose to ignore the information but it must be understood that the computer aided systems cannot solve problems that can only be solved at sea.

(2.4.0) Interpreting the Archived Data

In order to analyse the CNIS data, the magnetic tapes containing archived data need to be read by the computer system at the Polytechnic of North London (PNL). However difficulties have been encountered in doing so. These difficulties have been a result of the incompatibility of the two computing systems. The problems are compounded by incomplete documentation of the ADP system and limited experience of the author.

The data were read from the CNIS magnetic tape to a disk on the DEC-10 system at PNL (Dec system-10 1975). The DEC-10 system is primarily a teaching machine and is not geared towards reseach projects. Nevertheless the DEC-10 was chosen as this was the only main-frame computer at PNL with graphics capabilities made available at the time this study was undertaken.

There are many ways a tape may be interpreted Choosing the appropriate method requires detailed knowledge of both systems. The problem was where to start. Initially the tape was read using the 'standard' method (ASCII). Although this allowed file identification it proved inadequate for data analysis and a good deal of time was spent appreciating what this method of reading had yielded.

The process of reading the tape became a two stage task. This is shown in Figure 2.4. A wavy line depicts the uncertainty of how appropriate a particular method was for dealing with the task. Each time the tape was read an attempt was made to identify the files so as to confirm the

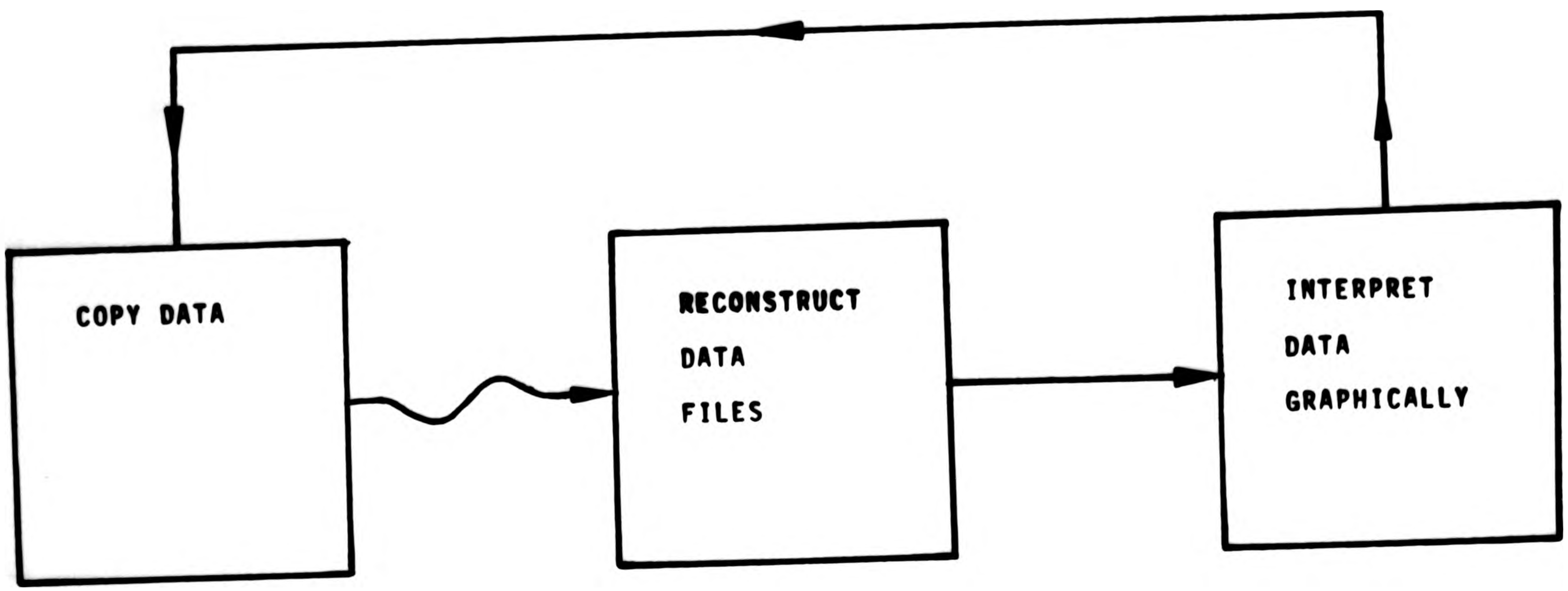

Figure 2.4 Logical view of tape reading.

validity of the reading method.

(2.4.1) Incompatibility

The main cause of the tape reading problem was the incompatibility of the two computer systems.

Computer systems are capable of storing positive integers (0, 1 , 2, ...). Each of these are stored in separate memory locations. These locations can be regarded as a set of switches which are either in an 'on' or 'off' position. If a switch in the 'on' position is interpreted as 1, and one in an 'off' position as 0, then it can be understood how a computer system stores integers in binary (base 2) form. For example 6 would be stored as 110_2 (binary). The zero signifies no 'units' , the one signifies one 'two' and the second one signifies a 'four', giving 4+2+0 = 6.

The maximum size of the number stored is dependent upon the size of each memory location. Each memory location is known as a WORD, and its length is the number of 'switches' it is comprised of. Each switch is known as a BIT (binary ~~integer~~ digit), and a group of 8 BITS is known as a BYTE. The machine from which the data are archived, HP1000, is a 16-bit machine (each word is made up of 16 bits) and the DEC-10 is a 36 bit machine.

Data and programs are invariably entered in alphanumeric form (characters and numbers). Many codes have been developed to represent characters as integers but there has been an attempt to standardise on one particular code. The American Standards Institute has published an American Standard Code for Information Interchange, known as ASCII. The code is widely used. Although ASCII code is standard, there can arise a subtle difference in the use of ASCII which is ~~particular~~ peculiar to a ~~respective~~ specific machine. Such a difference exists between the HP1000 and the DEC-10 use of ASCII.

The character 'A' is represented by the binary number 1000001_2 which is decimal 65. All ASCII codes occupy a maximum of 7 bits. This means that the DEC-10 can store a maximum of 5 ASCII codes, which represent characters, per word. So on the DEC-10 each 7-bits form an ASCII ~~byte.~~ character. For the HP1000, which is a 16-bit machine, a maximum of two ASCII codes may be stored in each word. On the HP1000 every set of 8-bits forms an ASCII byte. Clearly 1000001_2 (DEC-10) has the same ~~representation~~ value as 01000001_2 (HP1000). The most significant bit of each HP1000 ASCII byte will always be zero.

When the tape was initially read in ASCII mode, the ASCII code was correctly interpreted but the most significant bit of each HP1000 ASCII byte was ignored. ~~Which~~ This meant that data stored as binary numbers is corrupted, an example is

given in Figure 2.5, showing how the octal number 257 on the HP1000 (10101111) is corrupted to 57 on the DEC-10 (0101111) where as the octal number 163 is copied correctly.

In order to overcome this problem the files needed to be read so that the original HP1000 bit pattern was preserved in its DEC-10 representation. The magnetic tape ~~disk~~ was read again not in ASCII mode as before but in industry/image mode. This method copies exactly what information there is on a tape, making no inferences about its nature.

To each 36-bit DEC-10 word, 32-bits were copied (two HP1000 words) from the tape. This meant that the end (least significant) four bits were left blank as shown in Figure 2.6.

Since the words have been copied with left justification a program was required to extract the original HP1000 bit pattern from the contiguously written DEC-10 words.

Programs were written in FORTRAN-77 so as to allow full portability (Seeds 1981). Unfortunately FORTRAN-77 is a recent addition to the PNL computer library and operational problems were encountered as a sympathetic user (i.e. errors may be the result of bad programming practice or system

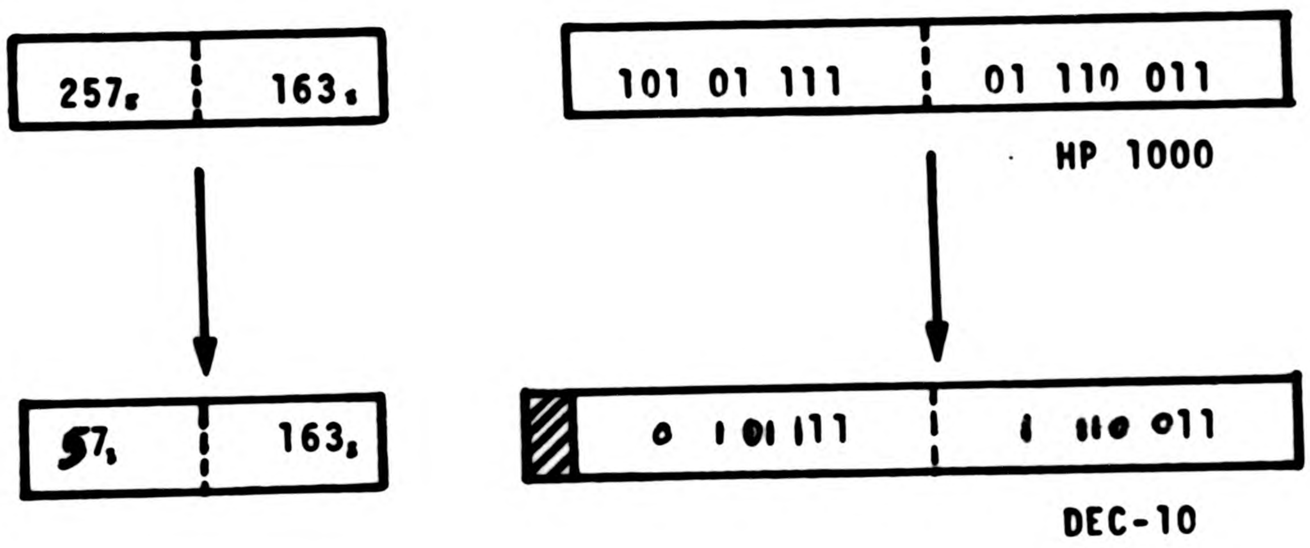

Figure 2.5 . Binary Copy.

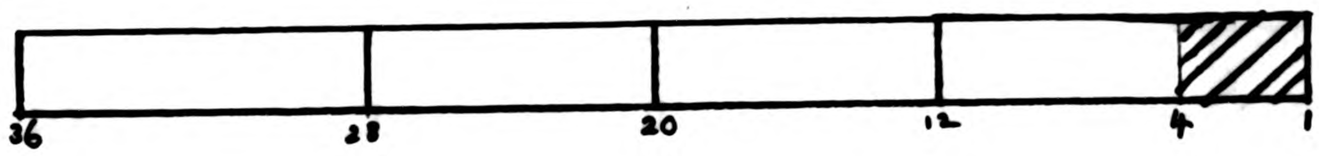

Figure 2.6 . Dec-10 Word.

deficiencies).

Diagrammatically what needed to be achieved is shown in Figure 2.7.

The program uses a Boolean mask to isolate each byte and then an arithmetic shift to move each respective byte to the right. Both the mask and the shift are expressed in octal (base 8) for simplification.

Mask (1)	776	000	000	000
Mask (2)	001	774	000	000
Mask (3)	000	003	770	000
Mask (4)	000	000	007	760

It is convenient to illustrate how the mask operates by referring to an example bit pattern shown in Figure 2.8.

Using the logical operator 'AND' on the operands Mask(1) and the example word,

Byte (1) = Word .AND. Mask(1)

this operation may be followed by referring to Figure 2.9.

Byte(1) is shifted to the right using shift(1).

Byte(1) = Byte(1) / Shift(1)

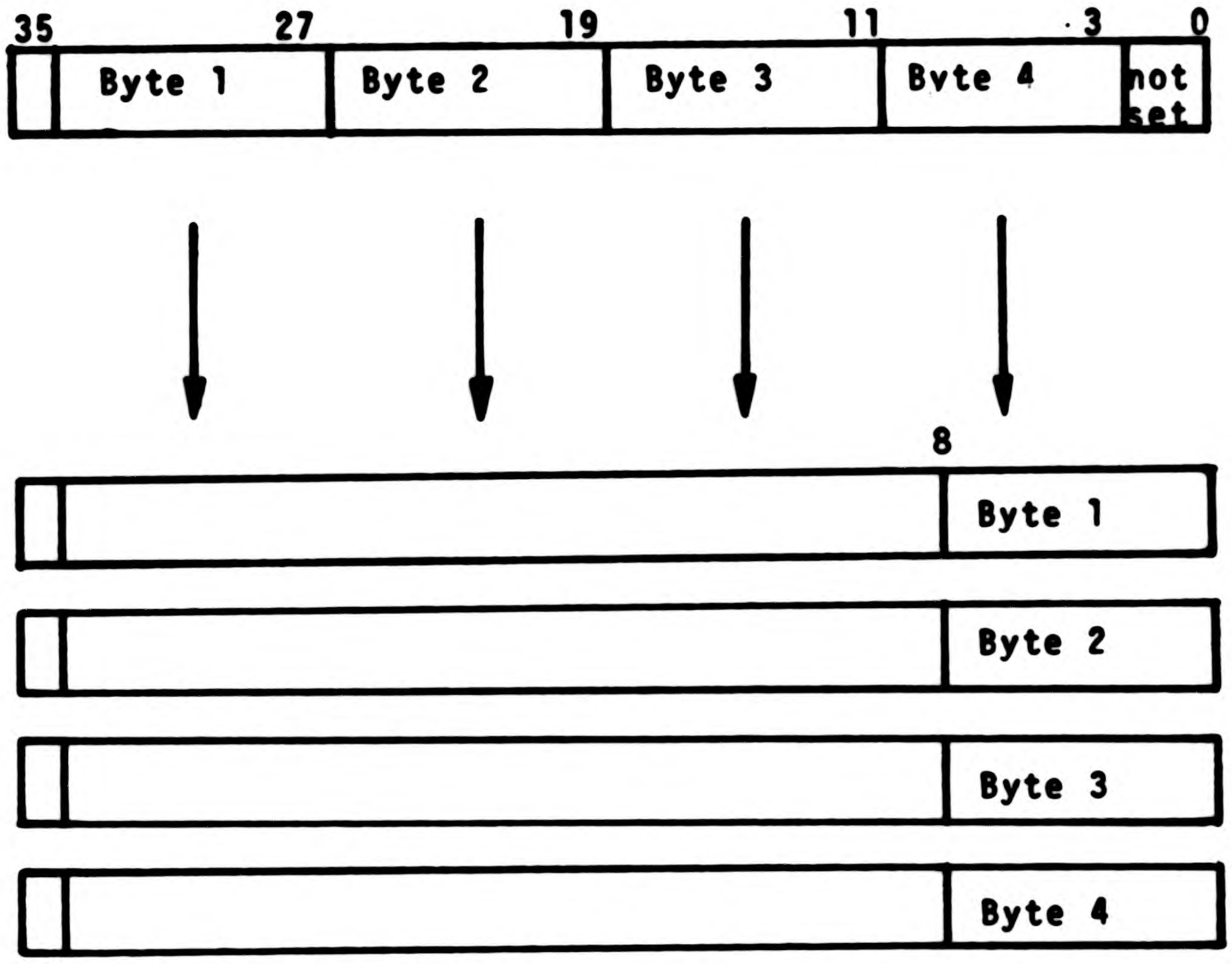

Figure 2.7 . Assembling HP1000 Bytes.

Figure 2.8 . Example Bit Pattern.

Using the logical operator 'AND' on the operands Mask(1) and the example bit pattern.

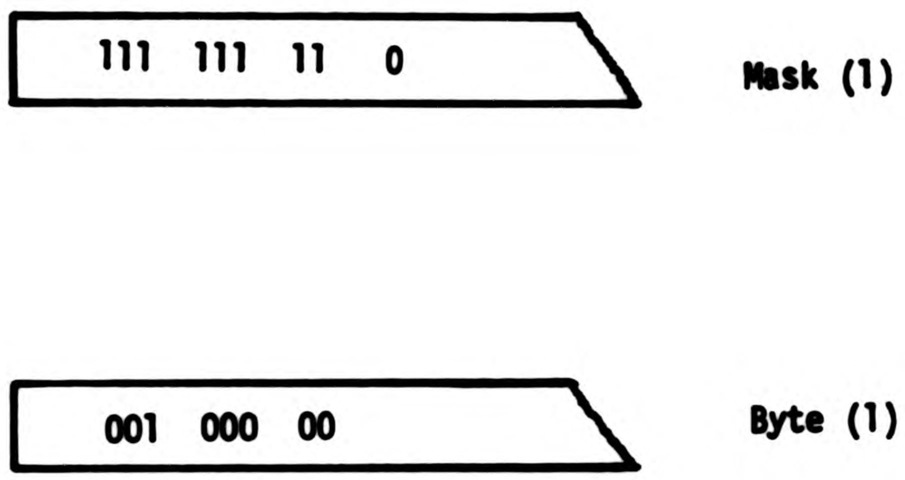

Figure 2.9 .Showing logical 'AND'.

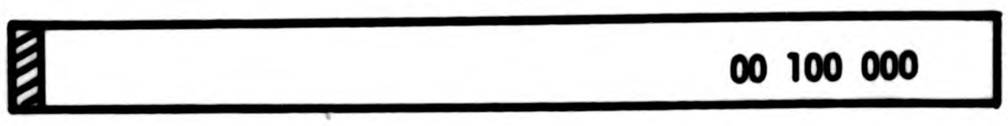

Figure 2.11 .Resulting Bit Pattern of Byte(1).

where shift is,

Shift (1)	002	000	000	000
Shift (2)	000	004	000	000
Shift (3)	000	000	010	000
Shift (4)	000	000	000	020

Where,

Shift(1) moves Byte(1) 28 places to the right.

Shift(2) moves Byte(2) 20 places to the right.

Shift(3) moves Byte(3) 12 places to the right.

Shift(4) moves Byte(4) 4 places to the right.

In a decimal number system when dividing by 10, the effect is to shift the numerals 1 place to the right. Likewise in a binary number system as used by a computer, when dividing by 2 the effect is to shift the numerals (bits) one place to the right.

In the example given the resulting bit pattern of Byte(1) is shown in Figure 2.11.
A further program has been designed to reconstruct the HP1000 16-bit word by combining each pair of 8-bit bytes previously obtained.

Once the magnetic tape had been successfully read and reconstructed an examination of the data and the extraction of relevant information could be completed.

(2.5.0) File Construction

All items of information that refer to a single basic logical unit are held as an entity known as a record. Records can be fixed or of a variable length. The track history file is made of records of fixed length 128 words (HP1000).

The track history file consists of a File Header, Track Snapshot Records, Waymark Snapshots (from the Waymark File) and Label Records. The logical record view of the Track History File is shown in Figure 2.12.

The file header which identifies the file occupies one record. Each record is of length 128 words. A full description of the Track History File format is given in the appendix to this chapter (Appendix II).

File Header

Snapshot Header

New Tracks

LT2 Table

Label Changes

LT1 Table

Waymark Snapshot

Label Table

End of Record

Figure 2.12 .Logical record view of the Track History File.

(2.6.0) Summary

With the understanding of the data organisation, software has been developed allowing data analysis. In the next chapter details of the developed software are given together with design considerations and applications.

Chapter Three

Real Life Data Examination

(3.1.0) Introduction

Once the CNIS magnetic tape had been successfully read, copied and the chosen data files had been extracted the next stage was to examine these files graphically. This examination initially helped to validate the file reconstruction and to allow analysis of navigational data.

A start had been made on the development of software at the Polytechnic of North London in co-operation with the National Maritime Institute but this proved to be of little use. For computer software to be of use to researchers it must be possible for the software to be adapted as requirements progress. In order for something to be adapted it must firstly be comprehensively understood. Similarly for a computer program to be adapted, adequate documentation must be written so that the interpreter is presented not only with a set of computer programs written in what might be an unknown language, but also a fairly detailed description of how the program works. This must include what the aims of the programs are and a schematic representation of the method used in achieving these aims. Software limitations must be indicated as well as possible design improvements, these are standard computer software design practices.

When presented with previously developed software no such documentation was available. Assuming the programs to be of use in that they were performing a task, they proved to be little use for further adaption and subsequent research. Consequently new software has been developed which can graphically represent the data contained in the track history file stored on the CNIS magnetic tape.

(3.2.0) General Requirements

The main problem when analysing the CNIS archived data is the sheer volume of it. One Track History File when expanded occupies some 3000 blocks of DEC-10 memory storage (128 words per block). Storage of data is not the main cost constraint in mainframe computer software design. On a time sharing system such as the DEC-10 the main constraint is the amount of 'working storage' required for a program to run. The working storage of a computer system can be regarded as the memory available for each program when executed. For a program to be executed on a time sharing system the source code along with all required memory location space is copied to working storage. This means that every variable has to be allocated space. With some 250 vessels tracked for a three hour period (positions and velocities recorded every minute) 72000 separate memory locations are required. This is certainly not operational and such a program would not run interactively. A method is required which scans the data files only referencing and storing those data relevant at a particular instant. This can be considered to be a restriction of the data set. A linked list method has been used consisting of two sets of 250 circular queues of length 30 (time units). Once the program is running it is necessary to scan back and forwards, with respect to time, within this restriction requesting position and velocity data at will with the facility to pinpoint and record any particular incident. For the graphical representation, the software had to be user friendly in that it is easy to operate providing clear unambiguous pictorial representation of vessels' position and track history. The coastline also had to be represented. Details of the graphical design considerations are given later in this chapter.

(3.3.0) Use of Data Structures

Programs have been written allowing an efficient method for plotting vessel progress, to enable encounter recognition and the measurement of requested behavioural parameters.

To access ship data efficiently in the Dover Strait interrogation in both snapshot and track mode is necessary. Snapshot mode consists of position and velocity information of all vessels for a given instant in time, this is required when automatically detecting encounters and measuring certain behavioural parameters. Track mode consists of historical position and velocity information of any specified vessel and is required when plotting vessel progress and calculating angle of manoeuvre, relative bearing and angle of approach. Once the data are expanded they are uniquely in snapshot format. The program constantly reads the data file allocating to working storage the positions and velocities of up to 250 vessels for a 30 minute period. The time period was chosen since it is unlikely that a detectable encounter will last any longer. The position and velocity time snapshots for each vessel are stored in two similar circular queues (x and y co-ordinates combined to save space), which allows a lookback facility of upto 29 time units. The specification allows for 250 vessels maximum which can be increased if necessary. The vessel tracks are stored in a linked list system so that as vessels leave and enter the system memory requirements are minimised. Once a vessel has left the CNIS monitoring system for 30 time units that vessel is deleted from the list and its storage location made available for the next acquisition.

A data structure in computing is a system for ordering data items so that both storage space and/or access time is minimised.
Lists are a type of data structure. The items are related in two ways. First they are all of the same group, for example ship identifiers. Second, they are stored in

sequential memory locations. This is shown in Figure 3.1.

In order to reference the list, its beginning and either its end or length need to be known. A list has some basic problems that arise on addition and deletion. When adding an element to the list somewhere between the end and beginning position, the problem is how to store existing elements so as to preserve the order.

To make a list more flexible and easier to update, a pointer (link) to each entry in the list is included. This is shown in Figure 3.2.

In a linked list each element contains a pointer that tells the location of the next element. The pointer eliminates the need to store the elements of a list in a contiguous memory region. The procedure of deleting and adding elements to a linked list may be followed by referring to Figure 3.3. A new entry enters the list at the selected point amending the pointers between existing elements. Likewise for deletion an element is overlooked by removing its pointer.

The data structure used is a linked list of ship identifiers each containing two circular queues of length 30.

The linked list data structure is a general purpose data structure. It can be used to store elements and maintain an order. However it does require time and programming effort

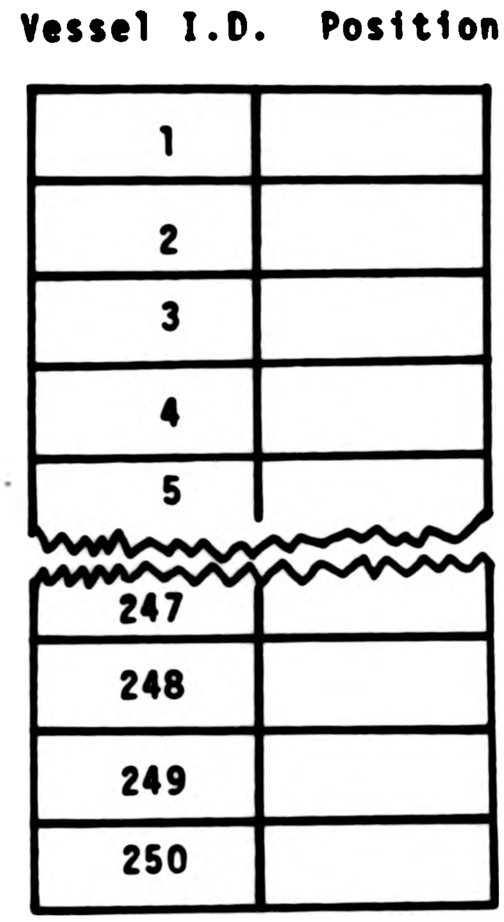

Figure 3.1 .A simple List.

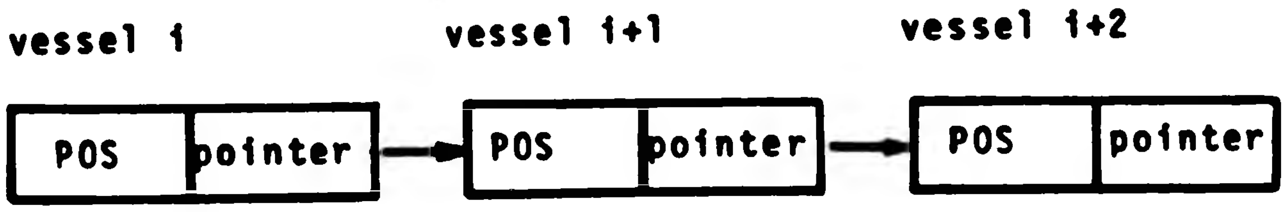

Figure 3.2 .A linked list.

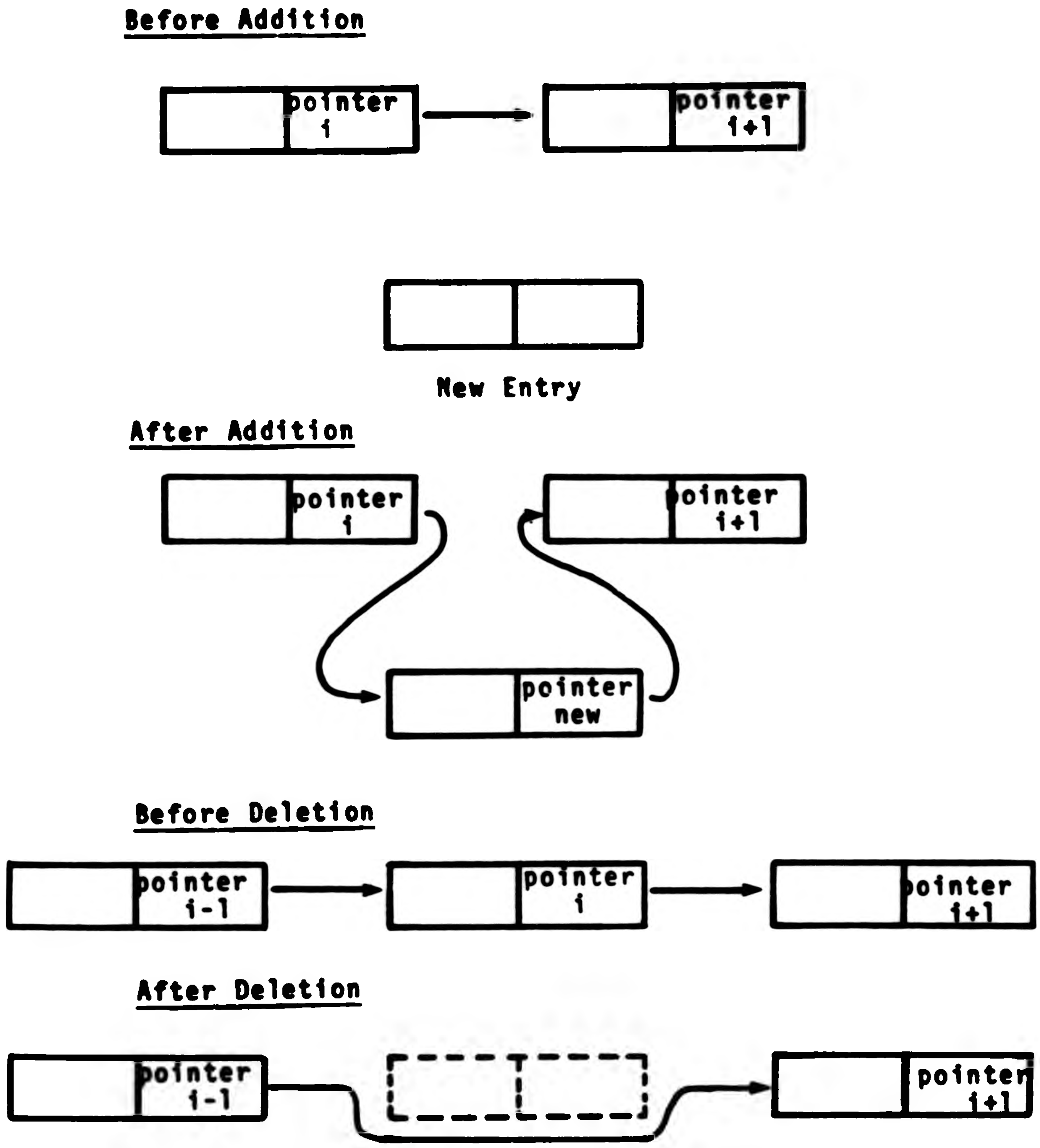

Figure 3.3 .Insertion and Deletion on a linked list.

to update and scan. Certain applications do not need to access every element of a list. Instead they may want to retrieve only the first or last element on the list. Any updates are made at the beginning or the end of the list. Such a structure is known as a queue. A record is kept of the current position of the queue and the next data item is entered into that position. The circular queue simply overwrites itself when full. As long as a record of the current position is kept only unnecessary data are deleted. Together this linked list of ship identifiers and the circular queues containing position and velocity data form the complete data structure for the graphically interactive suite of programs. Diagrammatically this is shown in Figure 3.4. For a greater explanation of data structure methods see Lewis and Smith (1982).

A number of smaller problems needed to be solved in arriving at the solution to the general problem. Vessels leaving and entering the system needed to be detected and the queue of a vessel which had left the system had to be advanced for 30 time units so that on looking back over the track histories vessels having recently left the system are not overlooked. The general order of operations is shown in Figure 3.5.

<u>(3.4.0) Graphical Representation</u>

The 1960's were characterised as the era of computer numbers, the '70's as the era of computer words while the

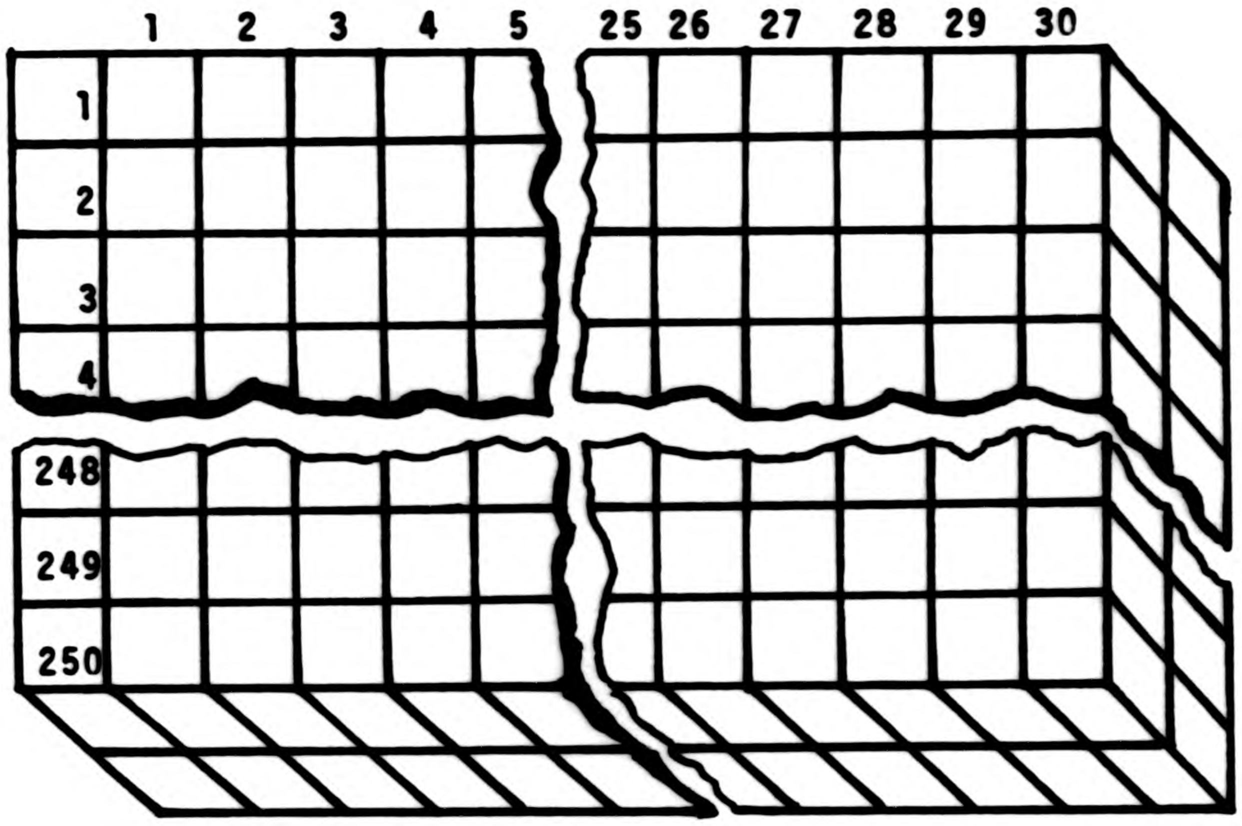

Figure 3.4 . Basic Overview of Data Structure.

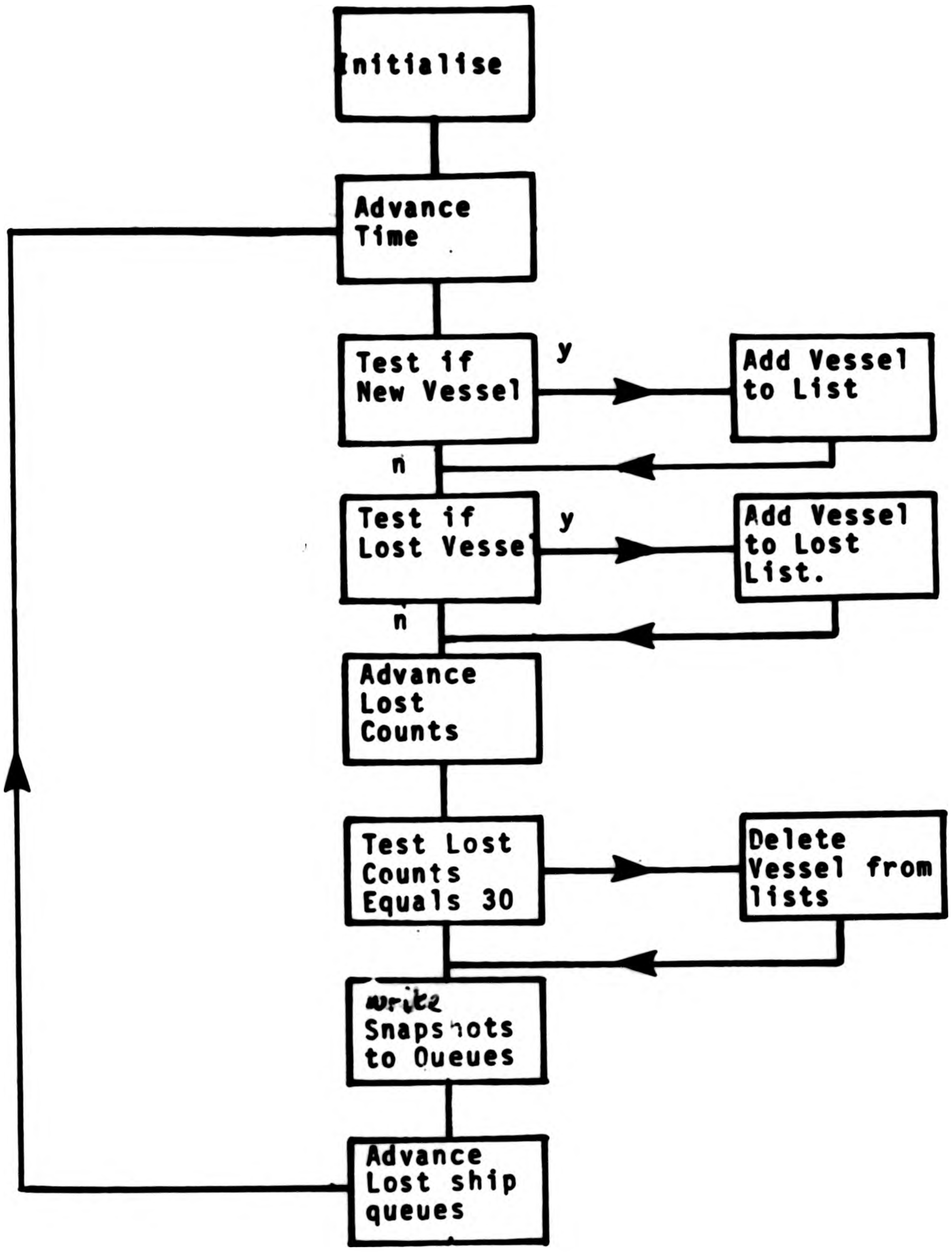

Figure 3.5 . Order of Operations.

80's as the era of computer graphics. Computer graphics has extended traditional data processing methods by providing a way of communicating information pictorially. A significant reason for the growth in the use of computer graphics is its role in the decision making process. Information can be both digested and understood more rapidly when it appears visually. Trends and anomalies in data often are more readily discerned when information is rendered in graphic as opposed to numeric or tabular form. Quite clearly the trace of a ship's track history is more easily understood than a sequence of position data. The advancement of computer technology itself has also contributed to the growth in the use of computer graphics.

Computer graphics and graphical communication are now being recognised by decision makers as a powerful and convenient mechanism for exchanging information between people in a wide variety of situations. Beyond the simple depiction of the graphic image itself, these images can be used in the context of a comprehensive information system to achieve expanded analytic and representational capabilities.

Computer graphics are playing a key role in flight deck and simulator designs to name just two examples of applications in the navigational environment.

When analysing the CNIS archived data in this study, it was decided that not only the data itself should be given graphical interpretation but all inputs requiring a decision from the software user. Programs have been written using FORTRAN-77 (Seeds 1981) programming language and the GINO-F (2.7a) graphical subroutine library (Gino 1976).

(3.4.1) Design of the Interface

In the past when developing computer software the role of the human-computer interaction specialist has been kept remote from the programmer or system designer until a specific problem arose. Currents trends in interface design are moving away from this pattern. If effective interaction products are to be bought and sold, all personnel involved in the design process must be aware of the basic issues and principles. In practice this means that the program specifications need to be drawn up early on in a project's development, indeed before any progress is made on the design.

There are many factors concerning visual perception to take into account when designing interactive software. It is beyond the scope of this project to investigate these detailed areas, but the reader is referred to Hulme (1985) as a basis for further study.

This review is concerned with design considerations for the specific construction of the graphical software developed to allow the user to interpret and manipulate navigational data.

(3.4.2) Input - Devices and Commands

Generally, a command specification is used when applications have a large possible number of facilities and it is to be used by experienced users of that software. When designing the navigational software the following questions need to be considered.

1. Who would be using the system and what knowledge will that user possess?

2. What expectations has the user of the system?

3. What hardware facilities are available?

4. How is the information to be communicated?

Visits were made to both the CNIS operations centre at Langdon Battery and the British Airways training centre at Heathrow to determine the nature of graphical interface design in the navigational environment.

At the operations centre at Langdon Battery a general overview of the CNIS system is given by means of a central console. An operator is presented with a synthetic radar screen whose magnification can be enlarged by means of a rotating tracker ball and key pad. Ship identifiers may be displayed on request and VHF/DF information is displayed by way of position fixing lines. Projected courses can also be superimposed over plots, these are based on velocity predictions and are represented as velocity vectors. The console is very easy to operate and particular situations of interest can be isolated by the operator and stored for subsequent plotting. Information concerning vessels required to report in may also be displayed.

The training centre at Heathrow uses various types of graphically interactive systems. These range from navigational simulators to instrument panels of aircraft including simulated displays of inertial navigational systems and flight computers. Some of the instrument panels incorporate touch sensitive screens. This form of input is designed to take the user away from the typewriter keyboard concept. Cross beams of light are projected across the surface of the screen, any break in the beams caused by the operator is detected, referenced on the screens grid and acted upon according to the software design. This system is both expensive and considered far from ideal. The main problems are that the best position for viewing a touch sensitive screen is further away than the comfortable position for pointing. Also the screens can/not give very high resolution though this has been considered secondary to the main advantage that the use of the keyboard is undesirable and the environment is considered too hostile for any other form of input device.

Soft keys are also used at the training centre. These are unmarked keys placed around the display screen whose function is indicated on the screen. This makes it possible to change the function of the keys depending on the context in which they are being used.

The following is a list of input devices widely available for differing input techniques. Reid (1985) arranges the list in preferred order with items separated by '/' considered of equal preference.

<u>Picking</u>	mouse, joystick/ tracker ball, light pen/ touch screen/ soft keys, function keys.
<u>Positioning</u>	mouse, joystick/ tracker ball, light pen/ touch screen, cursor keys.
<u>Numeric Input</u>	numeric key pad, alphanumeric key pad, tablet.
<u>Text Input</u>	alphanumeric key pad, tablet (limited input only).
<u>Drawing</u>	tablet, mouse, light pen.
<u>Digitising</u>	tablet.

Digitising is where the user enters a sequence of discrete co-ordinates to represent images from some two dimensional source. The mouse is good for positioning and picking and is pushed along a flat surface near to the display. By means of either a light beam or tracker ball type potentiometers movements of the mouse are translated to and interpreted by the program. The joystick is also an effective method for picking or positioning it though needs to be supplemented by a key pad in many cases. At the Polytechnic keyboards incorporating joysticks are available but are biased towards right handed operators. The light pen is a forerunner and cheaper version of the touch sensitive screen and suffers from dirt problems and relies on suitable levels of ambient lighting.

Clearly when choosing an input device the designer is constrained by the avilability of hardware facilities. The data have been given representation close to the operations centre display. A tracker ball is not available on the main frame computer at the Polytechnic, but SIGMA graphics terminals provide both suitable resolution and joystick facilities. For entering numerical information the terminal provides a separate numerical key pad and menu items may be chosen by 'hitting' a designated key.

With the input device and the format of the graphical display chosen, the design of the program driver needs to be considered.

(3.4.3) Input-Output Detail

The setting up of any soft keys is impractical and a command driven system is not suitable for this system. A general user of the system would be either a maritime researcher or a mariner. In either case the user would need quick access to the system without reference to a manual and would prefer to pick items off a menu rather than enter long strings of commands. A menu driven sytem has been developed where items and choices are selected by means of the joystick. Any data output is displayed within the graphical screen and positioned neatly by appropriate menu options. The package incorporates seven menus, all on the same level i.e. there is no hierarchical structuring. Some options are common to several menus as they can be applied in differing contexts.

The viewing screen is split into two main distinct areas, the plotting screen and the menu display which are shown in Figure 3.6.

The plotting screen is used to represent graphically the archived CNIS ADP data. The screen incorporates a scaled border in nautical mile graduations whose spacing depends on the size of magnification referred to as the 'zoom factor' which may be altered by the user at any stage of analysis

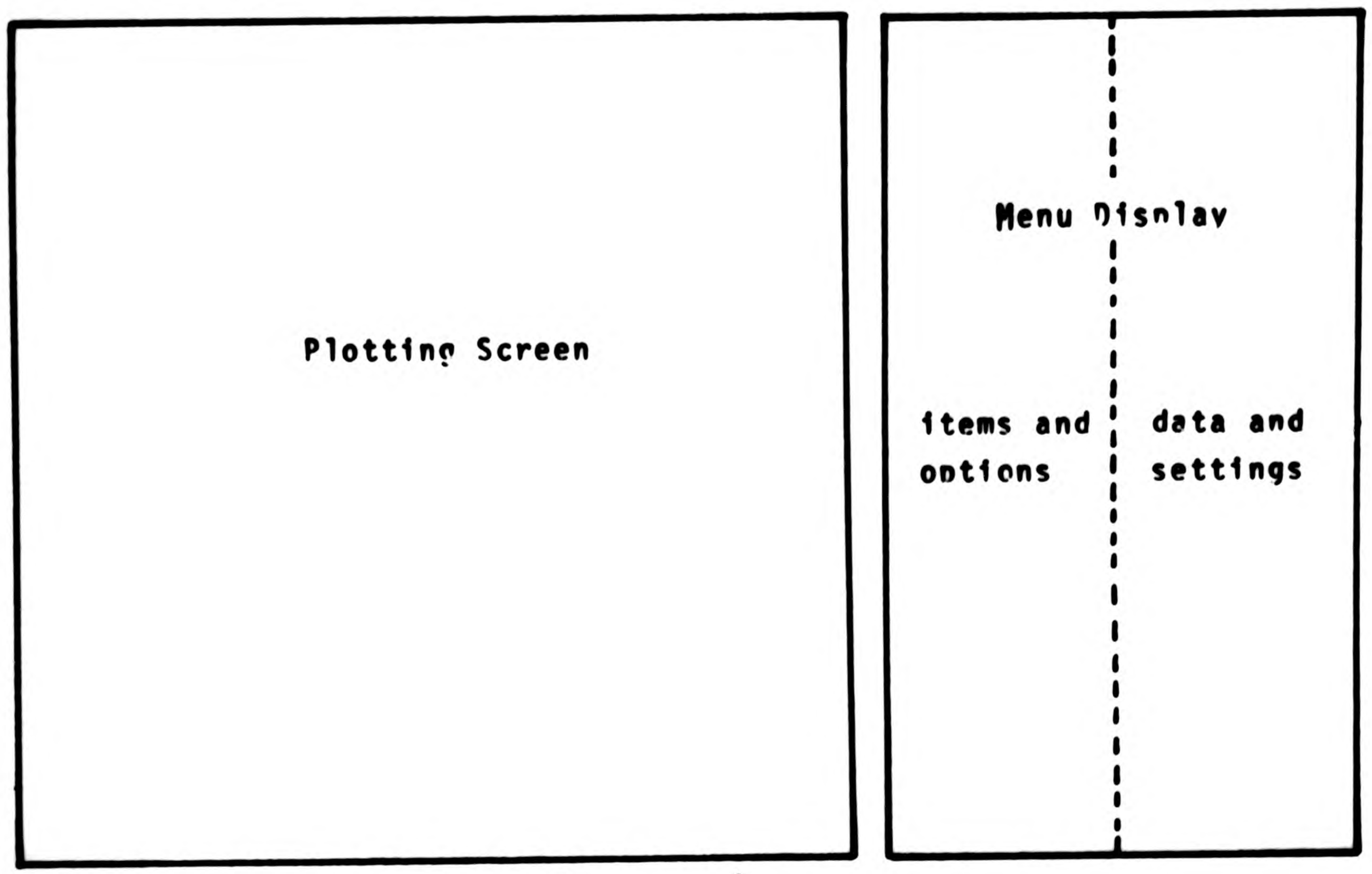

Figure 3.6 . Viewing Screen.

without affecting the data structure.

The menu display is on the right hand side of the viewing screen and displays information to the user either on request or automatically and accepts instruction by way of menu options. Each menu has a unique identification colour. A full description of menus and menu options is given below.

The plotting screen occupies the major part of the viewing screen. Vessel positions are represented as 'dots' whose radius ~~size~~ is scaled linearly by the zoom factor. The most recently plotted position of any vessel is displayed in an identifier colour which differs from track history colour. In this way the heading of any vessel may be estimated. The track history length displayed may be varied interactively. The distance between successive dots of the same vessel allows relative speed appreciation. The position 'dots' are plotted at minute intervals corresponding to the stored snapshots whose time is displayed automatically on the menu. Any situation may be magnified or reduced using the 'ZOOM' option. The package allows measurement of a number of parameters relevant to this research project and incorporates the developed RDRR+ technique for automatic encounter detection detailed in chapter four. The package may be amended to measure parameters other than those offered.

(3.4.4) Menus and Menu Options

MENU 1 (main menu-display colour red)

HELP: It is envisaged that if the package were to be sold commercially all necessary help documentation would be built into the program and retrieved while the program is running. By selecting the help option followed by any other offered option help details could be superimposed over the plotting screen. Options could be given for more detailed information with the plotting screen refreshed on conclusion of the help required. The implementation of the help facility is relatively straightforward but has not been included as a facility within the framework of this particular research. The help option would be common to all menus.

TIME: Every snapshot read from the original CNIS data file has a time reference. This time reference has been copied to the expanded data file of track history. As the plotting screen updates successive plots the time window automatically displays the time of the most recently plotted snapshot. This includes snapshots viewed in lookback mode. The 'TIME' option cannot be selected but is for the output of information to the user. The information is offered on all menus except MENU3.

ZOOM: (zoom factor and focal point) option is the one

menu option offered where the user graphically interacts with the data. On selection the cursor may be positioned anywhere over the plotting screen to record a focal point of interest. The zoom factor is then selected, the plotting screen cleared and refreshed with the new plot. On refresh the current snapshot is displayed with track history length 1. The CNIS grid reference of the focal point is displayed adjacent to the 'REF:' menu item.
To select, the cursor is positioned over the option and the space bar depressed. The cursor is then positioned over the focus of interest and the zoom factor selected from the numeric key pad. The magnification is fixed and calculated as; (zoom factor - 1)*5 + 1. On refresh the border scale is redrawn accordingly.

LABS: (labels) On selection the External Track Number (ETN) of every vessel displayed inside the plotting screen is drawn near to the most recently plotted snapshot. This display is suspended where it would infringe the plotting boundary. To select this option the cursor must be positioned over the displayed command. On selecting the '1' key from the numeric key pad the ETNs are displayed, a '0' selection will remove all ETNs. Labels are scaled so they increase in size linearly as the zoom factor. This option is offered on MENU 2, MENU 4 and MENU 5.

LKBK: (lookback) allows the user to plot any previously plotted snapshot and continue plotting from that point. The maximum lookback is 29 minutes. Any subsequent calculations will be performed for specified vessels for the displayed snapshot. On selecting 'LKBK' a white flag is displayed in the top right hand corner of the menu until the lookback is completed. Plotting is more rapid in the lookback mode as new snapshots do not have to be read and stored from the expanded data file. File reading resumes when the lookback is completed. Following option selection the program expects two further entries from the numeric key pad each in the range of 0 to 9 inclusive, which combine to give the two digit lookback increment.

ENCT: (automatic encounter detection) is concerned with the technique developed during the research programme. On selection the program scans the previous 10 and next 20 snapshots for situations considered to be encounters. Detected encounters are entered into a queue of maximum length 30. The developed technique monitors the RDRR+ relationship and checks for critical values. Detailed explanation of the RDRR+ method is given in chapter 4. When the scan is completed the cursor returns to the menu and the total number of encounters detected during the 30 minute scan is displayed adjacent to the option. The user can then either plot the encounter at the head of the encounter queue or display the encounter table over the plotting screen. The encounter table lists the next five recorded encounters (yet to be viewed). Encounters are referenced by time, the ETNs of the two vessels involved and type (meeting, crossing and overtaking determined by angle of approach). On plotting, the reference to the encounter at the head of the queue is deleted and further displays of the encounter table will not include that plotted encounter. When the encounter table is removed from the plotting screen the last snapshot displayed is refreshed.

To select the encounter scan the cursor is positioned beyond the right hand side of the menu option and a '1' is selected from the numeric key pad. The cursor will not be visible and returns on completion of the scan.

To plot the head of the encounter queue the cursor must be positioned over the 'ENCT' option and the space bar depressed. The encounter is displayed with maximum zoom factor. To display the encounter table a '1' from the numeric key pad must be selected whilst the cursor is over the menu option. A '0' selection will remove the encounter table. The next stored encounter may be displayed without having to remove the encounter table, this is automatically achieved. When the encounter queue is empty a null table is displayed if requested and a request to plot the head of the encounter queue is ignored.

DISP: (display) allows the user to specify the track history length. The option is selected by positioning the cursor over the option and requesting the length from the numeric key pad. A '0' selection will give a track history of infinite length known as a fixed plot.

RNGE: (range) offers the facility of range rings to help represent scale. Scale is continuously displayed by way of marks at nautical mile intervals along the plotting border. On selecting 'RNGE', rings are superimposed over the plot and the distance between successive rings is displayed on the menu adjacent to the option. To select, position the cursor over the option and depress '1' from the numeric key pad to draw the rings, and '0' to remove the rings.

ADV : (advance) The plotted snapshot is advanced by selecting this option. The advance increment may be entered or the plot may be advanced by the previously entered increment (one from start). The cursor is returned to the menu on completion of an increment. If the program is in lookback mode the advance will terminate when the lookback is completed. A new advance increment is entered by positioning the cursor to the right hand side of the option and entering the new increment from the numeric key pad. The currently held increment is selected by positioning the cursor over the option and depressing the space bar. The advance increment is displayed after calls between menus. The 'ADV' option is offered on MENU2.

RWND: (rewind) allows the user to return to the top of the expanded data file without changing any of the entered parameter or option values. Selection is made by positioning the cursor over the option and depressing the space bar. The menu is refreshed and the initialising screen displayed.

MENU: allows the displayed menu to be changed. Selection is made by positioning the cursor over the option and requesting the required menu from the numeric key pad, values in the range of 1 to 7 inclusive are expected. This option is available on all menus.

REF : (reference) as with 'TIME' display, this item is one way in that it displays information automatically. As subsequent snapshots are plotted X and Y components of the centre of the plotting screen are displayed adjacent to the item. The components are those taken from the CWIS artificial tracking grid, and are displayed as a cross reference.

<u>MENU 2</u> (encounter specifying menu - display colour green)

<u>VES1:</u> (vessel one) allows the user to specify a designated 'own ship' (sometimes referred to as the central vessel) for any statistics selected following this specification. On selection the item is cleared of any previously held value (zero on start), and expects a three digit input from the numeric key pad. The three digits refer to the ETN of a chosen vessel. The input is selected by positioning the cursor over the item and the space bar depressed.

This ETN is entered automatically when the head of the encounter queue is plotted from MENU1. Any ETN entered automatically or manually is held until input is again selected.

<u>VES2:</u> (vessel two) allows the user to specify a designated 'target ship'. Selection of this is input is as for 'VES1:'.

<u>DIST:</u> (direct distance separation) on selection displays, adjacent to the item, the distance separation of the 'own' and 'target ships' (nautical miles). The display is updated automatically when the plot is advanced by selecting the 'ADV:' option from MENU2. The output is selected by positioning the cursor over the

item and depressing the space bar.

ECPA: (expected closest point of approach) on selection displays, adjacent to the item, the expected closest point of approach for the two specified vessels. This is calculated from position and velocity information, and is updated automatically as the plot is advanced by selecting the 'ADV:' option from MENU2. The display is requested manually by positioning the cursor over the item and depressing the space bar.

RDRR: or RR : or RDR+: (Range to Domain over range rate or Range over Range Rate or extended RDRR) The menu item displayed may be selected. This is achieved by positioning the cursor over the currently displayed item (RDRR on start) and selecting '0', '1' or '2' from the numeric key pad where '0'- RR; '1'-RDRR; '2'- RDR+. The ratio value chosen is displayed adjacent to the chosen menu item. By positioning the cursor to the right hand side of the item and depressing the space bar the value of the currently displayed output is updated. The displayed item is updated automatically on advancing the plot by selecting the 'ADV:' option from MENU2.

$RR = R/\dot{R}$; $RDRR = (R-D)/\dot{R}$;

$RDRR+ = ((R-(D+\delta)/\dot{R} - \vartheta_1$

where R is range (n.m.)

$\dot{R}$ is differentiation of R w.r.t time.

D is the size of the domain (n.m.).

ϑ_1 is a time increment (mins).

δ is a distance increment (n.m.).

and D, ϑ_1, δ can all be specified interactively from MENU5.

ADV: (advance and update) as MENU1 but after each plot displays of 'DIST:', 'ECPA:' and 'RR/RDRR/RDR+:' are updated.

MENU3 (quick access of expanded data file menu - display colour dark blue)

This menu differs from all others in that it deals directly with the reading of the expanded file of track history. The user may specify an exact position in the expanded file from where the program initialises data structure. The reference information is the ETN of a vessel (optional) and the time of snapshot.

ETN: (external track number) The ETN of any vessel may be specified as a reference point. On location the corresponding vessel is plotted at the centre of the plotting screen with maximum zoom factor. If the ETN is invalid the origin of the CNIS ADP grid is displayed. The ETN is entered by positioning the cursor over the item and depressing the space bar. Three digits are then expected from the numeric key pad as for the 'VES1:' option on MENU2.

TIME: The time of any snapshot may be specified as a reference point. This time is entered by positioning the cursor over the item and depressing the space bar. Four digits are expected from the numeric key pad. The first two digits represent the hour and the second two the minutes past the hour of the snapshot.

SCAN: on selection of this item the program scans through the expanded file of track history having previously entered the ETN and TIME as reference points.

On locating the specified snapshot and vessel the data structure is initiated, the plotting screen cleared and refreshed with the specified vessel as focal point with maximum zoom factor. The previous 20 snapshots are stored to facilitate lookback. To select, position the cursor over the option and depress the space bar.

MENU4 (primary parameter menu - display colour light mauve)

VEL : (velocities) on selection displays adjacent to the item the velocities of both 'own' and 'target ships' (knots). To select, position the cursor over the item and depress the space bar.

__RLBG:__ (relative bearing) on selection displays adjacent to the item the relative bearing of the 'target ship' from the 'own ship' (degrees). Selection as for 'VEL:'.

__RVEL:__ (relative velocity) on selection displays adjacent to the item the velocity of the 'target ship' relative to 'own ship'(knots). Selection as for 'VEL:'.

__AMVR:__ (angle of manoeuvre) on selection displays adjacent to the item the angle 'own ship' has manoeuvred (degrees). A straight line course between positions one and two minutes previous is assumed and the angle of deviation from this straight line is calculated. Selection as for 'VEL:'.

__APCH:__ (angle of approach) on selection displays adjacent to the item the angle that the two vessels ('own and target ship') are approaching each other (degrees). The angle is calculated as the difference between headings and is used to classify encounter type. Selection as for 'VEL:'.

__VES :__ (vessels) automatically displays the ETNs of 'own' and 'target ships' adjacent to the item on call to the menu and cannot be selected. The information is also displayed on MENU7.

<u>MENU5</u> (data entry menu - display colour light blue)

This menu provides facilities to specify domain sizes and RDRR+ parameter value settings.

<u>MEET:</u> (meeting encounter domain size) allows specification of the size of the meeting encounter domain size (n.m.). On selection the held value is cleared and three digits from the numeric key pad are expected. These digits represent unit, tenths and hundredths of nautical miles. The accepted value is displayed adjacent to the item. To select the item position the cursor over the item and depress the space bar. The default value is 0.24 n.m.

<u>CROS:</u> (crossing domain encounter size) allows specification of the crossing domain size (n.m.). Selection and input as for 'MEET:'. The default value is 0.50 n.m.

<u>OVER:</u> (overtaking encounter domain size) allows specification of the overtaking encounter domain size (n.m.). Selection and input as for 'MEET:'. The default value is 0.29 n.m.

<u>DELT:</u> (delta) allows specification of the distance increment value (n.m.) used in calculating the RDRR+

ratio for determining automatic encounter detection. Selection and input as for 'MEET:'. The default value is 0.0 n.m.

__THET:__ (theta 1) allows specification of the time increment value (mins.) used in calculating the RDRR+ ratio for determining automatic encounter detection. Selection and input as for 'MEET:' (minutes not n.m.). The default value is 0.00 minutes.

__MENU7__ (secondary parameter menu - display colour light mauve)

__TCPA:__ (time until the expected closest point of approach) displays the time until the expected closest point of approach (mins) of 'own' and 'target ships' and is calculated from position and velocity information. The value is displayed adjacent to the item automatically on menu call.

__INDS:__ (indirect distance separation) displays the total indirect distance separation (n.m.) between 'own' and 'target ships' via their closest point of approach and is calculated from position and velocity information. The value is displayed adjacent to the item automatically on menu call.

<u>MENU6</u> (relative plot menu - display colour red)

menu selection displays a relative plot of the selected encounter on the plotting screen. The menu is displayed as MENU1 and is inoperative.

Menu selection must follow a lookback, 'own ship' is placed at the centre of the plotting screen (North up) surrounded by its relevant domain which is dependent on the encounter type. The 'target ship' is plotted relative to 'own ship' for the lookback period and the relative track is given continuous time mark digits initialised at zero. The plot has maximum zoom factor and is displayed in white. On completion of the plot depression of the space bar returns to MENU1 and refreshes the plotting screen with the last plotted snapshot. Information concerning the encounter type and the domain size is displayed over the plotting screen in the left hand top corner.

<u>(3.5.0) Summary</u>

The availabilty of the CNIS ADP archived data presents the researcher with great opportunity to investigate vessel traffic and vessel traffic system behaviour. A software package has been developed to analyse these data. Data have been structured allowing quick access for plotting and calculation. The package uses current graphical facilities so that the user may interact with these data. Possible facilities offered are limited only by imagination but those included have been in the context of this research project namely specific parameter measurement and the development of an automatic encounter detection technique.

If work is to be extended on this package, the help facility should be developed to provide information interactively retrievable. A hierarchical menu structure such as the one suggested in Figure 3.7 could be included.

Most importantly errors in plotting and encounter detection have been caused by both faults inherent in the CNIS ADP tracking system and by the inappropriate data search specification.

In some instances when two vessels come within a minimum distance of each other with a particular relative velocity, the tracking of one vessel is seduced by the other causing the apparent loss of the seduced vessel track. If the Coastguard recognises this seduction the lost track may be manually reassigned to the vessel assuming it is subsequently detected by the tracking system as a new entry. This seduction causes plotting and encounter detection errors. The developed package could determine seduction from the coincidence of position and differentiate between

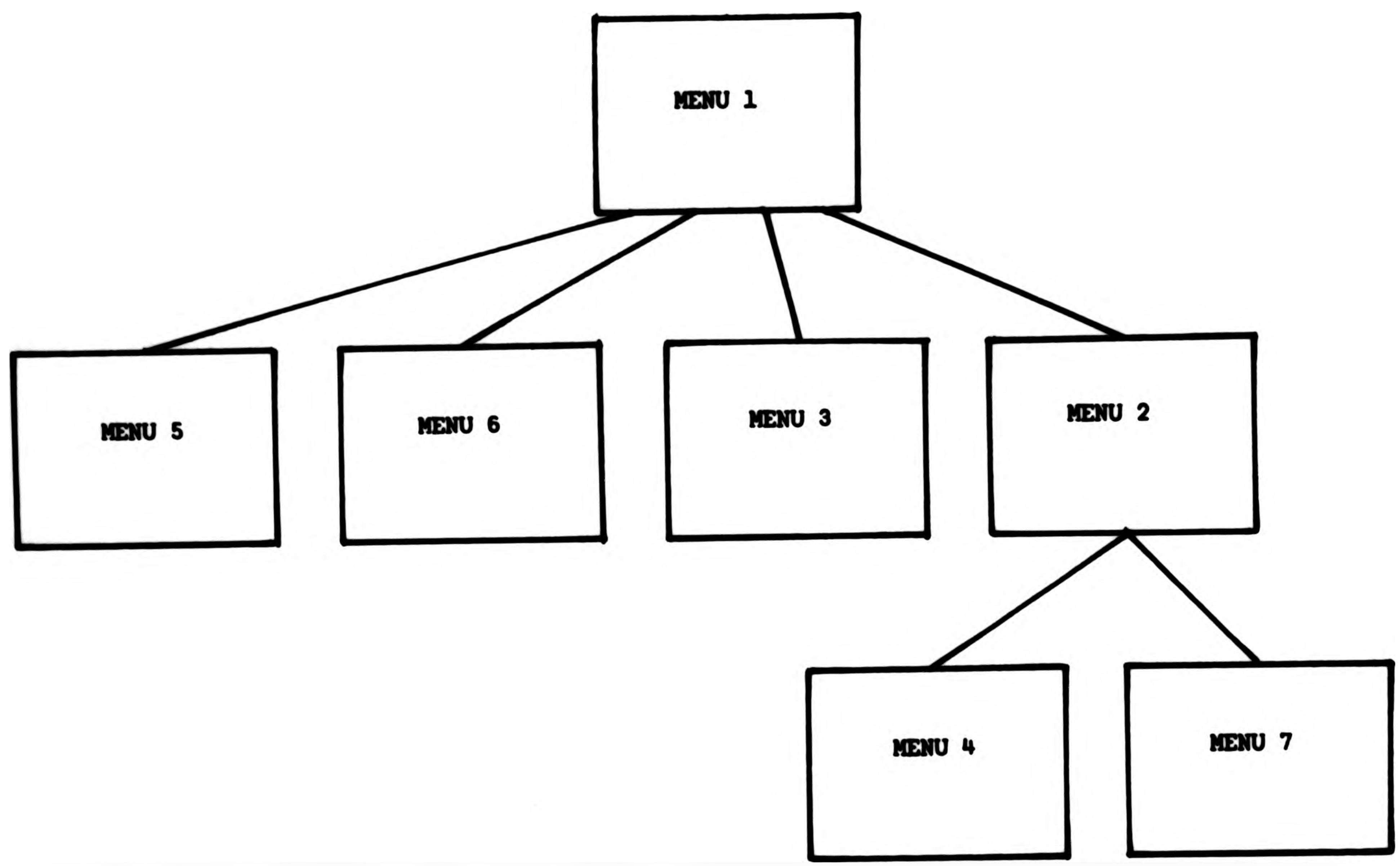

Figure 3.7 . Possible structuring of menus.

emerging vessels, and maybe even predict and plot the unrecorded track.

Errors in encounter detection have also been due to the inappropriate searching of encounters. The searching of encounters in discrete distinct time periods could be amended to achieve overlapping continuity.

With the replacement of the DEC-10 during the summer of 1986 at the Polytechnic the file writing and reading process will have to be adapted to allow operation on the proposed VAX-11 system.

The package has performed well and has allowed the development and testing of the technique for the automatic detection of real life ship encounters developed as part of this project. Additionally with the measurement of real life behavioural parameters further analysis and comparison with data obtained from a training simulator has been possible.

Photographs of the graphical display are given in Appendix I

Chapter Four

Automatic Encounter Detection.

(4.1.0) Introduction

When investigating marine traffic behaviour it is often necessary to identify encounters. These investigations can be in assessing risk for a particular sea area or, as is the case with this study, a more specific study into vessel behaviour in a collision avoidance situation. If the researcher adopts the purely distance based encounter definition, and wishes to count the number of two ship encounters over a given time period then the task of encounter recognition is relatively straightforward. A computer program can be written to test whether the encounter distance is achieved or this method may be applied manually. Whalley (1982) uses a distance based automatic encounter recognition technique. The method is used on a digital computer and checks to see if any ships are going to pass within 1.5 n.m. of any other on a simulation model.

If the potential encounter rate needs to be estimated then the purely distance based encounter definition is inadequate. Manually a two ship potential encounter can be recognised as a situation where vessels pass within their Encounter Distance (ED), or where one vessel manoeuvres so as to prevent the ED being achieved. This recognition depends on the analyst recognising a manoeuvre or a minimum value Closest Point of Approach (CPA).

(4.2.0) Alternative Methods

Distance based encounters are inappropriate for this study. Consider the situation where two vessels in an overtaking situation with a closing velocity of .1 knot Their distance separation is say 6 n.m., with an estimated CPA of 0.3 n.m. considered to be critical. Now any distance based technique would register a potential encounter, clearly this situation is not one. It would take some 60 hours for this CPA to be realised, hardly a dangerous situation. Of course a maximum range could be introduced but this would not accommodate close approaches of varying speeds. The inclusion of a time criteria seems appropriate.

Stratton (1971) developed the idea of an encounter area with the following postulates;

(i) Unless or until evidence to the contrary is obtained, warning and manoeuvre should be based on the assumption that a collision course exists.

(ii) Warning and manoeuvre time allowances are treated as constants independent of encounter conditions.

These combine to give an encounter area defined by a 'time to go' τ , which is equal to the range divided by the closing velocity. The area can be shown to be bounded by a circle with one vessel at the end of a diameter (τ.relative velocity), aligned to the direction of the relative velocity. This early attempt to incorporate a time criteria in an encounter recognition technique was used by Barratt (1980) in a computer program with a value for τ of 10 minutes to detect encounters. Also included in the technique was a minimum range of 1 n.m. set to detect close approaches at low closure rates. No indication of the efficiency of this method is given.

The method as used by Barratt is unclear. It is difficult to determine whether the method uses the relative velocity or the velocity of approach in calculating the 'time to go'. If the technique uses the relative velocity rather than the velocity of approach (range rate) then the method does not take into account the angle of approach. The method is deficient in any case because the size of the circle centred on any vessel is dependent on the relative velocity only. In this way the technique, as is stated in Stratton's postulates, is independent of the type of encounter considered rather like the method based on an arbitrarily chosen encounter distance.

Following analysis of both simulator and real life data sets Holmes (1979) fitted a number of regression models using ordinary least squares techniques. These models predict critical values for the indirect distance separation for given values of selected independent variables including target vessel speed, time until domain infringement and relative bearing of the target vessel. In order to calculate the dependent variable, indirect distance which is the total distance separation of the two vessels via the expected point of intersection of the courses, the vessels must be on convergent courses which is not necessarily the case in both meeting and overtaking situations. This model does not consider the angle of approach, but classifies encounter types from the relative bearing of the target vessel for possible targets.

(4.2.1) Adopted Definition

The encounter definition adopted for this study is, a situation involving two or more ships which can be considered to be of a high collision risk relative to a non encounter and involves at least collision avoidance consideration and on many occasions a collision avoidance manoeuvre. In this way encounters and potential encounters (hence referred to as encounters) may be detected allowing subsequent parameter measurement even if, i) no avoidance action is taken and, or ii) a minimum critical distance is not achieved.

(4.2.2) Range to Domain Over Range Rate

The importance of a time consideration in modelling collision avoidance situations was acknowledged by Colley et al (1983). Using a time based technique known as the Range to Domain over Range Rate method (RDRR), adapted from air traffic control theory (Ratcliffe 1982), a selected section of the main South West bound lane of the Dover Strait separation scheme was successfully modelled.

The RDRR method models the expected point of manoeuvre using the concept of a ship domain by calculating the time until its infringement from the range rate (velocity of approach). When this time until domain infringement reaches the critical value T_C, then a collision avoidance manoeuvre is modelled in accordance with the collision avoidance regulations.

Mathematically the RDRR model is represented as,

$$RDRR = \frac{R - D}{\dot{R}}$$

R = range n.m.

$\dot{R}$ = differentiation of R w.r.t time n.m/min.

D = domain size n.m.

and provides a computationally effective method for modelling the expected point of manoeuvre. The method has since been used by Colley et al (1986) to control the manoeuvres of target vessels on a marine radar simulator.

(4.3.0) Extending the RDRR Method

The work of this project has been to extend the RDRR model and allow the automatic detection of two ship encounters in real life marine traffic situations. The extended model is hence referred to as the RDRR+ method.

Fundamental to the understanding of how the RDRR+ method operates is the acceptance of statistical variation in the RDRR value at the point of the expected manoeuvre. Colley et al's model used a critical value T_C , of 5.5 minutes to model meeting, crossing and overtaking encounters. This fixed value has been suitable in modelling traffic flows. and was validated by direct comparison of gate counts set up at the Varne light vessel and by graphical comparisons with real life plots obtained from the French surveillance system. In the real life situation there is a degree of variation in the RDRR value when the collision avoidance manoeuvre, if any, is effected. This variation has been estimated during the course of this study following analysis of sample data obtained from the CNIS magnetic tapes.

To detect encounters the RDRR+ method isolates situations before any manoeuvre is made, ie. early on in the encounter development. For meeting encounters the development time is small and the time increment before the point of manoeuvre required to detect meeting encounters accounts for the relatively small statistical variation in the RDRR value at the time of manoeuvre.

Overtaking encounters take a comparatively longer period to develop, a fact acknowledged by Colley. Consequently the variation in the RDRR value at the point of manoeuvre for overtaking encounters is larger than for meeting encounters. Hence the time increment before the point of manoeuvre required for the detection of overtaking encounters is larger than the increment needed to detect meeting encounters. The time increment required to detect crossing encounters lies somewhere between the time increment values for meeting and overtaking encounters.

Mathematically the time increment ϑ_0 is introduced as;

$$RDRR+ = \frac{R - D}{\dot{R}} - \vartheta_0$$

where ϑ_0 is a time increment.

and an encounter is detected when the RDRR+ value is less or equal to the critical value T_C.

This form of the RDRR+ model requires differing values of ϑ_0 depending on the type of encounter detected, (the type of possible encounter may be detected using position and angle of approach information). With ϑ_0 split into a time and distance component the model accommodates all three encounter types for given values of the time and distance increments.

So mathematically,

$$\text{RDRR+} = \frac{R - D}{\dot{R}} - \frac{\delta}{\dot{R}} - \vartheta_1$$

$$= \frac{R - (D+\delta)}{\dot{R}} - \vartheta_1 \qquad \text{(minutes).}$$

Where δ = distance inc. n.m.

ϑ_1 = time inc. minutes.

From this equation in an overtaking situation the range rate $\dot{R}$, becomes very small and the time increment ϑ_1, is of negligible size compared to $\delta/\dot{R}$. In a meeting situation $\dot{R}$ is large and $\delta/\dot{R}$ is small relative to the value ϑ_1. So in an overtaking situation the distance increment δ n.m. dominates the RDRR+ relationship whilst in the meeting situation it is the time until the point of manoeuvre, ϑ_1, that dominates the relationship.

This described method is run interactively on a digital computer. It is because of this that efforts are made to conserve computer processing time, hence only vessels in a possible encounter situation were to be considered.

Two techniques have been examined which determine whether vessels are approaching each other, and so prevent redundant calculations.

(4.3.1) Allocating a Sign to the RDRR

The RDRR value is a measure of time, but is a scalar quantity. Therefore vessels which have passed their CPA can take RDRR values of similar magnitude to those of vessels yet to achieve their CPA. By allocating a sign to the RDRR value, this distinction can be made.

(4.3.2) Methods Considered.

There are two main methods available for determining the direction of the RDRR value:

i) Analysing historical data,

ii) mathematical techniques.

The first of these methods is based on the fact that if vessels are approaching each other the RDRR value will generally diminish over time until the closest point of approach is reached. It is this method that is used by

Colley (1984) for vessel traffic simulation, and is confirmed by the findings of this study. Indeed in all the cases the CPA coincides with minimum RDRR. The main disadvantage of this method is that a record of previous RDRR values must be kept as a data base so that a comparison with current RDRR values can be made. In practice this requires substantial computer memory allocation, reducing its cost effectiveness.

The second of these methods is mathematical and requires vector analysis of positions and velocities of the two vessels under investigation. A prototype of this method has been tested resulting in amendments which have proved to be successful.

Expressing the position and velocities of the vessels in vector form shown geometrically in Figure 4.01 ;

For given vessels A and B, their positions are given by vectors

$$\underline{r}_a = a_1x + a_2y$$

$$\underline{r}_b = b_1x + b_2y$$

Then the relative position of vessel B from vessel A can be expressed in vector notation as;

$$\underline{r}_b - \underline{r}_a = \hat{\underline{r}} = (b_1 - a_1)x + (b_2 - a_2)y$$

$$\underline{= \alpha_1 x + \alpha_2 y} \qquad \text{(I)}$$

Allocating a direction sign to the RDRR

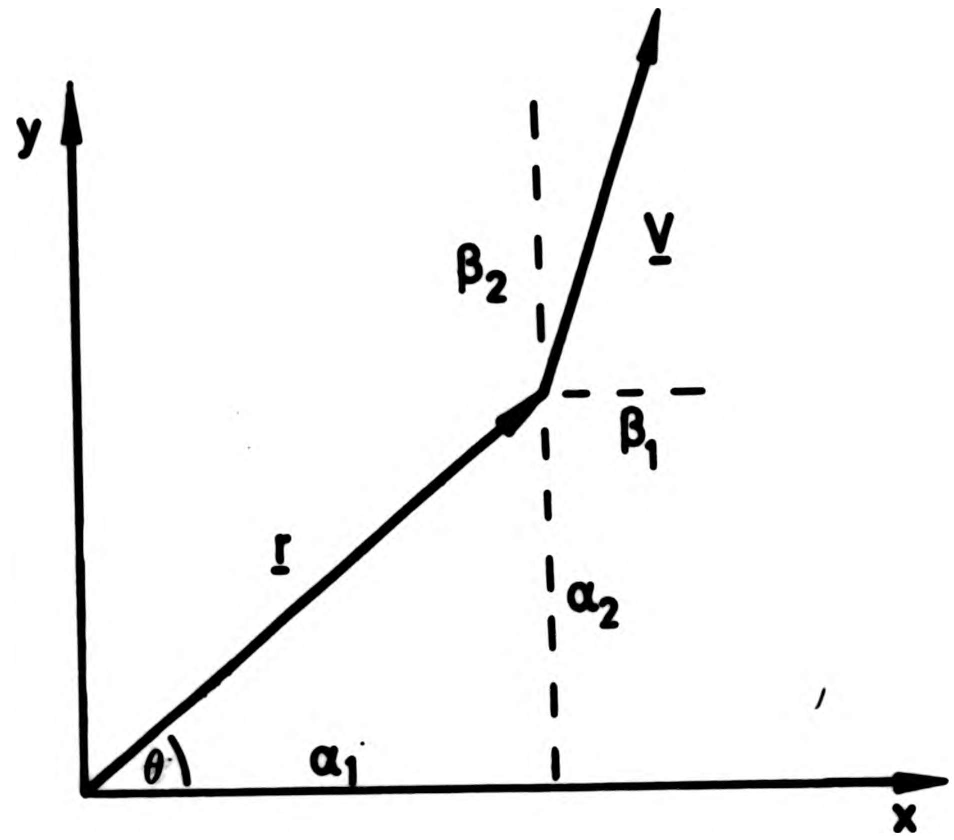

Figure 4.01 Showing relative position and velocity components.

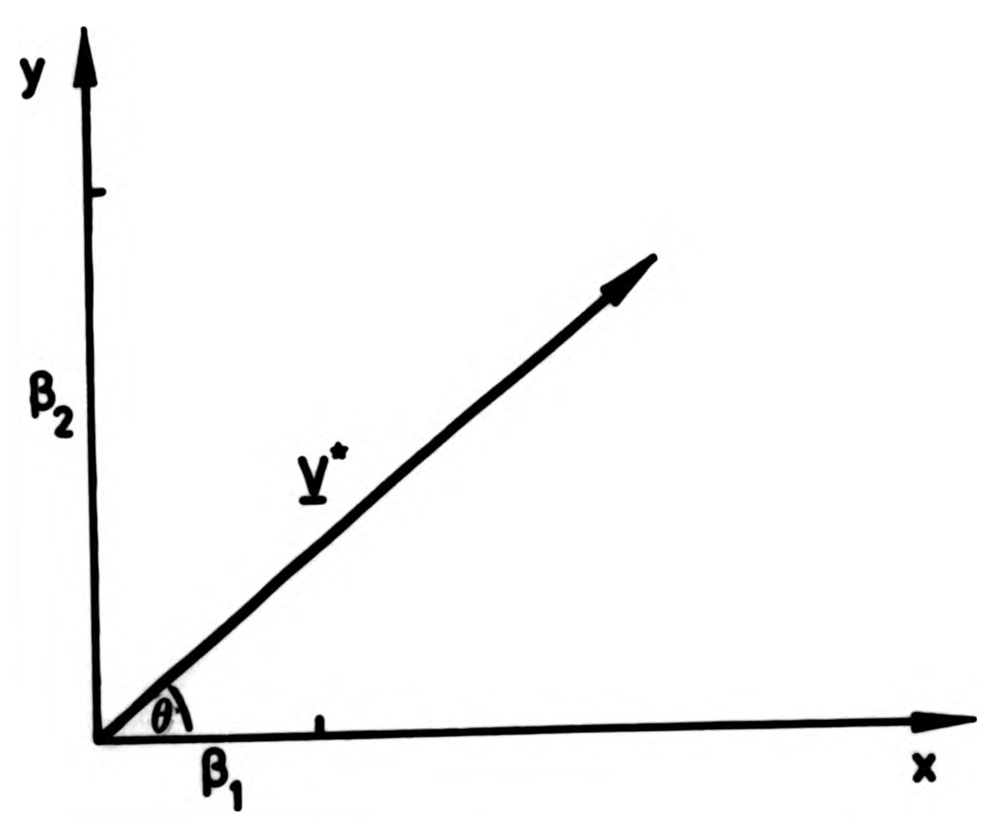

Figure 4.02 showing relative velocity resolved along the direction of the relative position.

If A and B have velocities expressed as vectors

$\underline{v}_a = u_1 x + u_2 y$

$\underline{v}_b = w_1 x + w_2 y$

Then the relative velocity of vessel B from vessel A may be expressed in vector notation as,

$$ {}_b\underline{v}_a = \underline{\hat{v}} = (w_1 - u_1)x + (w_2 - u_2)y $$

$$ \underline{= \beta_1 x + \beta_2 y} \qquad \text{(II)} $$

This method detects encounters when two vessels are approaching in both the x and y sense and when the extended RDRR method, RDRR+, is critical. This is formally expressed in the following three conditions;

i) RDRR+ $\leqslant$ Critical value,

ii) $\alpha_1\beta_1 \leqslant 0$

iii) $\alpha_2\beta_2 \leqslant 0$

and $\alpha_1\beta_2 = \alpha_2\beta_1$ will be true for an actual collision.

This method has been tested with inconsistent results. Crossing encounters are correctly classified but meeting encounter results are unsatisfactory. This is because the method can only recognise potential encounters where the vessel tracks will actually cross each other. For many meeting encounters vessels will manoeuvre so as to pass each other outside a minimum distance without their extended tracks ever crossing one another.

(4.3.3) The Method Adapted

The method is adapted so that the relative velocity is resolved in the direction of the relative position. In this way vessels which are moving towards each other can be identified whether or not their projected tracks cross each other.

From (I) and (II)

$$\underline{\hat{r}} = \alpha_1 x + \alpha_2 y$$
$$\underline{\hat{v}} = \beta_1 x + \beta_2 y$$

Resolving the relative velocity in the direction of $\underline{\hat{r}}$ the relative position vector shown geometrically in Figure 4.02,

$$\underline{v}' = \beta_1\cos(\theta) + \beta_2\sin(\theta)$$

Now, $\sin(\theta) = \dfrac{\alpha_2}{(\alpha_1^2 + \alpha_2^2)^{1/2}}$

and $\cos(\theta) = \dfrac{\alpha_1}{(\alpha_1^2 + \alpha_2^2)^{1/2}}$

so, $\underline{v}' = \dfrac{\alpha_1\beta_1 + \alpha_2\beta_2}{(\alpha_1^2 + \alpha_2^2)^{1/2}}$

If $\underline{V}^*$ is less or equal to zero, vessels A and B are approaching each other. ie.

$$V^* = \frac{\alpha_1\beta_1 + \alpha_2\beta_2}{(\alpha_1^2 + \alpha_2^2)^{1/2}} \leqslant 0$$

Giving,

$$\alpha_1\beta_1 + \alpha_2\beta_2 \leqslant 0 \qquad \text{(III)}$$

So formally an encounter is detected if the following conditions are satisfied,

i) RDRR+ <= Critical Value,

ii) $\alpha_1\beta_1 + \alpha_2\beta_2 \leqslant 0$

Which provides a reliable, easy to program and economical to utilise method for allocating a direction sign to the RDRR value (and the RDRR+ value).

(4.4.0) Results

To test the described automatic encounter detection technique estimates have been made for the values of δ and ϑ_1.

For a meeting encounter, detection will depend on the time increment ϑ_1. This accounts for the statistical variation in the RDRR value at the point of manoeuvre. By analysing a sample of encounters the point of manoeuvre is estimated to occur when the RDRR value lies between 4.65 and 6.35 minutes for the majority of encounters (90%) in the Dover Strait sea area, with an average value of 5.5 minutes. This average value agrees with that used by Colley et al (1983) to successfully model traffic behaviour in the Dover Strait sea area. This initially fixes the value of ϑ_1 to be 0.85 minutes.

By fixing the value of ϑ_1 to be 0.85 mins. initially, and varying the value of δ, an operational value of 0.17 n.m. for δ has been used in this study. With these values for ϑ_1 and δ, and by approximating $\dot{R}$ by the relative speed which is typically 24 knots in the meeting situation, an encounter is detected just over 1 minute before the expected point of manoeuvre. This will pick out at least 90% of meeting encounters since the 1 minute before the expected point of manoeuvre is outside the 90% confidence upper limit for the modelled manoeuvre point.

The average value for the RDRR at the expected point of manoeuvre for any encounter type is 5.5 mins. The average spread of the RDRR values at the point of manoeuvre around this average value of 5.5 mins, the standard deviation, will be greater for overtaking encounters than for either meeting or crossing encounters. By again approximating $\dot{R}$ by the relative speed which is typically 4 knots in the overtaking situation, an overtaking encounter is detected some 3 minutes before the expected point of manoeuvre. This 3 minutes represents a range of nearly 0.25 n.m., which from experimental results is sufficiently large to detect most overtaking encounters before ships manoeuvre.

The sequence of the automatic encounter detection method can be followed by referring to Figure 4.03, 4.04 and 4.05 which give the detection sequence for a crossing encounter. Figure 4.03 shows the RDRR+ development with respect to time and has been plotted from shortly before the automatic detection. Initially the ships are approaching such that the give way vessel would, in the absence of a collision manoeuvre pass close ahead of the stand on ship (less than 1/10 n.m. at the time of automatic detection). When the RDRR+ (Figure 4.03) reaches the critical value of 5.5 minutes, the computer detects the encounter, and would normally start to plot either the relative track in Figure 4.04 or the actual plot in Figure 4.05. The plotted point before this instant is arbitrarily called time 0 minute; subsequent 1 minute track plots are labelled relative to this point in time. The central vessel has a surrounding circle in the relative track plot representing the

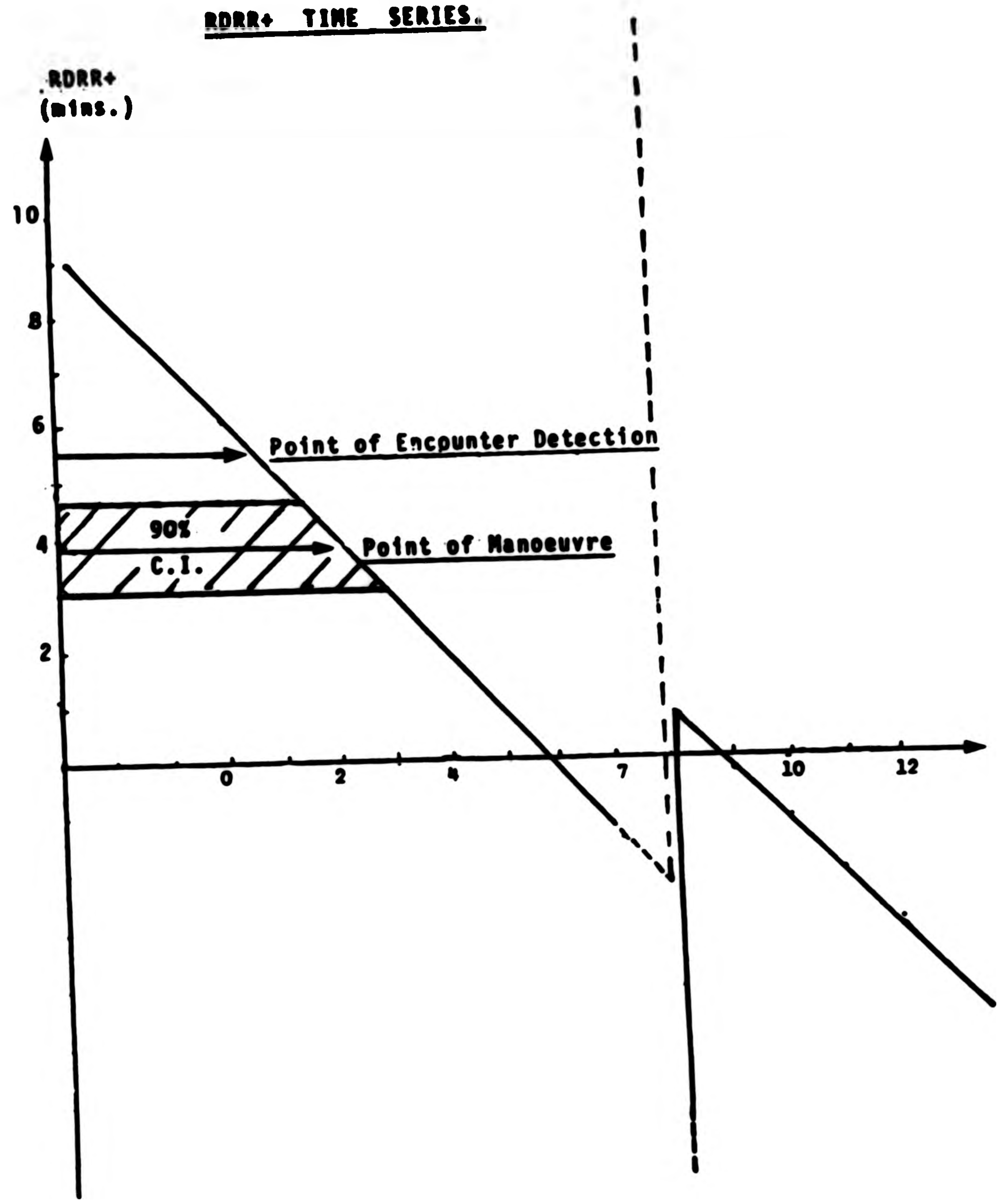

Fig 4.03 showing the RDRR+ time series for vessels in a crossing encounter.

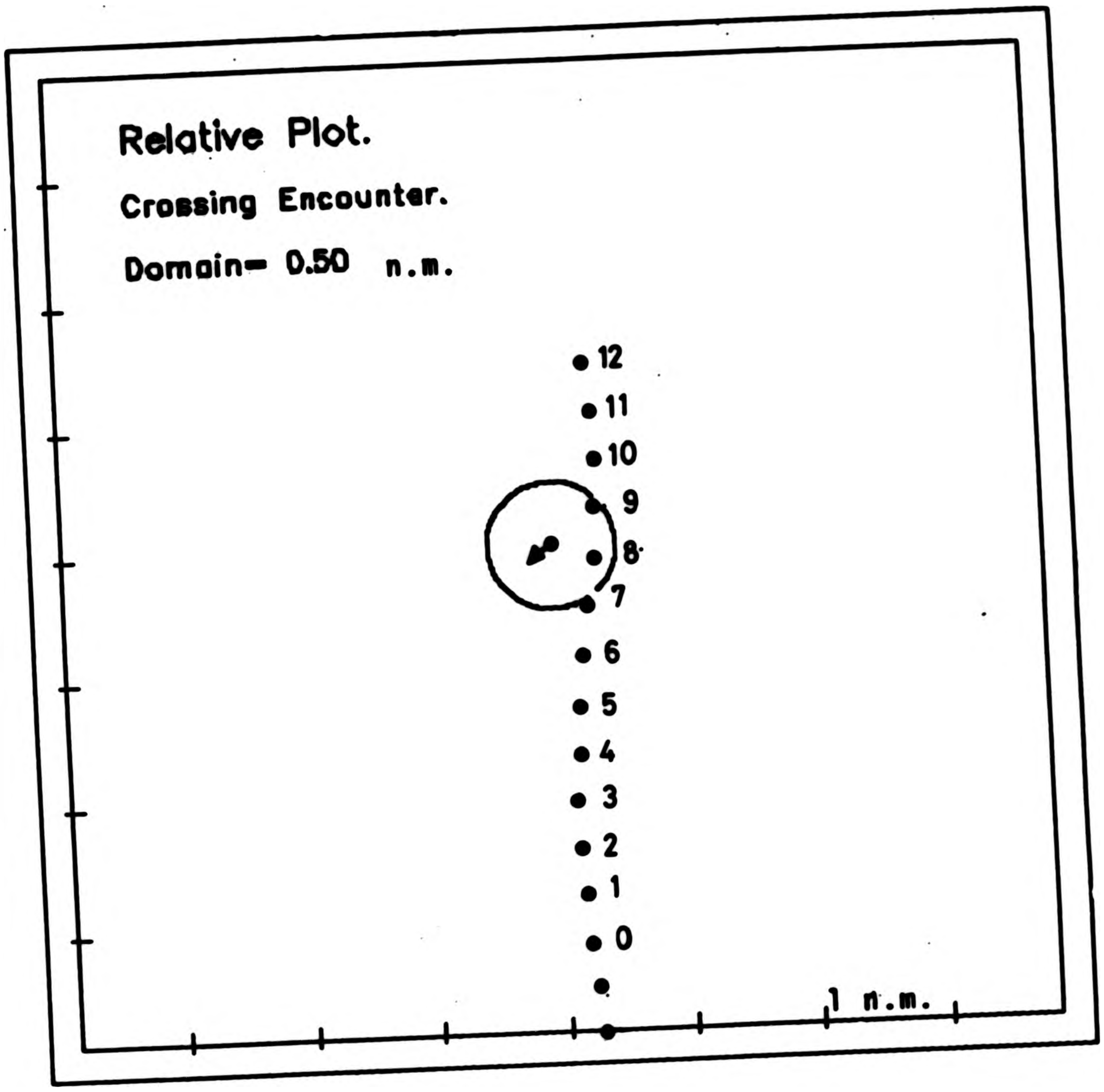

Fig. 4.04 showing the relative motion (north up) plot for vessels whose RDRR+ time series is shown in Fig. 4.03.

(track plot time in minutes).

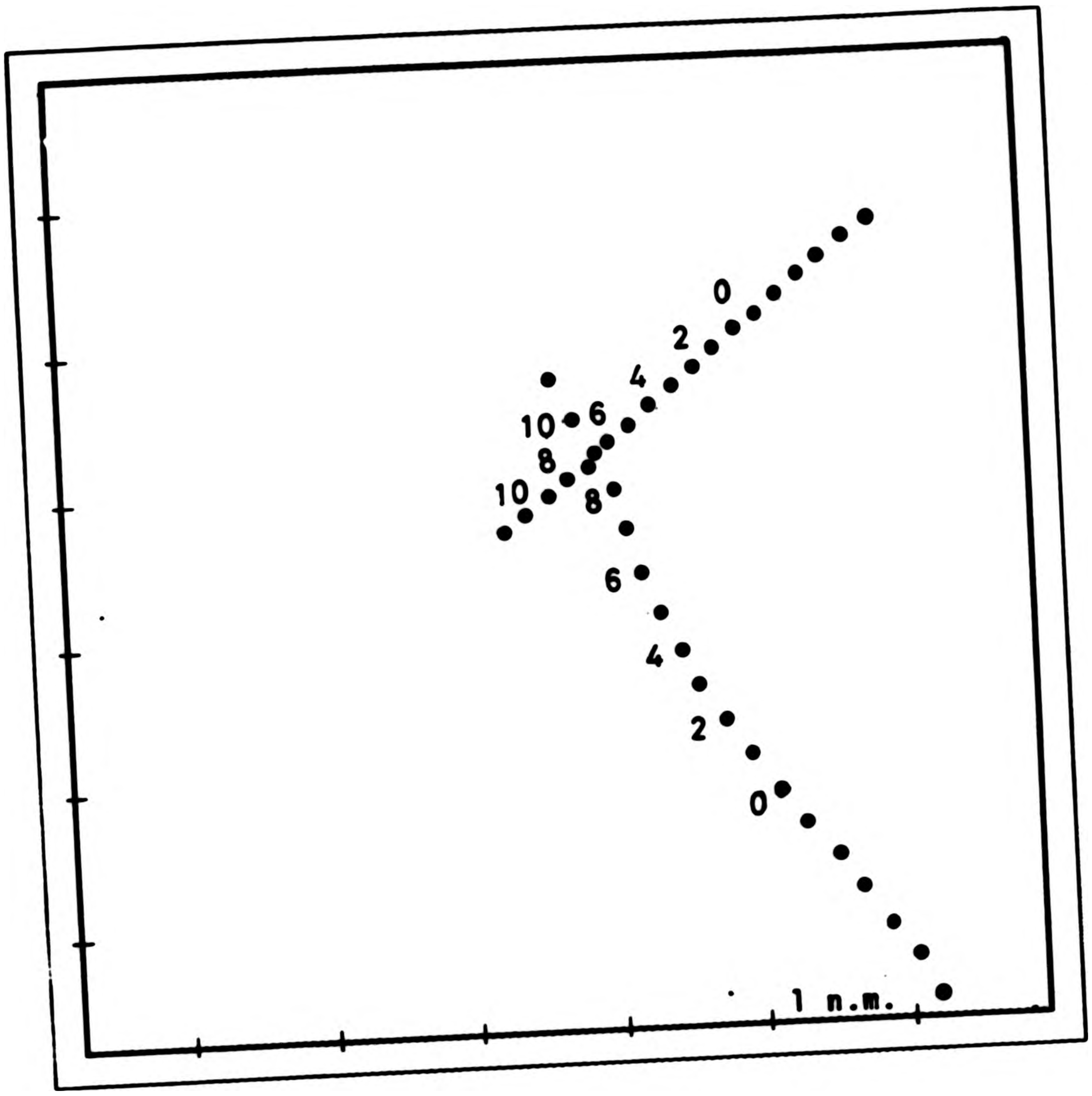

Fig. 4.05 showing a true motion plot of vessels in the crossing encounter whose RDRR+ time series is shown in Fig. 4.03. (track plot time in minutes)

particular domain applicable to this type of encounter. The value of the RDRR+ continues to reduce and when its value reaches just under 4 minutes, the give way vessel is expected to manoeuvre, and it does. This corresponds to the track plot point of 2 minutes. The shaded region around the point of manoeuvre is the 90% confidence interval (i.e. where the point of manoeuvre is expected to be 90% of the time). The encounter progresses and at a track time of 8 minutes the ships reach their CPA, the value of $\dot{R}$ passes through zero and the RDRR+ has asymptotic values from minus infinity to plus infinity. The ships now resume course and the encounter is over; but the computer had automatically detected it and plotted it from two minutes before the ships manoeuvred.

Similar sequences are presented in Figures 4.06, 4.07, 4.08, and 4.09, 4.10 for meeting and overtaking encounters. A true plot is not presented for the overtaking encounter as this is generally impractical.

An increasing value for δ allows the technique greater sensitivity in detecting overtaking situations. Likewise an increasing value for ϑ_1 allows greater sensitivity in detecting meeting situations, though these are less frequent in the separation scheme. Crossing encounter detection is affected by both ϑ_1 and δ of varying degrees depending on the crossing angle ϕ.

RDRR+ TIME SERIES

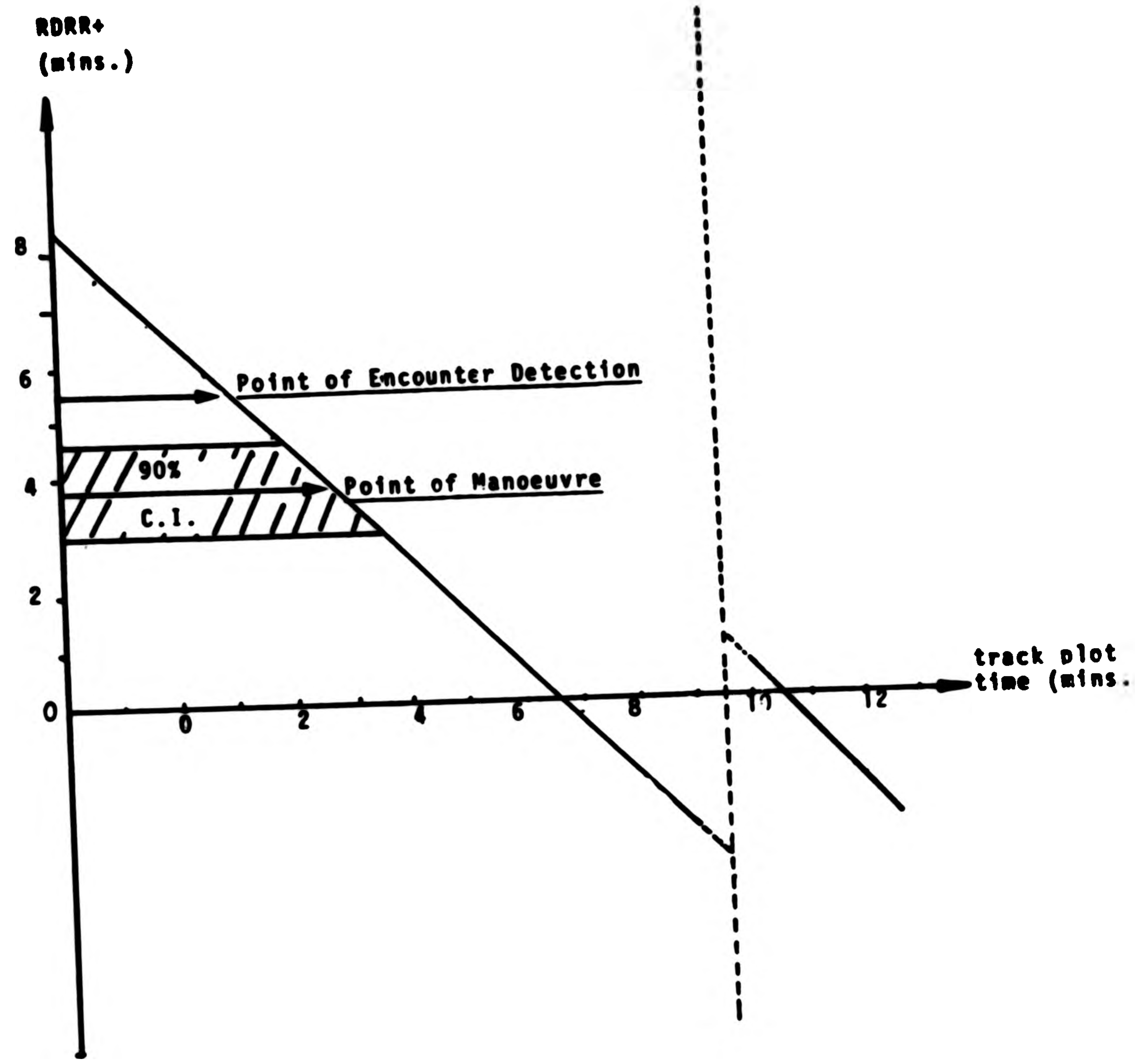

Fig.4.06 showing the RDRR+ time series for vessels in a meeting encounter.

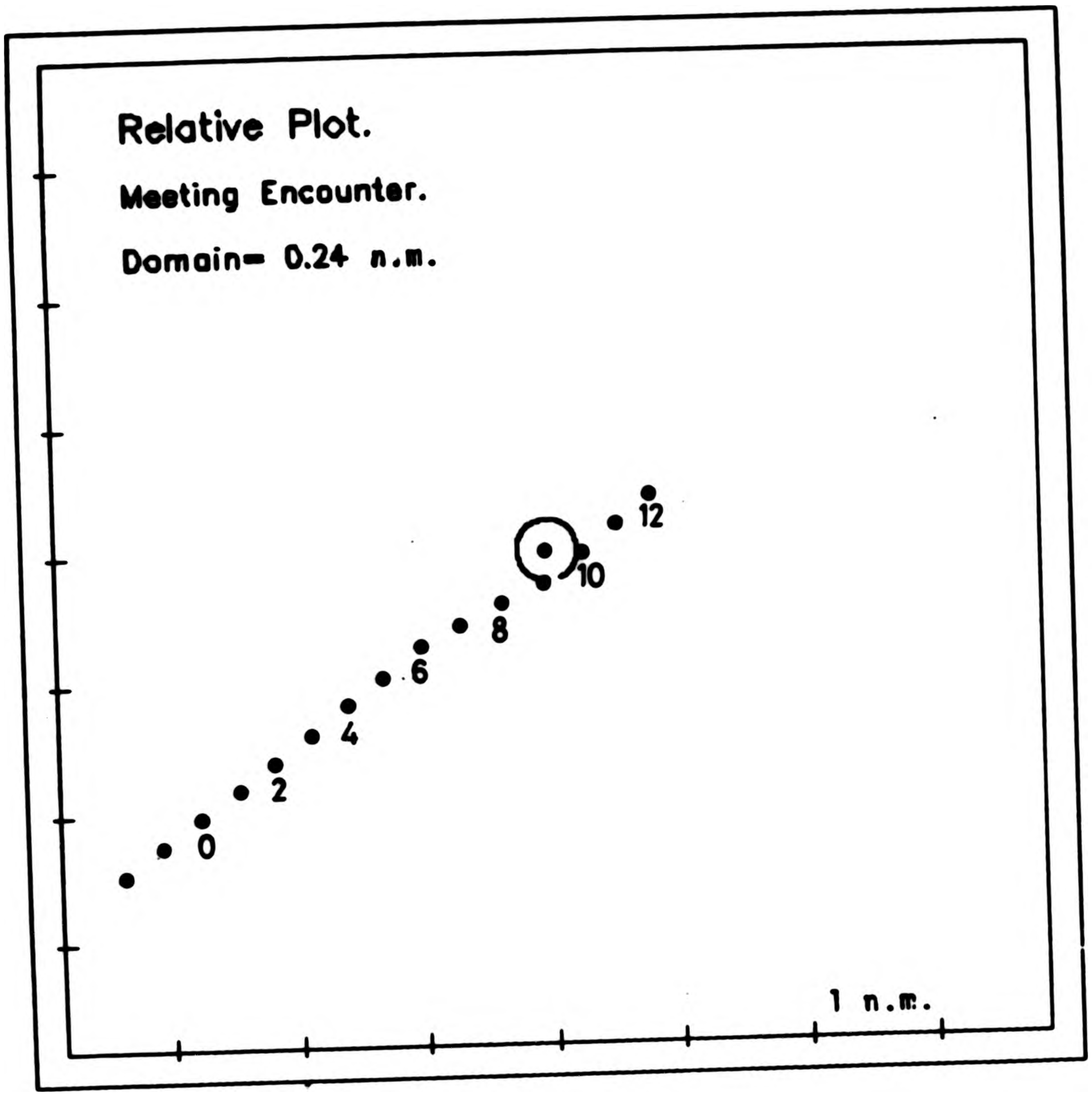

Fig. 4.07 showing the relative motion (north up) plot for vessels whose RDRR+ time series is shown in Fig. 4.06.
(track plot time shown in minutes).

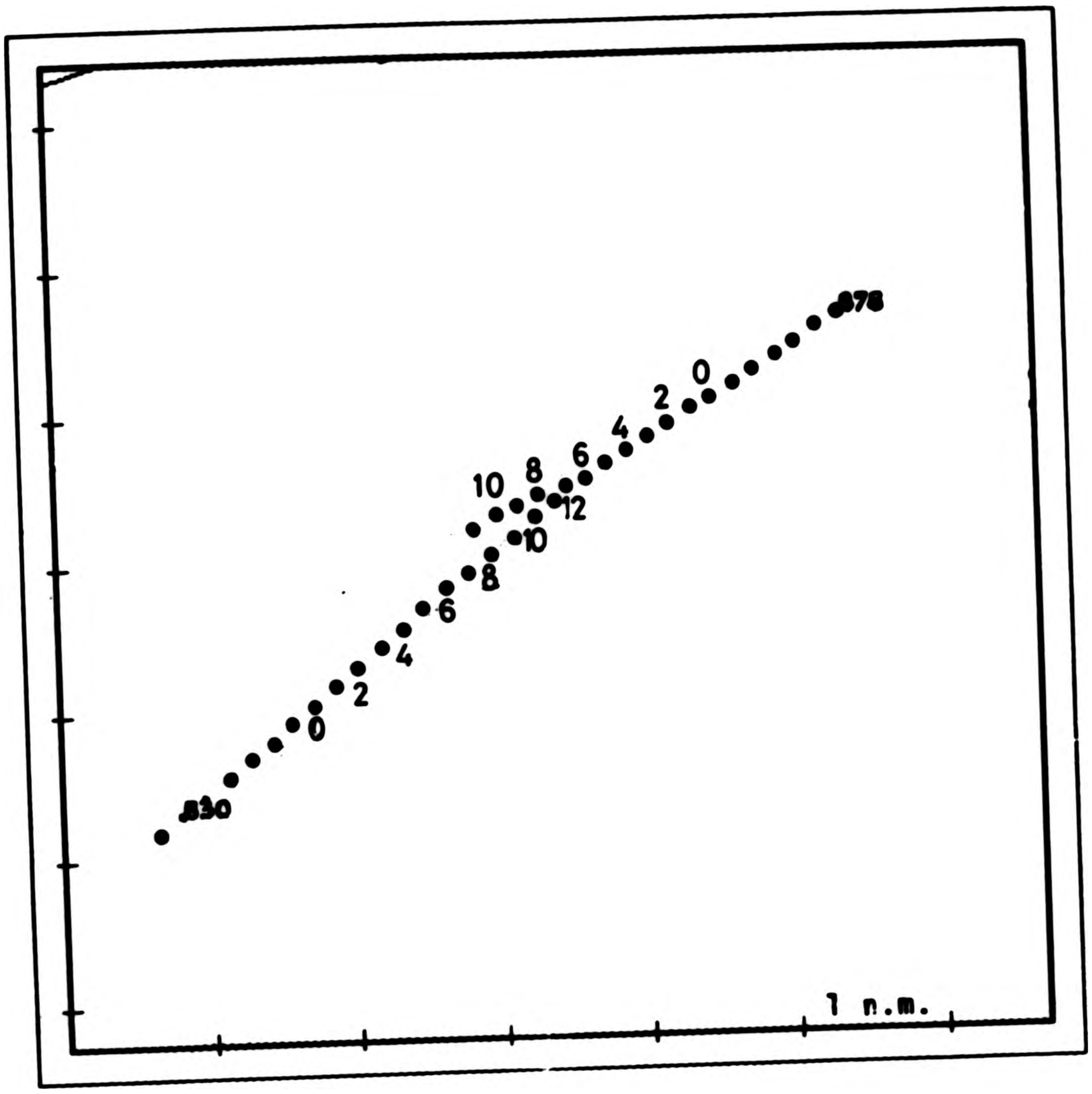

Fig 4.08 showing a true motion plot of vessels in the meeting encounter whose RDRR+ time series is shown in Fig. 4.06. (track plot time in minutes).

RDRR+ TIME SERIES

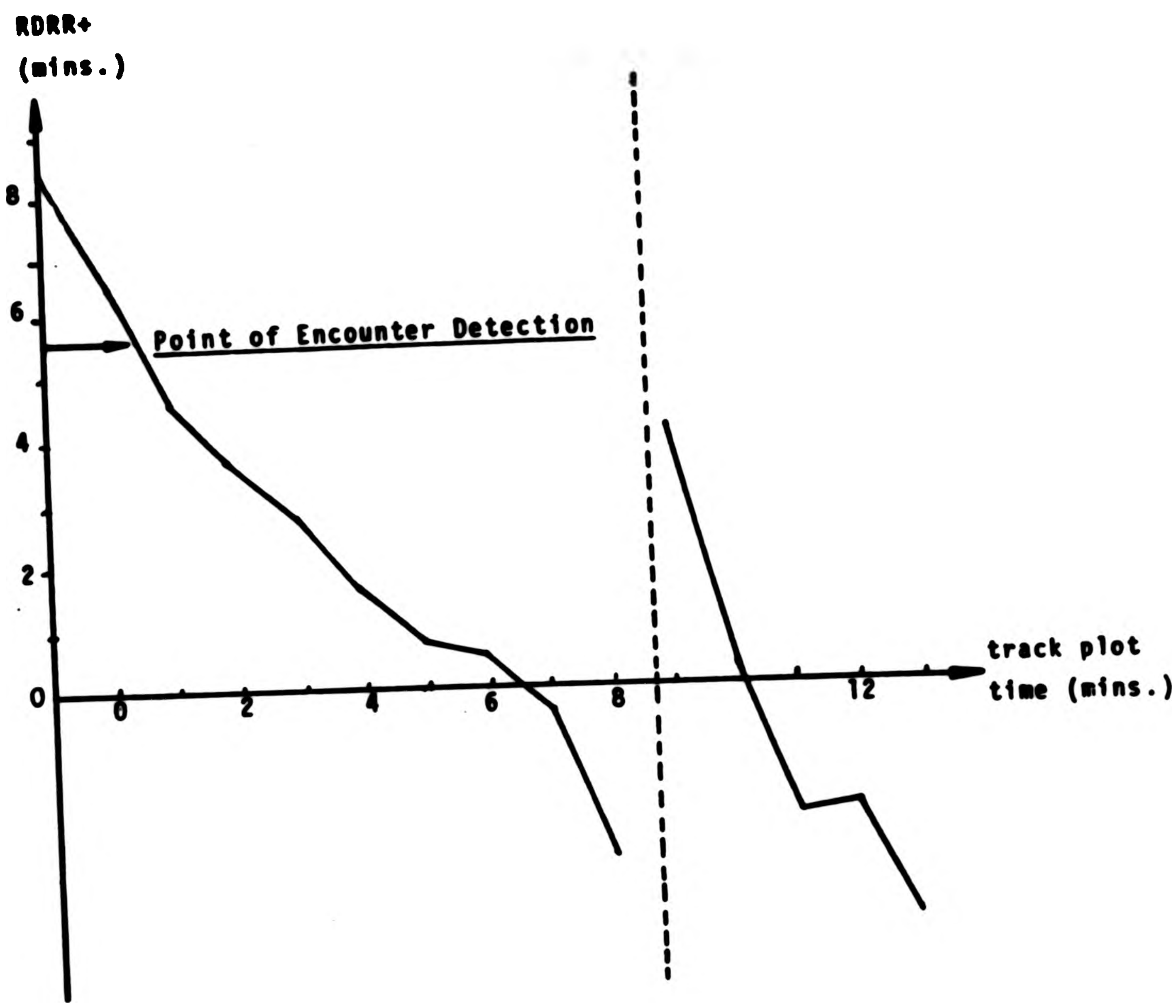

Fig. 4.09. showing the RDRR+ time series for vessels in an overtaking encounter.

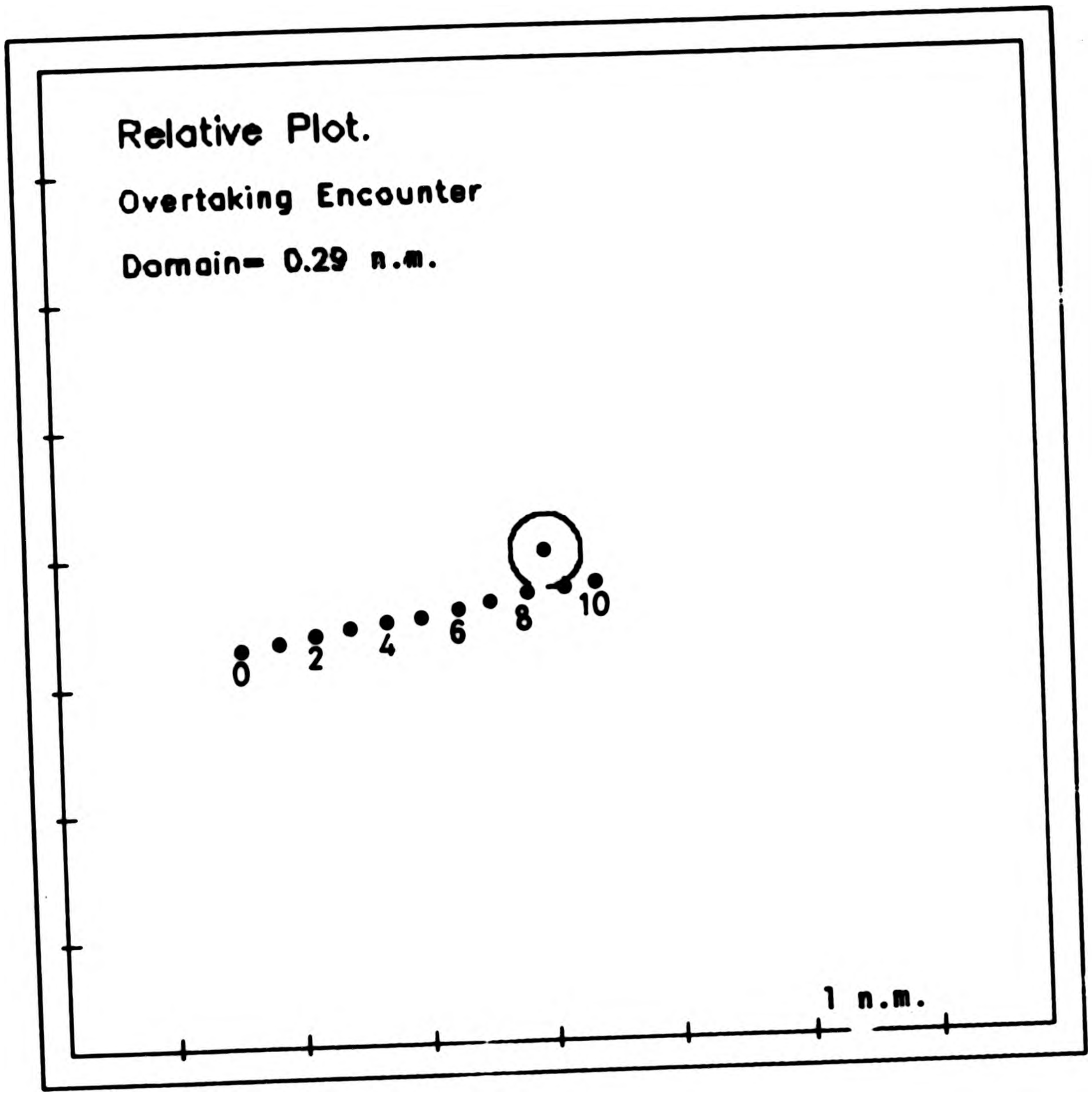

Fig. 4.10 showing the relative motion (north up) plot for vessels whose RDRR+ time series is shown in Fig.4.09. (track plot time in minutes).

(4.4.1) False Detections

On manually checking that the encounters automatically detected were indeed valid encounters, a number of similar situations were falsely detected by the computerised model. These situations tend to be overtaking situations involving vessels with largely differing velocities. By modelling this type of situation mathematically, the false detection is confirmed.

The situation shown in Figure 4.11 depicts a fast moving vessel overtaking a near stationary vessel. The Relative Velocity is 20 knots. with an estimated CPA of 1.03 n.m. due to be achieved some 11 minutes from the present position (time T=0). The vessels are initially 4.03 n.m. apart.

As the fast moving vessels position is modelled upto the CPA the RDRR value becomes critical 8.0 minutes after the initial position. The progress of the RDRR, the range and the range rate, with respect to time is given in Table 4.01.

With a CPA of 1.03 n.m., in assumed clear visibilty conditions, the situation cannot be considered to be an encounter. The situation involves the overtaking of one vessel by another, Curtis (1977) states that in good visibilty it is not safe to overtake at less than 1 n.m. for

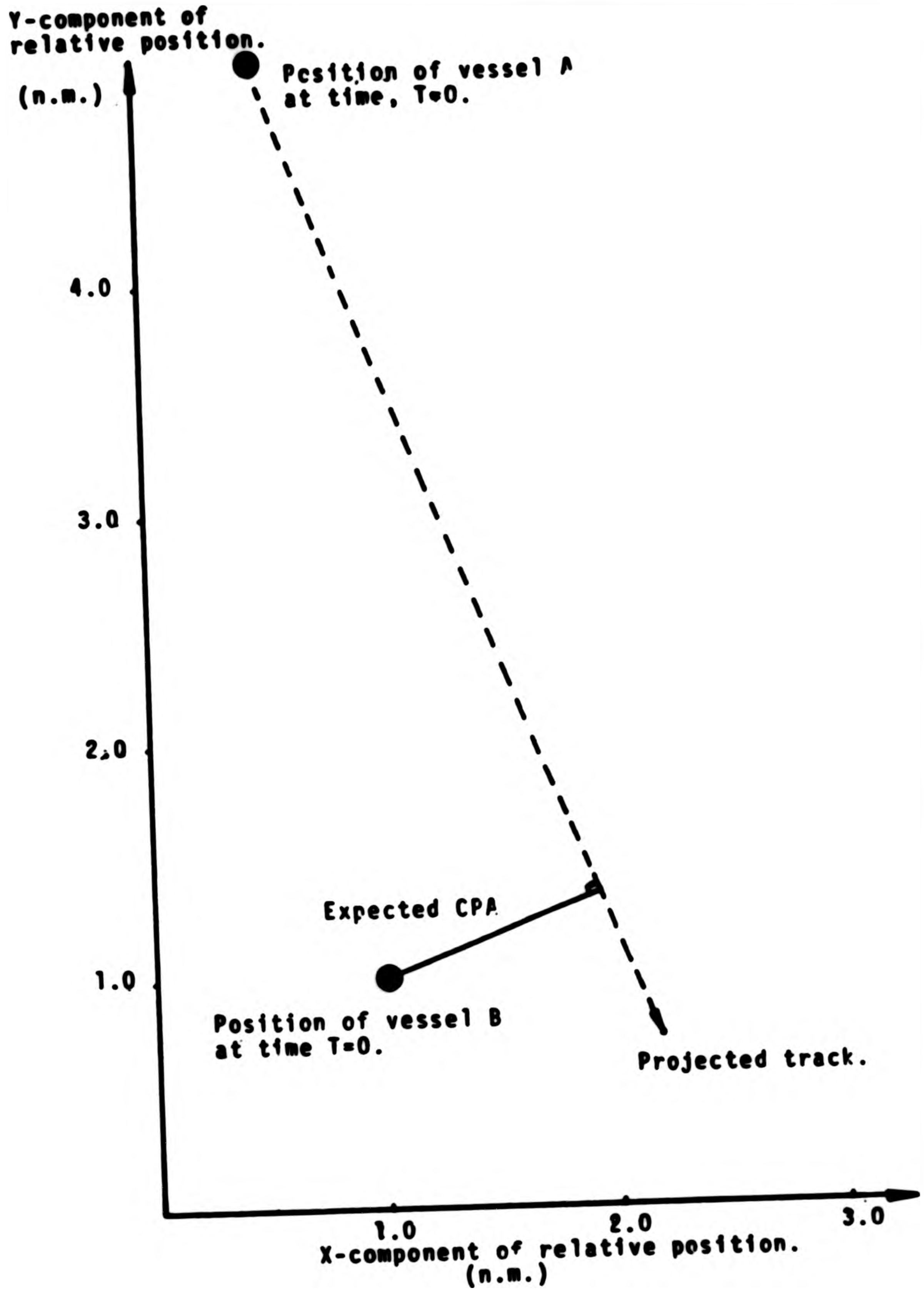

Fig. 4.11 showing the projected track of vessel A relative, assuming constant speed and course.

T (mins)	t (mins)	R (n.m.)	$\dot{R}$ (n.m./min)	R-D (n.m.)	RDRR (mins)
0	11.71	4.031	0.323	3.79	11.74
1	10.70	3.710	0.321	3.47	10.81
2	9.71	3.391	0.318	3.15	9.90
3	8.71	3.076	0.315	2.84	9.00
4	7.71	2.764	0.310	2.52	8.14
5	6.71	2.458	0.303	2.22	7.31
6	5.71	2.160	0.294	1.92	6.54
7	4.71	1.873	0.279	1.63	5.85
8	3.71	1.605	0.257	1.37	5.31 *
9	2.71	1.366	0.220	1.13	5.11
10	1.71	1.173	0.162	0.93	5.76
11	0.71	1.052	0.075	0.81	10.83

Overtaking situation. Domain = 0.24 n.m.
Relative speed = 0.33 n.m./min.

* First critical RDRR value.

Table 4.01 Mathematically modelled RDRR+ time series data.

a VLCC overtaking a 12 knot vessel. In the example given the overtaken vessel is stationary, making the situation at least as safe as the one described by Curtis.

Figure 4.12 shows an actual example of this type of situation from the CNIS ADP data. The accompanying time series shown in Figure 4.13 outlines the detection criteria falsely fulfilled.

(4.4.2) Distance Based Condition

To prevent such situations being wrongly detected, a distance based condition has been added.

A critical value for the CPA has been introduced. Colley et al (1984) collected real life data from the Dover Strait in good visibility conditions, in which all vessels that manoeuvred to avoid collision had a CPA of less than 0.8 n.m. This suggests a critical CPA value of 0.8 n.m.

Curtis (1977) suggests a value of 1 n.m. in good visibilty for overtaking vessels and Goodwin (1975) found the maximum domain size to be equal to 0.8 n.m. for the Dover Strait.

When deciding on what critical value for the CPA should be used, the effect of the variation in the estimated velocities given by the real life data system on the

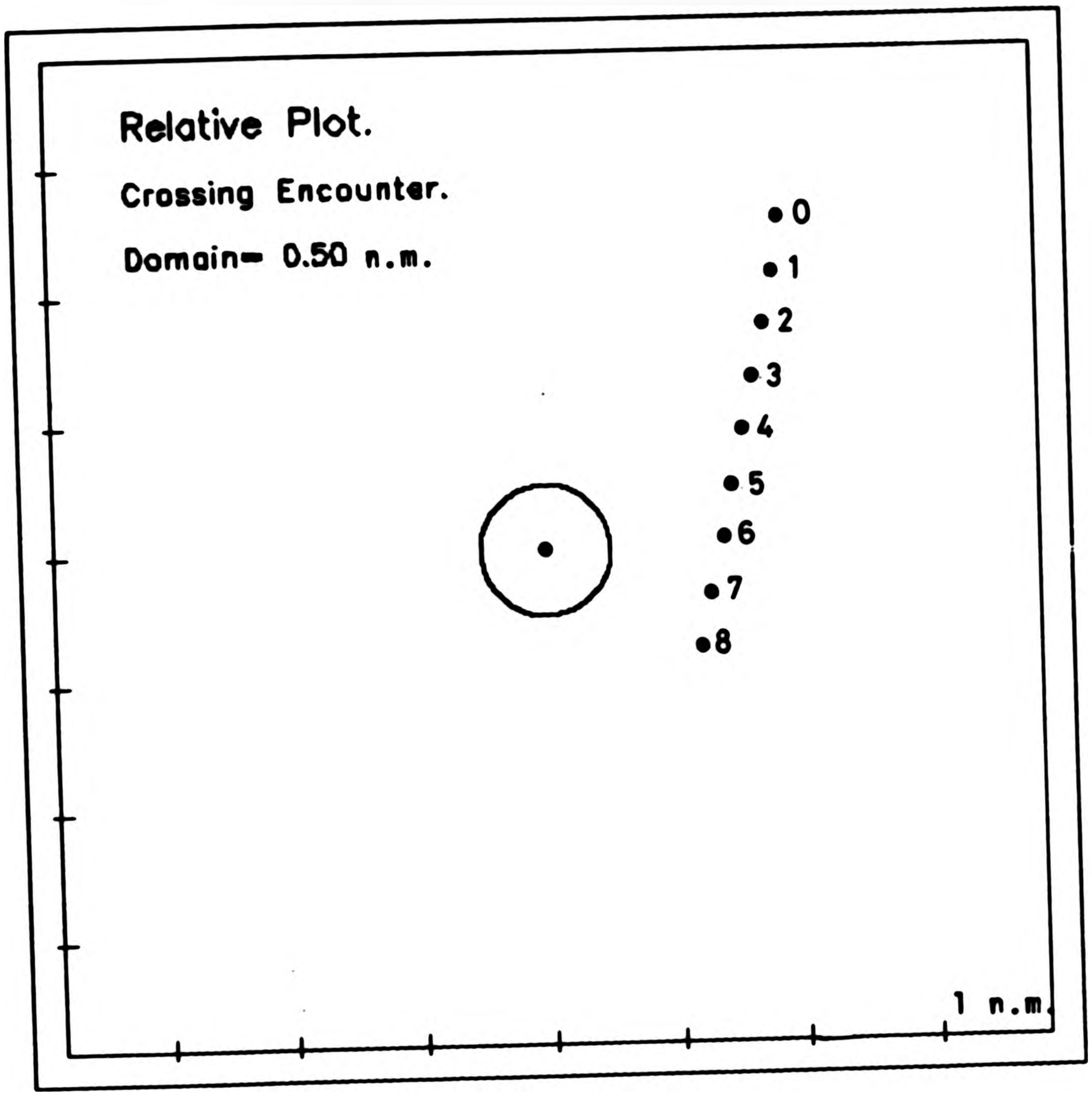

Fig. 4.12 showing the relative motion (north up) plot for vessels in a real life falsely detected encounter, the RDRR+ time series for this false detection is shown in Fig. 4.13.

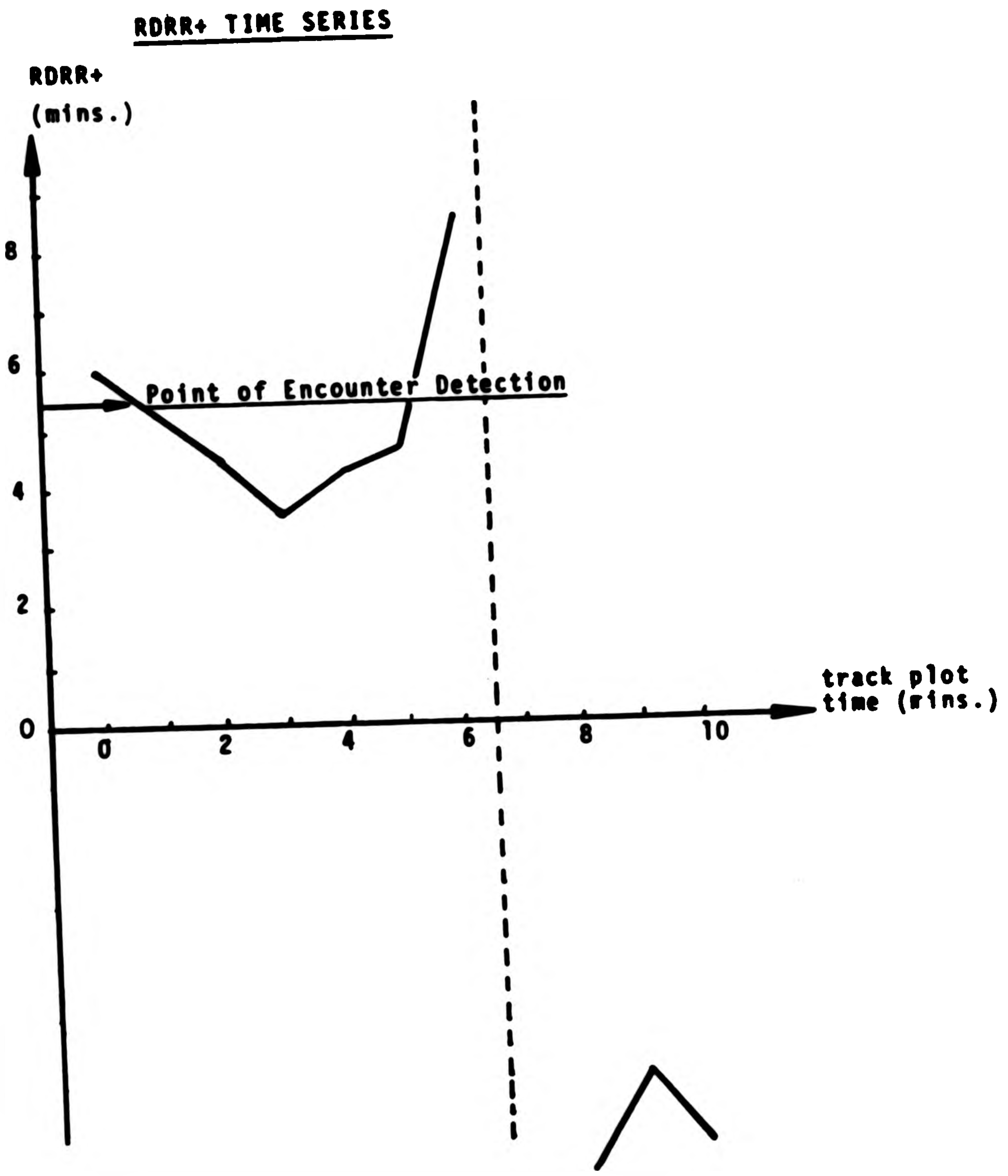

Fig. 4.13 showing the RDRR+ time series for vessels in a falsely detected real life encounter.

predicted CPA are considered.

Two methods for investigating the covariation of the predicted CPA and the estimated velocity components are given. The first, an optimisation method, broadly outlined here proved to be unnecessarily complex. The second method, geometrical, yields a convenient result.

(4.4.3) Assessing the effect of Variation in the Velocity Component predictions on the Estimated CPA.

The X and Y components of ship velocities are predicted and given by the CNIS ADP system. These predictions are based upon repeated position fixing, some five times per minute. The accuracy of these predictions will affect the accuracy of the estimated value for the CPA. By assuming say a Normal probability distribution of these predicted components, whose mean is the actual component values, and by calculating the 95% Confidence Intervals for the projected relative track, (i.e. the actual projected track lies between the calculated limits, assuming constant velocity), then a maximum and minimum value for the expected CPA as shown in Figure 4.14 may be calculated.

The maximum and minimum values for the expected CPA can be calculated by the two methods described below. The first involves the optimisation of the expected CPA values with

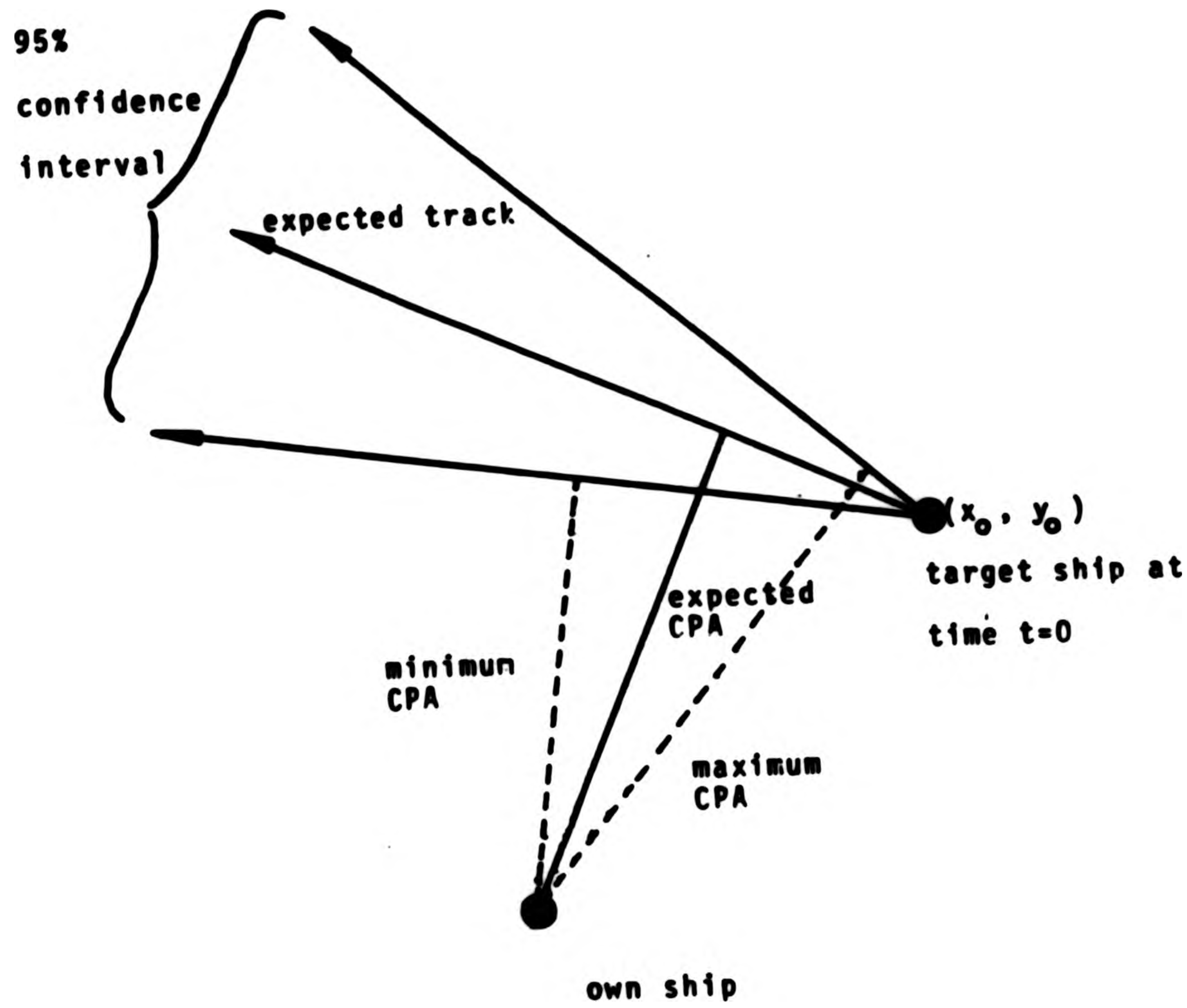

Fig. 4.14 showing the effect of variability in the predicted relative velocity of a target ship on the expected value for the Closest Point of Approach.

time varying, and the second is geometrical requiring the construction of maximum and minimum expected CPA's given the equation of the 95% Confidence Interval lines.

The study is interested in the minimum value for the predicted CPA so as to check domain infringement.

Relative Position of target vessel at time T=0 is (x_0, y_0), with relative velocity components (δ, γ). δ and γ are independent.

The basic assumptions are :-

$\delta \sim Nor(\bar{\delta}, \sigma^2)$; $\gamma \sim Nor(\bar{\gamma}, \sigma^2)$ independent;

$Var(x_0) = Var(y_0) = 0$;

$E(x_T) = x_0 + T\bar{\delta}$; $E(y_T) = y_0 + T\bar{\gamma}$;

$Var(x_T) = Var(y_T) = T\sigma^2$.

(4.2.4) Optimization Technique

From Figure 4.15 it can be seen that the true position prediction for time T will lie approximately somewhere in the square of side $4\sqrt{T}\sigma$, 95% of the time.

To evaluate the minimum value for the CPA in terms of x_0, y_0

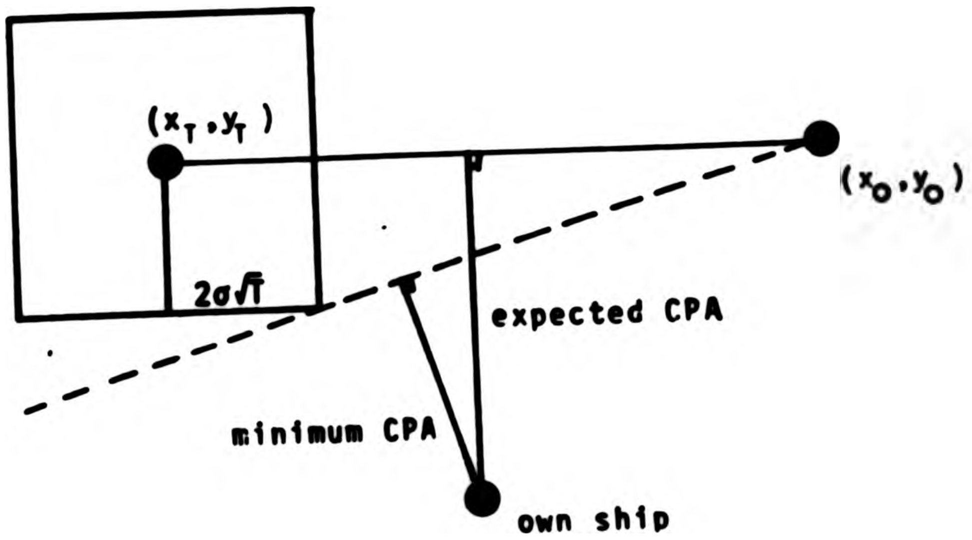

Fig. 4.15 showing the minimum value for the expected CPA given a 95% Confidence Interval for the velocity components.

---- lower 95% C.I.

and σ^2 directly, the optimisation technique minimises the distance between the two vessels with respect to time. The relative position of the target at time T is given as:

$$(x_0 + \bar{\delta}T), \ (y_0 + \bar{\gamma}T)$$

and the distance separation of the two vessels at time T, D_T is:

$$D_T = ((x_0+(\bar{\delta}T-2T^{1/2}\sigma))^2 + (y_0+(\bar{\gamma}T-2T^{1/2}\sigma))^2)^{1/2}$$

Differentiating w.r.t time to find a possible minimum value for the expected CPA given a 95% C.I. for the position of the target vessel at time T:

$$\frac{d(D_T^2)}{dt} = 2(x_0+(\bar{\delta}T-2T^{1/2}\sigma))(\bar{\delta}-T^{-1/2}\sigma) + 2(y_0+(\bar{\gamma}T-2T^{1/2}\sigma))(\bar{\gamma}-T^{-1/2}\sigma).$$

Equate to zero to minimise:

$$0 = (x_0 + (\bar{\delta}T - 2T^{1/2}\sigma))(\bar{\delta} - T^{-1/2}\sigma) + (y_0 + (\bar{\gamma}T - 2T^{1/2}\sigma))(\bar{\gamma} - T^{-1/2}\sigma)$$

$$0 = (\bar{\delta}^2 + \bar{\gamma}^2)T - (\bar{\delta} + \bar{\gamma})T^{1/2}\sigma - (x_0 + y_0)\,T^{-1/2}\sigma$$

$$+ x_0\bar{\delta} + y_0\bar{\gamma} - 2T^{1/2}\sigma(\bar{\delta} + \bar{\gamma}) + 4\sigma^2$$

This could be solved for $T > 0$ for given $x_0, y_0, \bar{\delta}, \bar{\gamma}$, and σ^2 numerically. This proves to be too complex, not providing a quick method for estimating the minimum CPA. The problem may be tackled (by line construction) geometrically.

(4.2.5) Geometrical Technique

Equation of lower 95% C.I. as shown in Figure 4.15 is given as,

$$y = \frac{y_0 - (y_0 + \bar{\gamma}T - 2\sigma T^{1/2})}{x_0 - (x_0 + \bar{\delta}T - 2\sigma T^{1/2})}\,x \qquad + \qquad c$$

Let T=1 (w.l.o.g)

$$y = \frac{\bar{\gamma} - 2\sigma}{\bar{\delta} - 2\sigma}\,x \quad + C$$

$$C = y_0 - \frac{(\bar{\gamma} - 2\sigma)}{(\bar{\delta} - 2\sigma)}\,x_0$$

So the equation of the lower line is,

$$y = \frac{\bar{\gamma}-2\sigma}{\bar{\delta}-2\sigma}\, x \;+\; y_0 \;-\; \frac{\bar{\gamma}-2\sigma}{\bar{\delta}-2\sigma}\, x_0$$

Equation of line passing through relative (0,0) and orthogonal to the above line is,

$$y' = -\frac{\bar{\delta}-2\sigma}{\bar{\gamma}-2\sigma}\, x'$$

Point of intersection of these lines given by X^{*} and Y^{*} is,

$$-\frac{\bar{\delta}-2\sigma}{\bar{\gamma}-2\sigma}\, x^{*} = \frac{\bar{\gamma}-2\sigma}{\bar{\delta}-2\sigma}\, x^{*} + y_0 - \frac{\bar{\gamma}-2\sigma}{\bar{\delta}-2\sigma}\, x_0$$

$$\left(\frac{\bar{\delta}-2\sigma}{\bar{\gamma}-2\sigma} + \frac{\bar{\gamma}-2\sigma}{\bar{\delta}-2\sigma}\right) x^{*} = \frac{\bar{\gamma}-2\sigma}{\bar{\delta}-2\sigma}\, x_0 - y_0$$

$$x^{*} = \frac{(\bar{\gamma}-2\sigma)(\bar{\delta}-2\sigma)}{(\bar{\delta}-2\sigma)^2+(\bar{\gamma}-2\sigma)^2}\left(\frac{\bar{\gamma}-2\sigma}{\bar{\delta}-2\sigma}\, x_0 - y_0\right)$$

$$y^{*} = -\frac{\bar{\delta}-2\sigma}{\bar{\gamma}-2\sigma}\, x^{*}$$

(4.2.6) Assessing the Co-variation of the CPA with

Translating the expression for the 95% lower value for the CPA into vector notation previously described,

$$\text{minimum (CPA)} = (x'^2 + y'^2)$$

$$x' = \frac{(\beta_2 - 2\sigma)(\beta_1 - 2\sigma)}{(\beta_1 - 2\sigma)^2 + (\beta_2 - 2\sigma)^2} \; \frac{\beta_2 - 2\sigma}{\beta_1 - 2\sigma} \alpha_1 - \alpha_2$$

$$y' = - \frac{(\beta_1 - 2\sigma)}{(\beta_2 - 2\sigma)} \; x'$$

By fixing the value of σ over a given range and varying the value for the expected CPA, an analysis may be made of how the CPA varies with σ.

Clearly CPA variation will depend on time from the Closest Point of Approach and σ.

(4.2.7) Estimating the Minimum Expected CPA

The minimum value for the expected CPA depends on both σ and the time until the Closest Point of Approach. By fixing the value of σ over a given range and selecting detected encounters both the minimum value for the expected CPA and the time until the CPA are calculated.

If the mean speed of a vessel is approximately 16 knots., then the mean X and Y component is .42 assuming uniform motion. Although the basic assumption is that the velocity components are normally distributed, i.e. the mean and the variance are independent, the variance can still be expressed as a proportion of the mean. The chosen range is μ, $\mu/2$, $\mu/4$, $\mu/10$, and $\mu/100$ which provides an adequate spread.

The resulting minimum value for the expected CPA is expressed as a percentage of the actual CPA achieved.

The situation is not the same for all encounters and complications can arise when certain encounters are detected late on in their development.

In Figure 4.16 the expected CPA is 0 in the displayed meeting or overtaking encounter. However the method described for calculating the minimum expected value of the CPA gives a result greater than 0. A similar error can occur in a meeting or a crossing encounter.

In Figure 4.17 the minimum expected value of the CPA is again greater than the expected value for the CPA using the geometrical method. For encounters that suffer from these errors the minimum value for the expected CPA is 0.

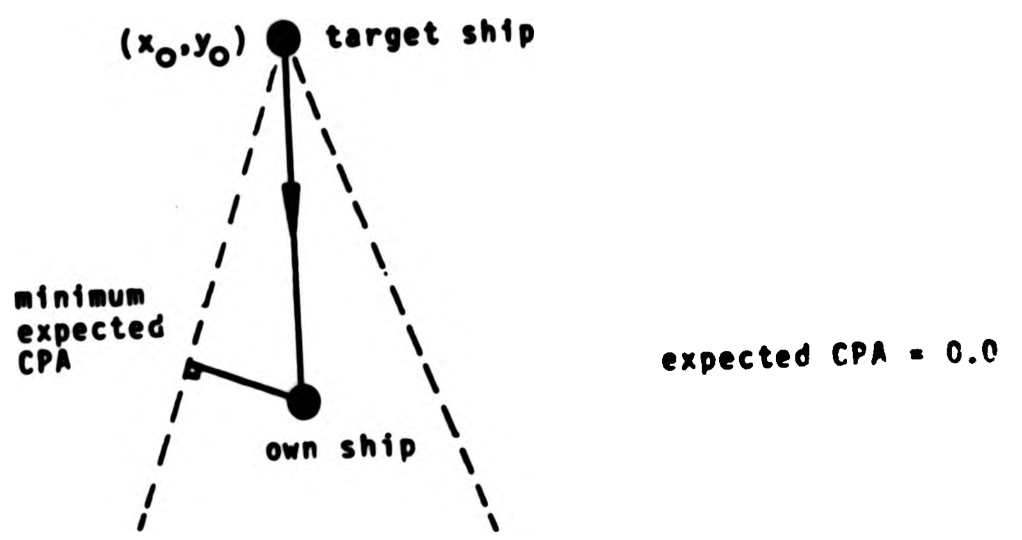

Figure 4.16 showing meeting and overtaking encounter errors.

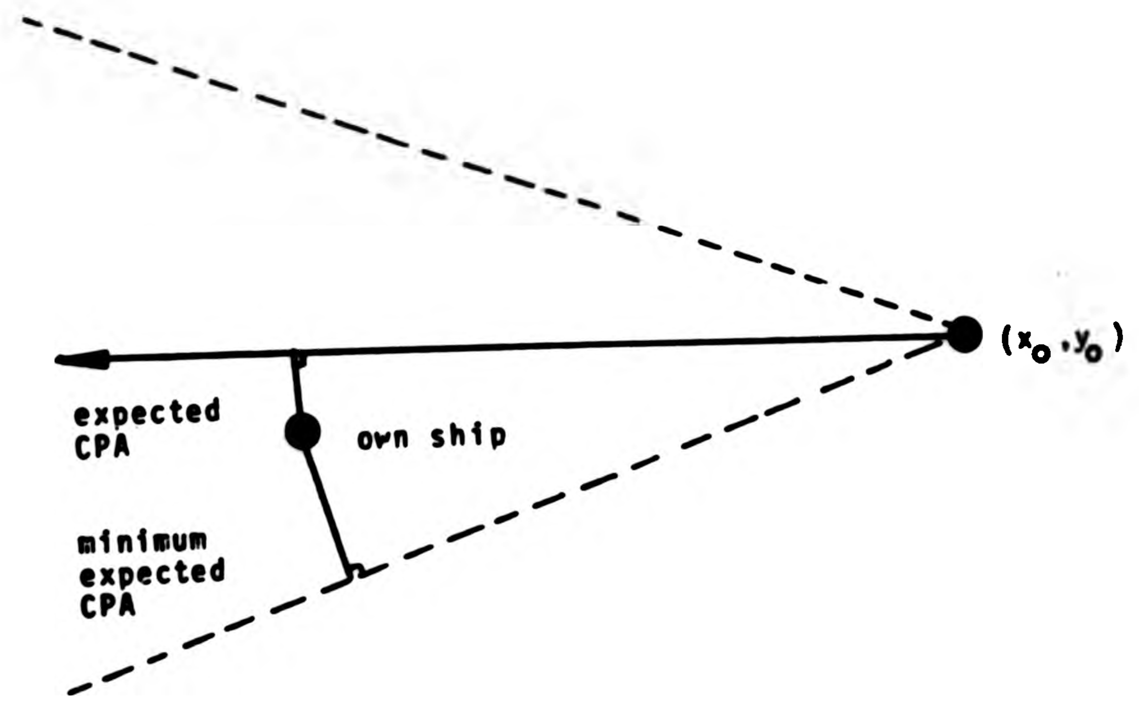

Figure 4.17 showing crossing encounter errors.

(4.2.8) Choosing a Critical Value for the Expected CPA

Results are presented in Table 4.02 in which minimum values for the expected CPA are given as percentages of the calculated expected CPA. These percentages differ depending on the type of encounter considered. Generally though from results obtained, if $\sigma \leqslant .042$ then the minimum value for the expected Closest Point of Approach is kept within reasonable bounds (50% of the actual CPA) for all types of encounter, provided that the time until the CPA is below 7.00 minutes.

However if $\sigma > 0.042$ or the time until the CPA is greater than 7.0 minutes then the minimum value for the expected CPA becomes very small relative to the actual value for the CPA, though this effect is less for meeting or overtaking encounters.

If the current position of the target ship (x_0, y_0) given is assumed to be subject to error then the minimum value for the expected CPA could become smaller, though this variation is less than σ and so less critical than the assumed variation in the predicted velocity components.

The proposed critical value for the CPA of 0.8 n.m. on this evidence will certainly account for all possible domain infringements. If a minimum passing distance is considered

Minimum expected CPA as percentages of expected CPA for differing values of σ, expected CPA and time until CPA.

		σ				
tcpa	cpa	.42	.21	.105	.042	.0042
8.62	.40	-	-	-	45	93
8.48	.68	-	-	-	37	93
8.20	.32	78	78	84	91	97
8.01	.32	-	-	-	3	94
7.64	.34	-	-	-	17	85
7.61	.64	-	-	-	33	89
7.56	.36	-	-	-	47	94
7.38	.07	-	-	-	71	71
7.29	.66	-	-	-	20	86
7.22	.56	-	-	-	39	98
7.19	.52	-	-	-	3	92
7.05	.61	-	-	-	26	85
6.88	.47	-	-	-	70	81
6.52	.56	-	-	-	43	86
6.38	.76	-	-	-	43	97
5.79	.42	57	62	69	81	98
3.63	.13	-	-	-	95	100
3.63	.48	92	94	94	96	100
2.66	.69	-	-	-	78	99
2.56	.26	-	-	8	50	92
2.17	.59	-	-	85	55	95
1.74	.75	-	-	1	81	99
1.71	.65	-	-	8	74	97
1.44	.71	4	18	45	76	97
.80	.50	9	12	48	88	100
.68	.76	2	24	57	84	99
.23	.65	-	35	73	96	100
(mins)	(n.m.)					

Minimum CPA **% CPA**

TABLE 4.02

to be 0.8 n.m. then the critical value for the CPA should be around 1.2 n.m. to account for the statistical variation in the predicted velocity component given by the CNIS ADP system.

Having decided upon a critical value for the expected CPA, the automatic encounter detection technique developed needs to be examined and assessed.

(4.5.0) Assessing the Models Performance

Having developed an automatic technique for detecting encounters it is useful to know how well the technique is performing. With this performance rating a comparison may be made with other techniques which may be subsequently developed. A method may be assessed in terms of how often it fails, and what risks are associated with these failures.

Any automatic encounter detection technique inherently will suffer from two error types. These are :-

A type I detection error is when an encounter has occurred but the automatic detection technique has failed to detect this encounter.

A type II detection error is when the automatic technique has detected an encounter when one does not exist.

Ideally, for any technique the probability of both a type I and a type II detection error occurring should be small. However, in real life, there will be a trade off. If the parameters are set to detect almost all encounters, then the number of false detections will be large; and conversely if the parameters are set so as to give a very low false encounter detection rate, then the number of encounters not detected will be higher. The choice of which error type to prioritise is user dependent. When the researcher is concerned with detecting all encounters a Type I detection error is of primary consideration. However if a penalty were associated with false detection (time or cost), a Type II detection error represents a greater risk.

Probabilistically,

<u>Type I :</u>

Probability of <u>Not</u> Detecting an encounter <u>GIVEN</u> an Encounter has occurred :
Pr(Not Detecting|Encounter) = P_1

<u>Type II :</u>

Probability of a situation <u>Not</u> being an encounter <u>GIVEN</u> that it has been Detected :
Pr(Not Encounter|Detected) = P_2

The probability P_1 , may be estimated by $\hat{P}_1$ directly by firstly manually detecting all encounters over a given time, then,

$$\hat{P}_1 = \frac{\text{no. manually detected} - \text{no. actual automatically detected}}{\text{no. manually detected}}$$

The definition of a type II detection error given above will give the probability P_2, that a detected situation is in fact not an encounter. This probability will depend heavily on the probability P_1, the probability of not detecting a bona fide encounter. The estimate $\hat{P}_2$, for P_2, used to measure the probability of a type II detection error in this study is given as,

$$\hat{P}_2 = \frac{\text{no. of false detections}}{\text{Total no. of detections}}$$

This estimate $\hat{P}_2$ together with the estimate $\hat{P}_1$ for P_1, give a good indication of how well the automatic detection technique is performing for a given sea area with a given traffic flow density and pattern.

The probability of each error type depends on the values given to both δ and ϑ_1.

By varying the values of δ and ϑ_1 the relationship between the values taken by these parameters and the size of the two detection error types may be understood. These relationships are summarised in Figures 4.18 and 4.19.

The values (1-Pr(Type I error)).100 and (1-Pr(Type II error)).100 can both be considered a measure of how well an automatic encounter detection technique is performing, with a rating of 100 interpreted as displaying no error. It is

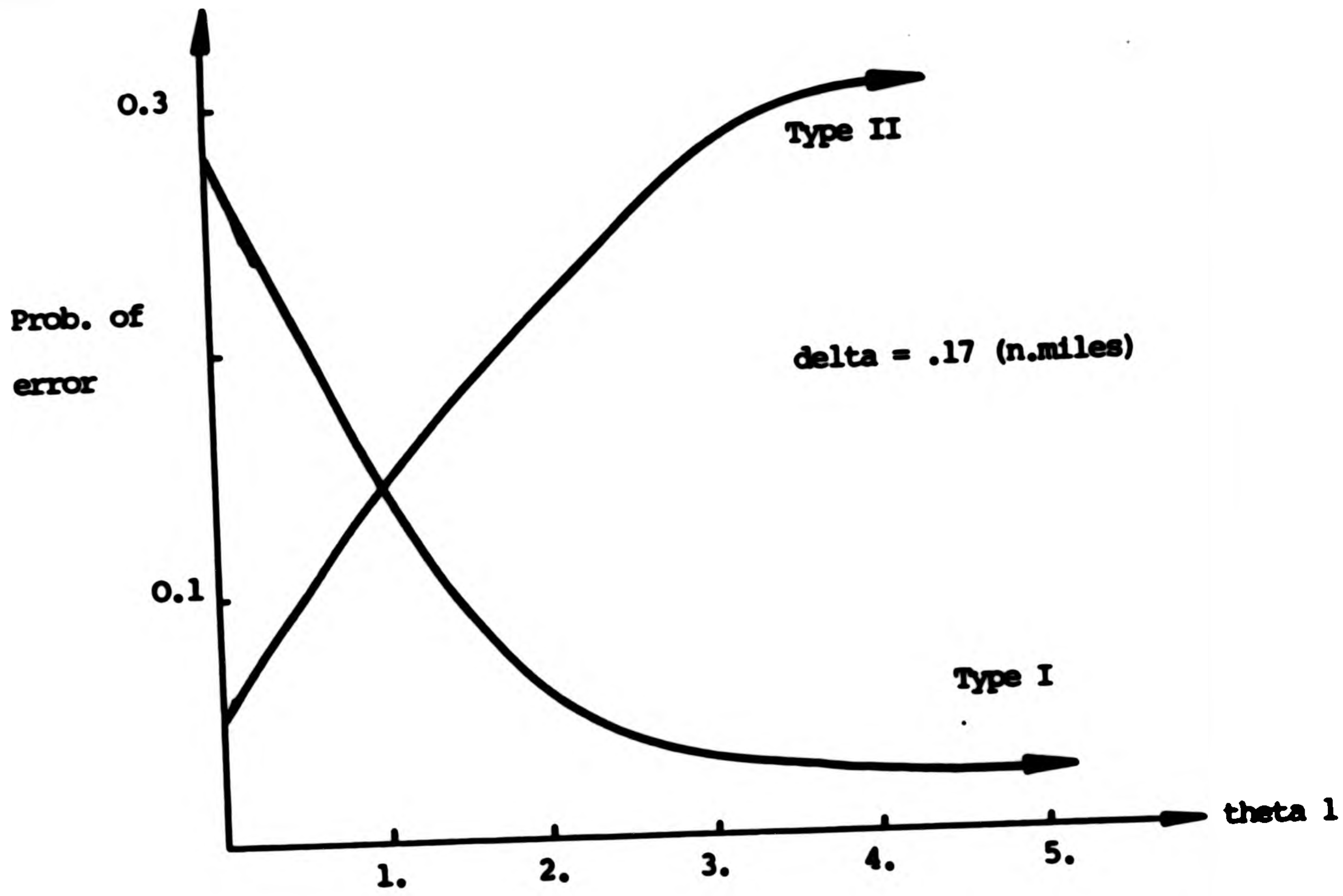

Figure 4.18

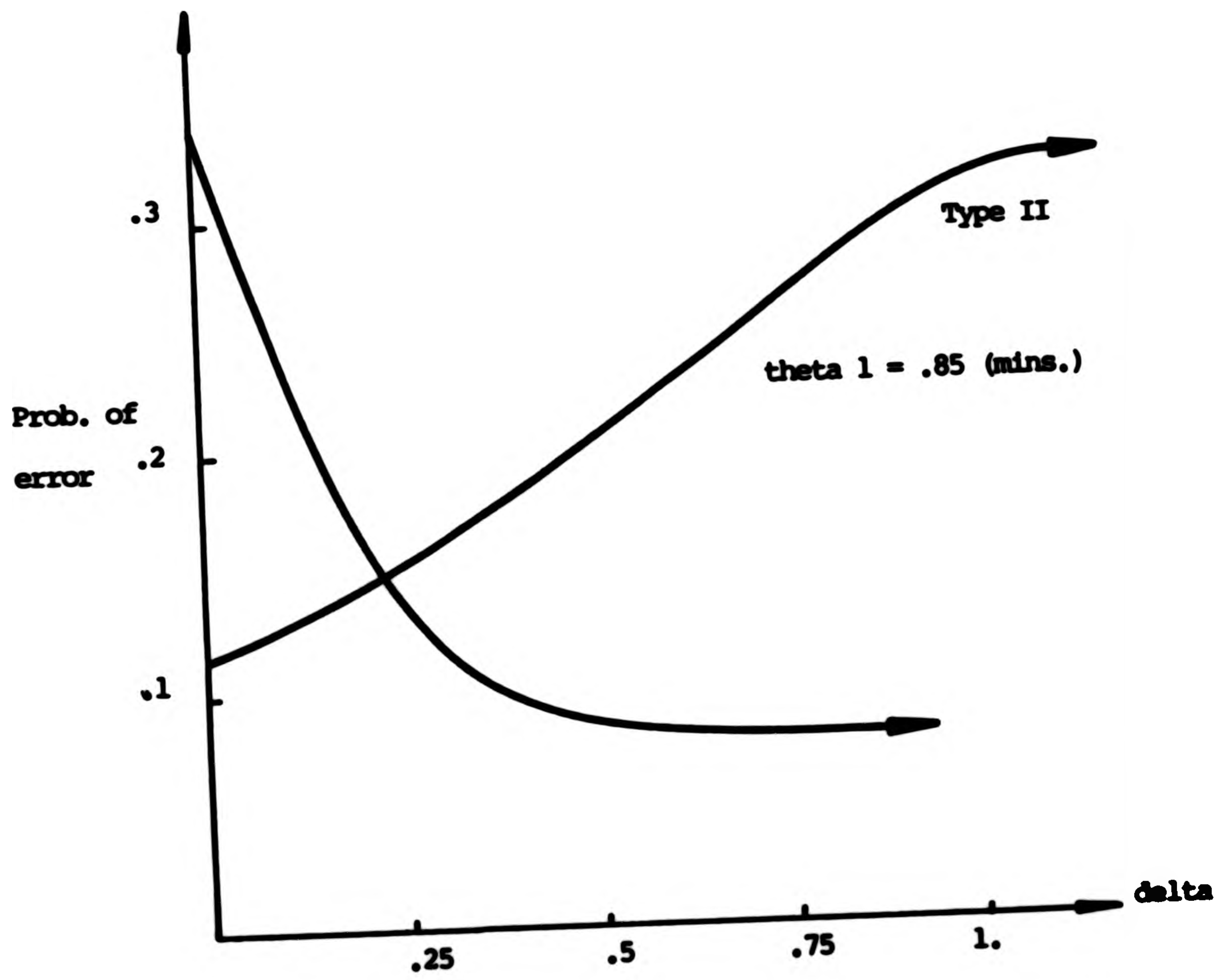

Figure 4.19

up to the user to decide which error to prioritise.

From experimental results the method described will detect on average 80% of all encounters, with 86% of those situations detected being actual encounters.

(4.6.0) Conclusions

In this chapter a review of encounter definitions has been presented with a view to develop an automatic encounter detection technique. Methods previously used are either purely distance based or they cannot distinguish between different encounter types.

The technique developed in this study, known as the RDRR+ method, has proved successful in detecting real life meeting, crossing and overtaking encounters. The method is an extension of the RDRR model developed by Colley et al (1983) for modelling the point of manoeuvre for vessels in two ship encounters.

The RDRR+ method for automatic real life encounter detection suffers from errors which are due to one or more of four factors.

In situations when vessels have a large relative velocity it is possible for the RDRR value to become critical when there is no risk of collision. Hence the RDRR+ value will similarly become critical when no encounter exists. This error occurs mostly in overtaking situations. To reduce this error a critical value for the expected CPA has been introduced. This critical value also accounts for the statistical variation in predicted velocity components.

If the RDRR+ achieves a critical value shortly before a navigational manoeuvre, a false detection may result. These errors are difficult to eliminate and require further investigation.

The real life data used for this study have been archived from the CNIS ADP system. Problems with this system, such as the failure to recognise a new vessel entering the system or the seduction of one track by another results in detection errors for any automatic technique. Again further work is required if these resulting errors are to be minimised.

The fourth cause of detection errors is due to software design. When sea areas are surveyed for encounters over discrete time periods then vessels achieving critical RDRR+ values close to the latter end of a period may cause late detection in the subsequent period. This error cause is perhaps the simplest to eliminate.

Given the above limitations the model has performed well. Two error type measures have been defined. The first being the probability of not detecting an actual encounter, and the second being the probability a detected situation not being an encounter. The latter measure is less informative than the former as if there are many encounters over a given period, an increase in the number of false detections will not significantly affect it.

The RDRR+ method has proved to be a useful tool for the researcher when collecting collision avoidance data. With situations detected and isolated, behavioural parameters may be measured for further analysis. In chapter five this study is undertaken and a statistical comparison between mariners behaviour at sea and on a marine radar simulator is presented in chapter six.

Chapter Five

Marine Radar Simulator Data Capture

(5.1.0) Introduction

The marine radar simulator presents the researcher with a relatively cheap and readily available source of behavioural data. These data have been used in many marine traffic studies, notably Curtis (1978, 1980, 1986) Goodwin (1975) and Holmes (1979). In previous studies these data have been analysed directly from exercise results presented in the form of graphical plots. For this study these plots have been digitised using computer facilities. In this chapter descriptions are given of the simulator used for data collection, the exercises completed, and the method used to analyse these data. As means of comparison, recent simulator designs developed to operate interactively on a digital computer are outlined.

(5.2.0) City of London Polytechnic Simulator

Data for this study have been made available by the City of London Polytechnic simulator. It is a 'three own ship' simulator consisting of three separate booths each fitted with a radar display and controls which a subject, or a group of subjects, can operate. Both the course and speed of the simulated vessel may be altered by the subject. The maximum speed and manoeuvrability (rate of turn) are preset by the instructor to represent the vessel being simulated.

Two of the control booths are additionally fitted with Automatic Radar Plotting Aids (ARPA).

The instructor from the master console has up to five moving and/or stationary target vessels over which he/she has direct control. The passage of the target vessel is predetermined and maintained by computer, though the instructor may intervene and manually control any of the target vessels at any time considered to be beneficial to the exercise. The instructor at all times can monitor the position, course and speed of any of the vessels pinpointing any alterations. The simulator incorporates a Hewlett Packard flat bed plotter which records the position of all vessels at minute intervals. The plots are examined in a debriefing session after the exercise is completed and can be stored for analysis. The subject cannot distinguish between other subject and computer/instructor controlled vessels. Since the subject is presented with a radar display only, the situation can be considered analogous to a poor visibility (less than 0.25 n.m.) situation in which a mariner relies totally on radar display for collision avoidance.

(5.2.1) The Exercises

Ship officers at varying stages of their careers attend the Polytechnic for a week course in radar navigation as radar training is considered very important. For each exercise there are usually two subjects per booth; one has the responsibility for navigation the other in a support role. By using a china graph pencil a vessel's progress is plotted on the radar screen. Charts are provided on a plotting desk.

The exercises may be grouped into three main categories;

1) Open sea,
2) Gibraltar Strait, and
3) Dover Strait.

Holmes (1979) applying a statistically based discriminant analysis procedure on data collected from this simulator suggested that there is little or no difference in mariners' behaviour between Gibraltar Strait and Dover Strait exercises and that these can be considered homogeneous restricted seaway exercises for analysis.

The open sea exercises require the subject to proceed as close as possible on the initial heading whilst avoiding incident. For the restricted seaway exercises subjects are given a destination. The subjects are required to keep a log of why manoeuvres were considered and exercises are discussed during the debriefing session.

<u>(5.2.2) Data Collection</u>

In previous investigations using simulator data statistics have been extracted and parameters measured directly from the graphical plots. Although it is certainly effective to trace ship tracks and measure distances and angles directly, with improved computer facilities techniques are available to automate the process.

Ideally information concerning vessel positions and velocities could be recorded directly whilst the exercises are completed. These recordings primarily would be actual X and Y co-ordinate signals interpreted by the Hewlett Packard Plotter and could later be processed to produce data files of track history or snapshots. These snapshot files could be of similar format to the expanded CNIS ADP Track History file. Although this is the desired procedure for simulator data collection it is not optimal for this study because of i) the development of such software is a major undertaking in itself and ii) at the time of data collection and analysis the simulator was no longer available for this software development.

(5.2.3) Plot Digitising

The flat bed digitiser has long been used by geographers to digitise maps and charts. A digitiser provides a useful method for obtaining relative co-ordinates translated from the two dimensional graph. The user of a digitiser enters a sequence of discrete co-ordinates to represent images.The flat bed digitiser consists of a sensitive board on which the graph is secured. The cross screen cursor, which incorporates a magnifier, is set in either continuous stream or point mode and the outline of the graph is then traced. Coordinates are interpreted by the DEC-10 main frame computer and later transformed using developed software.

The digitising tablet is nominally 30.5 cm. square though it is not practical to digitise a drawing more than 28 cm. square. This has not been a restriction as all collected plots are within this area. The digitiser which is shown in Figure 5.0 has been used in conjunction with the package NHIPAD. This package creates a data file containing all cursor movements. Comment statements have been used for vessel identification. On securing a plot to the tablet point mode is selected and the reset button is depressed establishing an origin. Additional software has been developed which reads the data file compiled by NHIPAD and creates the Track History file of correct scale. These data are then analysed by a software package similar to the one developed for the analysis of the CNIS ADP data. Plotting using this package is relatively fast as all data are read to working storage on examination and no further file reading or data organisation is required. Vessels are colour coded so that the analyst can differentiate between individual subject controlled and computer controlled vessels. Each exercise is stored in a separate data file.

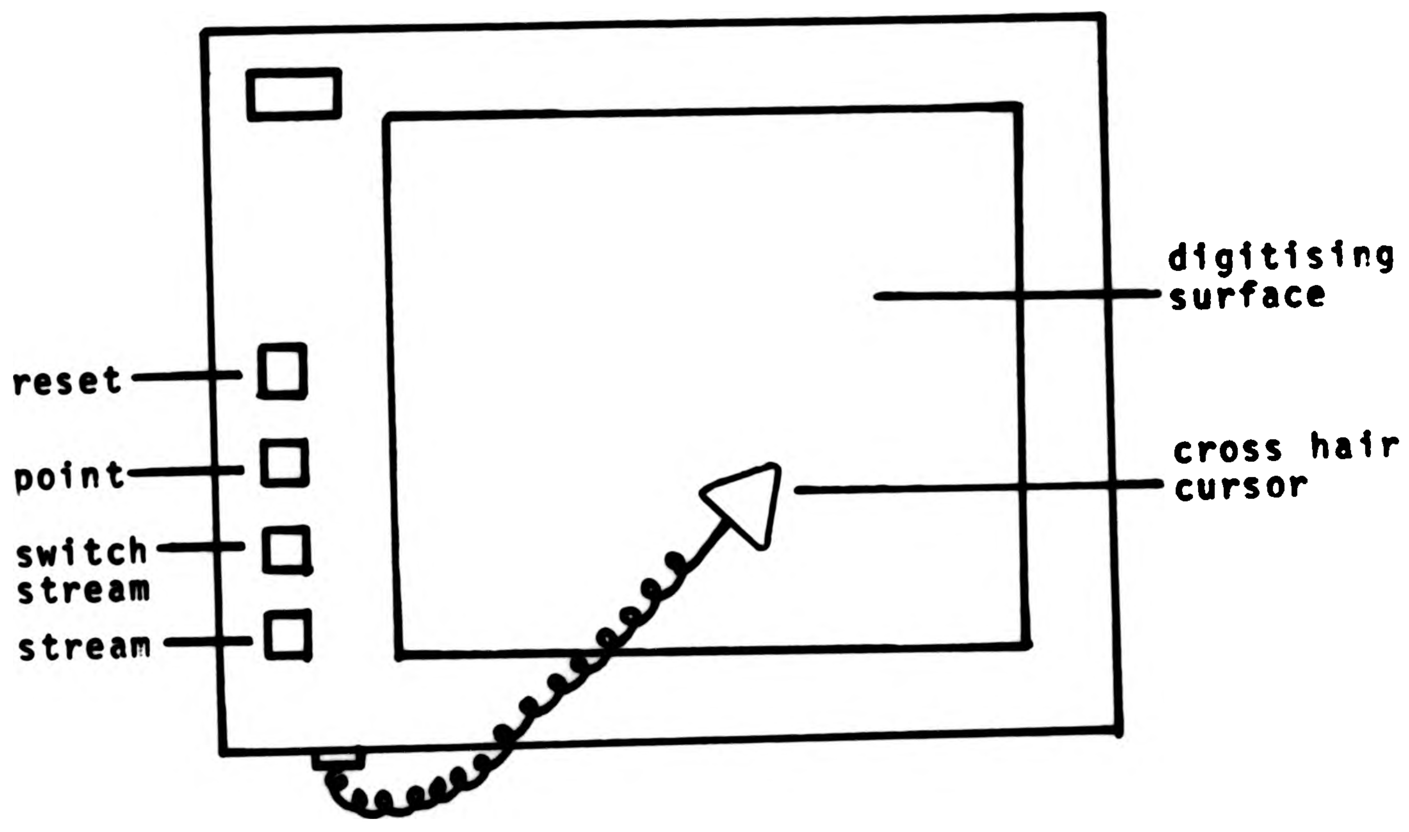

Figure 5.0 The Hipad Digitiser.

(5.2.4) Simulator Data Errors

Errors in the simulator data are generated at two levels. The first level is when the Hewlett Packard plotter at the City of London Polytechnic produces exercise plots. 'Dots' are drawn at 1 minute intervals representing the position of individual vessels. The position of these 'dots' is subject to error which depend on the accuracy of the plotter. No information has been made available as to how accurate these plots are. The second level of error is when these plots are digitised using the flat bed digitiser at the Polytechnic of North London. Duplication and averaging minimises this error but does not eradicate it, and should be taken into account when analysing such data.

To further reduce the effect of digitising errors on velocity predictions, velocities have been estimated using a weighted average of the difference in position over time. In this way, any random fluctuations in recorded positions are smoothed.

(5.3.0) Other Simulators

Some simulators incorporate a visual representation of the sea area. These 'view from the bridge' type simulators use projection methods to enhance the realism of simulation, but are expensive to maintain and are consequently rare in application.

With the now more readily available and economical micro computer the potential to offer a 'desk top' radar simulator has been realised.

From 1976 to 1982 ORION developed for the French Administration, a maritime traffic simulation model for the Channel based on vessel speed and destination. The model was judged realistic, validated by comparison with true survey radar pictures and was instrumental in the design of new separation schemes in the Channel proposed by the United Kingdom and France in 1981.

As the model performed well, Lefèvre (1984) developed a simple version for a micro computer. One of the aims of this version has been to simulate the synthetic radar display of a planned or existing survey station so as to evaluate the work load of the operators and to offer training facilities.

The viewing screen offers displays of the marine chart, the actual positions of each target in the area, the last positions of the targets, the predictions of future positions and information on targets pinpointed by the subject. Additionally the simulator offers the facility to centre the display relative to any vessel chosen by the subject. If the ARPA radar display is selected, certain statistics may be displayed. Details of exercise recordings for subsequent analysis are not given but the procedure required should not be a problem.

A number of micros may be connected to allow collective simulation where the instructor may manually control any of the targets.

Colley et al (1986) used the [illegible]d RDRR model to govern the behaviour of target vessels in an interactive simulation of a section of the Dover Strait. The simulator had been developed to operate on the main frame computer at Plymouth Polytechnic. The subject relays input to the operator who maintains the simulation. Different scenarios can be presented with data recorded in an output file for later analysis. The subject is presented with a synthetic radar screen with much the same format as that presented by the City of London Polytechnic simulator. A choice of true motion, relative motion ship's head up or relative motion north up is offered for the display. This simulator has only been used to demonstrate the effectiveness of the RDRR method to model the expected point of manoeuvre and no detailed investigation of the results have been made.

Clearly the potential to design simulators using computer technology is well recognised. Many colleges and training centres throughout the world are already equipped with the necessary hardware and it would be an efficient use of resources to design simulators to operate on these machines. However this type of simulator is another step away from realism. The dedicated simulator such as the one at the City of London Polytechnic presents the subject with a mock navigation room and actual radar displays. The pure computer simulators use standard graphical screens and resemble computers rather than vessel bridge equipment. Whether this further detachment from realism is significant depends on the purpose of the simulation and needs investigation.

(5.4.0) Summary

The analysis of simulator data is crucial for vessel traffic behavioural studies. Ideally these data would be read directly from the simulator. This has not been possible for this study and a technique has been developed to digitise the presented area plots. Using advanced computer graphical facilities these plots have been analysed and selected behavioural parameters measured. In the next chapter these parameters are compared with those measured from the real life data set to investigate the validity of using the marine radar simulator as a data source for research.

Chapter Six

Comparative Collision Avoidance Manoeuvres

(6.1.0) Introduction

The marine radar simulator presents the researcher with a relatively cheap and convenient data source when investigating vessel traffic behaviour. Real life data collections can be expensive and difficult to obtain.

There is a temptation to collect large simulator data sets and apply any findings to the real life situation. However any conclusions should be restricted to mariners behaviour on a simulator unless the researcher has a strong belief that a mariner behaves in a similar manner in both the real life and simulator situations. It has been one of the aims of this study to compare mariners behaviour in both these situations. An investigation into the possible parameters for comparison has been made. In previous studies simulator data have been collected following detailed experimental design and consultation between the analyst and the simulator supervisor. The simulator at the City of London Polytechnic was scrapped early on in the progress of this project when the navigation department of the polytechnic was closed. Consequently the level of involvement of the analyst with regards to data collection and experimental design has been well below ideal. The lengthy software development period compounded this inadequate data collection so that the resulting comparison has not been as comprehensive as originally hoped. Nevertheless, by reducing the dimensionality of the problem a statistical comparison of the two data sets has been made.

Appropriate statistical methods have been chosen for this comparison and these are outlined in this chapter. These methods known as non-parametric methods make no assumptions about the two data sets and only inadequacies inherent in the data collection restrict the scope of the conclusions.

(6.2.0) Comparing Behavioural Data

Essentially when comparing the simulator and real life data sets a comparison of human behaviour is made. When seeking to investigate human behaviour the analyst requires some form of quantitative measure to gauge the human response. The effectiveness of the comparison depends heavily upon the ability of the chosen measure to reflect the behaviour in question. In this study, the comparison of human behaviour in differing environments is of interest.

When investigating mariners behaviour in an encounter the analyst needs to quantify any action taken by the mariner to reduce the risk of collision. There is an extensive choice of possible parameter measurements available to the analyst but their collection is contrained by two limiting factors. The first is due to data collection. The accuracy of any measurements can only be as high as the level of accuracy of results ~~...~~. It is meaningless to derive greater 'accuracy' than exhibited by original data.

The second limiting factor is due to the type of analysis the researcher wishes to perform. Many statistical procedures require the data to follow a particular distribution. In many cases these restrictions are violated which quite often reduce the confidence of the conclusion. Some statistical procedures although requiring the fulfilment of certain assumptions, perform well when these assumptions are violated. Such procedures are referred to as 'robust'.

From previous studies (Goodwin 1975, Holmes 1979, Curtis and Barratt 1981, Colley et al 1984) the following set of parameters were originally identified as relevant.

1. Own ship velocity.
2. Own ship change in velocity due to manoeuvre.
3. Relative bearing of target ship from own ship at time of encounter detection.
4. Change in relative bearing of target ship from own ship due to manoeuvre.
5. Direct distance separation of target and own ship at time of encounter detection.

6. Time taken for manoeuvre.

7. Angle of manoeuvre of own ship.

8. Angle of approach of own and target ships.

9. RDRR value at time of manoeuvre.

10. Relative velocity at time of encounter detection.

11. Target ship velocity at the time of encounter detection.

12. Indirect distance separation of own and target ships (via closest point of approach) at time of encounter detection.

13. Time until closest point of approach from time of encounter detection, assuming straight line courses of ships.

Holmes (1979) highlighted the indirect distance separation as an important measure in determining the expected, if any, point of manoeuvre. The measure as used by Holmes differs from that used in this study. Holmes measures the indirect distance separation as the total distance between two vessels via the point of intersection of the two courses. In overtaking and meeting situations the courses may intersect well beyond a high risk situtation if at all. For this study the indirect distance separation has been measured as the total distance between two vessels via their closest point of approach thereby eliminating this anomaly.

This is not the complete set of measurable parameters and clearly many of these are related to others listed.

The CNIS ADP data includes velocity estimates and allows measurement of required parameters. The simulator data consists of position data only. Velocity estimates at a given time T have been calculated using a weighted average of the difference in position over time.

For both data sets problems arise when determining the point of manoeuvre and consequently when trying to measure the angle of manoeuvre, the time τ taken for manoeuvre and the change in relative bearing due to manoeuvre. This problem is overcome by considering the multivariate distribution of the parameter estimates described later.

(6.3.0) Multivariate Distributions

Since the analysis involves the measurement of several parameters it is necessary to consider the multivariate distribution of these estimates.

For the thirteen parameters listed the joint distribution of the estimates is expressed as,

$$f(x_1,\ x_2,\ x_3, \ldots\ldots,\ x_{13}) = f(\underline{X})$$

where $\underline{X}$ is the vector of univariate random variables or parameter estimates.

Marginal and conditional distributions may be easily defined. The marginal Probability Density Function (pdf) of one component of $\underline{X}$ say x_i, may be found from the joint pdf by integrating out all other variables. Thus,

$$f_i(x_i) = \int_0^{\infty} \cdots \int_0^{\infty} f(x)\, dx_1 \ldots dx_{i-1} dx_{i+1} \ldots dx_p$$

The random variables are independent if the joint pdf is equal to the product of the marginal pdf's for every x. The density functions of continuous distributions can be found by dividing the joint pdf by the appropriate marginal pdf.

The conditional joint pdf of $X_1, \ldots\ldots, X_k$

given $X_{k+1}=x_{k+1}, \ldots, X_p=x_p$

is given by,

$h(x_1, \ldots, x_k | x_{k+1}, \ldots, x_p) = f(\underline{X})/f_m(x_{k+1}, \ldots, x_p)$

where $f_m(x_{k+1}, \ldots, x_p)$ denotes the marginal joint pdf of

$X_{k+1}, \ldots, X_p$.

The reader is referred to Chatfield and Collins (1983) for a greater discussion on multivariate distributions.

(6.4.0) Parameter Estimate Distributions

When analysing multivariate data it is desirable to reduce the dimensionalilty of the problem as far as practical. This can be done by following principal component analysis procedures which seek to transform the existing set of variables into a new set of <u>independent</u> variables. Often these variables are difficult to interpret and consequently are of limited practical use and are most useful when investigating relationships within sets of dependent variables.

Curtis and Barratt (1981) seek to explain differences in behaviour by comparing cumulative distributions of passing track separations for vessels in an overtaking situation after accounting for differing initial track separation distributions. This idea of summarising a collision avoidance action has been adopted for this study. This is because inadequate and insufficient data have been made available for the direct comparison of many of the behavioural parameters. By estimating the closest point of approach at the time of encounter detection it is possible to consider fewer variables when comparing mariners' behaviour in both the real life and simulator situations. The difference between expected closest point of approach and actual closest point of approach accounts for changes in course and speed due to a collision avoidance manoeuvre. By considering conditional distributions of these differences given an initial expected CPA a suitable comparison of behaviour can be made. It is possible that these differences are due to other factors particular to the two respective data collections, but these comparisons are optimal in the sense they do not try to 'extend the accuracy' of the samples whilst discriminating between behaviour difference.

(6.5.0) The Two Data Sets

(6.5.1) Real Life Data

Using the RDRR+ method for automatic encounter detection described in previous chapters, samples of crossing, meeting and overtaking encounters have been collected from the Dover Strait separation scheme. Software developed and described in the third chapter has been used to investigate these encounters, usually allowing the measurement of selected behavioural parameters.

The survey area was split into five square sub-areas, each of which was interrogated for encounters. The CNIS ADP magnetic tapes were analysed providing some 18 hours of continuous track history. Some encounters were incomplete due to the seduction of one vessel track by another, these have been ignored. The RDRR+ method for automatic encounter detection proved invaluable when satisfactorily implemented on the designed software.

By far the most common of the encounters detected were overtaking ones. This is expected as in a separation scheme crossing vessels traverse the system at a suitable point to minimise the risk of encounter. Meeting situations are most rare and are the result of rogue through vessels or vessels approaching each other near port entrances. The automatic tracking system performs least effectively near dropping points which tend to be at port entrances. These dropping points are where vessels are detected as entering or leaving the system. It was also for these associated errors that some coastal regions were discounted from the search areas.

The collection of additional data does not present a problem if the work is to be extended. The processes of tape reading, file expansion and graphical software operation (see chapters two and three) are all routine. The RDRR+ method which is built into the software package allows the quick collection of encounter information.

All the parameters listed on Pg 179 except (2), (4) and (6) can be measured directly using the software package. Parameters (2) and (4) can be computed but (6) is difficult to assertain as the start and end points of the encounter are highly subjective. The comparison is mainly limited by the simulator data set.

Samples have been collected of real life overtaking, meeting and crossing encounters. All of those collected encounters have been detected using the RDRR+ method. Some 93 overtaking, 37 meeting and 65 crossing encounters have been collected. For the real life encounters, the Expected Closest Point of Approach at the time of encounter detection

(ECPA), the actual Closest Point of Approach achieved (CPA), the Relative Velocity at the time of encounter detection (RELVEL) and the Angle of Approach at the time of encounter detection (APCH) have also been recorded. The difference between ECPA and CPA has been calculated. The data collected are given in Appendix IV in tables A.1 (real life meeting encounters), A.2 (real life overtaking encounters) and A.3 (real life crossing encounters). Descriptive statistics for these data sets are given in table 6.1. This table contains mean and standard deviation of recorded parameters.

(6.5.2)Simulator Data

When this project was initiated it was thought that of the two data sets the simulator data would prove most reliable in yielding comparable results. The simulator is an ideal source of navigational data, not least because simulator experiments may be completed by different subjects allowing the analyst to account for variation in subject performance rather than apportion all variation to the exercise. The simulator made available for this study was based at the City of London Polytechnic, but was unfortunately scrapped early on in the project's development when ths School of Navigation at the Polytechnic was closed. Exercises previously completed by subjects attending courses at the Polytechnic had been saved, though less systematically than ideal. Additionally a large number of exercises requiring vessels to overtake a moving target have been made available

Table 6.1

Real Life Data Summary

mean/standard deviation		ECPA(n.m)	CPA(n.m)	RELVEL(knots)	APCH	DIFF(n.m)
Meeting	mean	0.24	0.38	26.21	167.19	0.14
	s.d.	0.18	0.15	10.42	36.97	0.14
Crossing	mean	0.31	0.50	19.11	93.21	0.20
	s.d.	0.19	0.17	6.12	37.39	0.16
Overtaking	mean	0.26	0.35	8.02	12.74	0.11
	s.d.	0.17	0.16	4.76	16.93	0.11

Table 6.2

Simulator Data Summary

mean/standard deviation		ECPA(n.m)	CPA(n.m)	DIFF(n.m)
Crossing	mean	0.37	0.85	0.48
	s.d.	0.29	0.32	0.36
Overtaking	mean	0.67	1.13	0.47
	s.d.	0.41	.47	0.51

by Dr. R.G. Curtis. These were collected as part of a previous validation study (1981).

Exercises were presented in the form of plots. These plots have been digitised as outlined in chapter five and analysed using the software developed. For a comprehensive comparison, a preliminary analysis of real life situations would be made, followed by experimental design after consultation between the analyst and the simulator supervisor. Circumstances during the stages of this project, previously explained, have prevented this. Given these restrictions a comparison has been made, though far less comprehensive than originally planned. The encounters recorded during the course of the simulator experiments are a direct result of experiments not specifically designed for a comparison with Dover Strait traffic separation scheme data. Measurements such as relative bearing, vessel velocity and angle of approach are far more indicative of the experimental design than of mariners' behaviour. However, any changes of course and speed during an encounter due to a collision avoidance manoeuvre will reflect mariners' behaviour. It is for this reason of the simulator data restriction that the difference between the actual closest point of approach achieved and the expected closest point of approach at the time of encounter detection has been chosen to quantify mariners' behaviour in a collision avoidance situation. By considering this difference the angle of approach is not accounted for, though again the analyst needs to input such considerations into the experimental design.

As with the real life data meeting situations were least common. In a real life meeting encounter it is quite often the case that both vessels manoeuvre to avoid collision. The simulator used at the Polytechnic did not incorporate intelligent target vessels. This means that in the majority of meeting situations only the subject controlled vessels can manoeuvre to avoid collision. For this reason results of meeting encounters are less reliable for comparison than either crossing or overtaking ones. This is not to say that this type of simulator could not be used to collect meeting encounter results, but these would have to be built into a designed experiment rather than rely on chance situations in general area simulations. Substantial data were collected for overtaking as well as for crossing encounters.

Samples of simulator overtaking and crossing have been collected. In total 131 overtaking and 37 crossing encounters have been collected. For the simulator encounters the Expected Closest Point of Approach at the time of encounter detection (ECPA) and the actual Closest Point of Approach achieved (CPA) have been recorded and a full listing is presented in Appendix IV tables A.4 (simulator overtaking encounters) and A.5 (simulator crossing encounters). As with the real life encounter data the difference between ECPA and CPA has been computed. Descriptive statistics (mean and standard deviation of measured parameters) given in table 6.2.

(6.6.0) Non Parametric Techniques

In statistics the mean, median, variance, range, and histogram etc. are used when describing a set of data. Each of these measures summarizes the data in its own unique way. When sample descriptions are used to infer some information about the population, the subject is called inductive statistics or statistical inference. The factor which makes inference a scientific method is the ability to make evaluations or probability statements concerning the accuracy of an estimate or reliability of decision. Unfortunately, such scientific evaluations cannot be made without some information regarding the probability distribution of the random variable relating to the sample description used in the inference procedure. The entire body of classical statistical inference techniques is based on fairly specific assumptions regarding the nature of the underlying population distribution. When these assumptions hold, certain test statistics can be developed. Quite often it is difficult to assertain whether these basic assumptions are fulfilled, either the sample size is too small or the researcher has little expertise in statistical application and may not understand or even be aware of these preconditions implicit in the derivation of statistical technique.

There is an alternative set of techniques available which may be classified as distribution-free inference, and nonparametric procedures (Gibbons 1971).

In a distribution-free inference, whether for testing or estimation, the methods are based on functions of the sample observations whose corresponding random variable has a distribution which does not depend on the specific distribution function of the population from which the sample was drawn. Hence, assumptions about the underlying distribution are not necessary. The term nonparametric test implies a test for a hypothesis which is not a statement about parameter values. If parameter is interpreted in the broader sense, the hypothesis can only be concerned with the form of the population, like a goodness of fit test, or with some characteristic of the probability distribution of the sample data, as in tests of randomness.

Although distribution-free and nonparametric tests are not the same, it is common practice to group both types of test together as procedures in nonparametric inferences.

The comparison of mariners behaviour in the real life and simulator situations is analogous to the two sample problem. The sampling situation is of two independent samples, not only are the elements within each sample independent, but also every element in the first sample is independent of every element in the second sample. By categorising the samples by their initial expected closest point of approach, a comparison of the conditional distributions is made between the two samples.

For each pair of conditional distributions, the universe consists of two populations, with cumulative distribution functions denoted F_r and F_s for real life and simulator situations respectively. For a random sample of size m drawn from the R population and a sample of size n drawn from the S population,

$$R_1, R_2, \ldots\ldots\ldots\ldots, R_m \quad \text{and} \quad S_1, S_2, \ldots\ldots\ldots\ldots, S_n$$

the hypothesis of interest is,

$$H_0: \quad F_S(r) = F_r(r) \qquad \text{for all } r.$$

If assumptions are made about the form of the common population, in particular the normal distribution, and that if differences between the populations exist it is only between means and variances, then the Student's t-test for the equality of means and the F-test for equality of variances are respectively appropriate. Any conclusions reached using these tests are only as valid as the underlying assumptions.

Since the conditional distributions of the parameter estimates are unknown, some nonparametric technique is in order.

The two sample situation is commonly discussed in nonparametric statistics with the null hypothesis almost always formulated as identical populations with the common distribution function. In the null case, the two random samples can be considered a single random variable of sample size $N=n+m$, drawn from the common, continuous, but unspecified population. Then the combined ordered configuration of the mR and nS random variables in the sample is one of the $\binom{m+n}{m}$ possible equally likely arrangements.

The sample pattern provides information about the type of difference which may exist in the populations. Hence almost all the tests are based on some function of the combined arrangement. There is a wide choice for alternatives to H_1, but the easiest type to analyse using distribution-free techniques states some functional relationship between the distributions.

When the particular interest is sampling a difference in location, the alternative is,

$$H_1 : F_S(r) = F_T(r-\vartheta) \text{ for all s and some } \vartheta \neq 0$$

and is called the location alternative. Similarly a scale alternative is,

H_S: $F_S(r) = F_T(\vartheta r)$ for all r and some $\vartheta \neq 1$.

For this study a non-parametric test of location known as the Mann Whitney U-test has been applied to as ertain differences between mariners' behaviour in the real life and simulator situations. The reader is referred to Gibbons (1971) for a full description of this test procedure and the underlying theory.

(6.7.0) Statistical Comparison

In total five samples containing encounter data have been collected. The collection of these samples has been greatly restricted by i) insufficient and inadequate simulator data and ii) the replacement of the Polytechnic of North London DEC-10 main frame computer system. Both these problems are discussed in the project evaluation presented in chapter seven.

The five samples collected are the real life meeting, crossing and overtaking encounters and the simulator crossing and overtaking encounters. To compare mariners' behaviour in the real life and simulator collision avoidance situation, it is necessary to divide this comparison into like encounter classes. This is appropriate as one would not necessarily expect a mariner to take the same action in a crossing encounter as he would in say an overtaking encounter. This can be verified by inspecting the summary statistics presented in Tables 6.1 and 6.2.

(6.7.1) Meeting Encounters

For reasons outlined in section 6.5.2, simulator meeting encounter data were not collected. Therefore the comparison could only be made between the two data sets for overtaking and crossing encounters. However data concerning real life meeting encounters have been collected using the RDRR+ method and summary statistics have been presented in table 6.1. Histograms of CPA, and ECPA and CPA differences have also been presented in Figures 6.00 and 6.01 respectively. Figure 6.00 shows that the majority (86%) of the meeting encounters identified have ECPAs of below 0.4 n.miles. The histogram of the expected and actual CPA differences, Figure 6.01, shows that nearly a third of vessels in a meeting encounter manoeuvre so as to increase their CPA by no more than 0.05 n.miles. Additionally, 94% of those sampled increase their CPA by no more than 0.35 n.miles. The summary statistics presented in table 6.1 are none too revealing. The mean relative velocity for the sampled real life meeting encounters was found to be 26.21 with a standard deviation of 10.42 knots, which is of the expected order.

sample size = 37

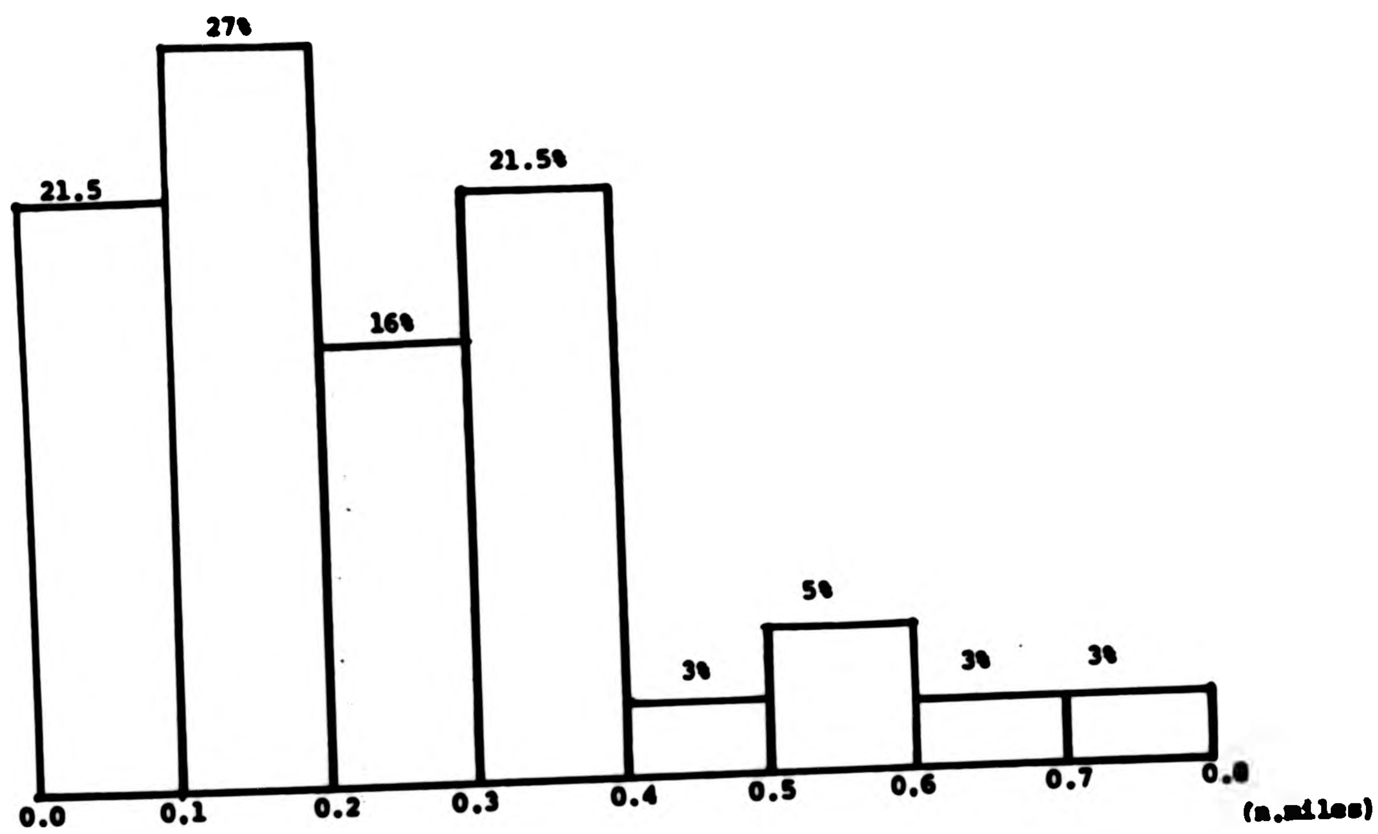

Figure 6.00 Histogram of Expected CPA for Real Life Meeting Encounters.

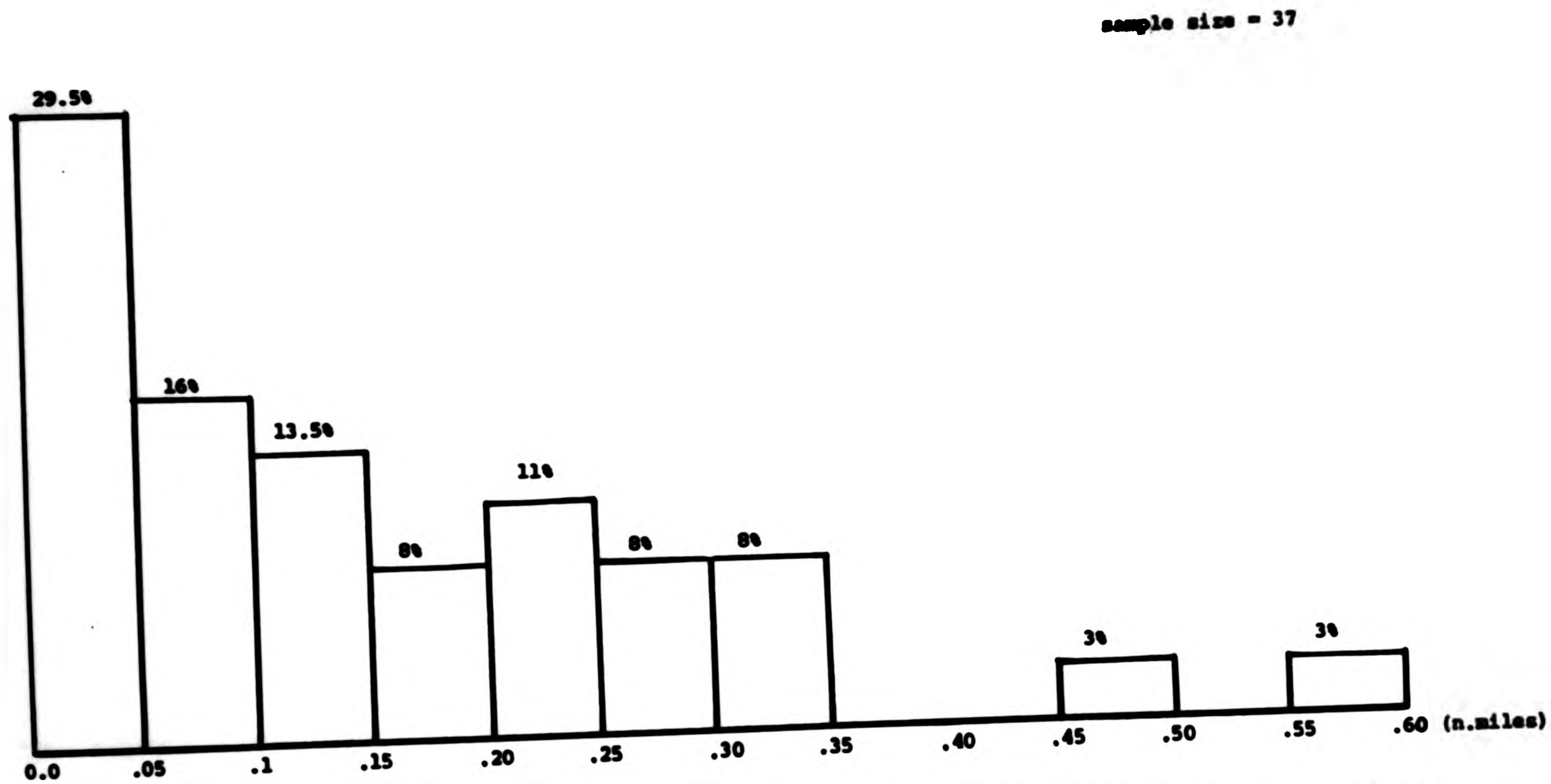

Figure 6.01 Histogram of Expected and Actual CPA differences for Real Life Meeting Encounters.

(6.7.2) Overtaking Encounters

A comparison of mariners behaviour in an overtaking encounter in both real life and simulator situations has been made. Both histograms for the expected CPA (real life Figure 6.02, simulator Figure 6.03), are presented. The distribution of the expected CPA for the simulator results is near uniform. The form of this distribution is not indicative of mariners behaviour but merely the result of the experimental design. By contrast the distribution of the real life expected CPA is positively skewed, indicative of the Dover Strait traffic separation system. Some 94% of the encounters detected have an initial CPA of less than 0.5 n.miles. Only a relatively small observed number of these encounters form the right hand tail.

Histograms of expected and actual CPA differences for real life and simulator overtaking encounters (Figure 6.04 and Figure 6.05), are positively skewed. The high percentage, 39.5%, of differences below 0.2 n.miles in the simulator situation is misleading. For the experiments where vessels were given an initial track separation of over 1.00 n.miles (35.5%) little or no manoeuvre would be expected. There is no obvious reason why few of the simulator exercises caused vessels to increase their CPA to between 0.8 and 1.0 n.miles.

The histogram of actual and expected CPA differences for

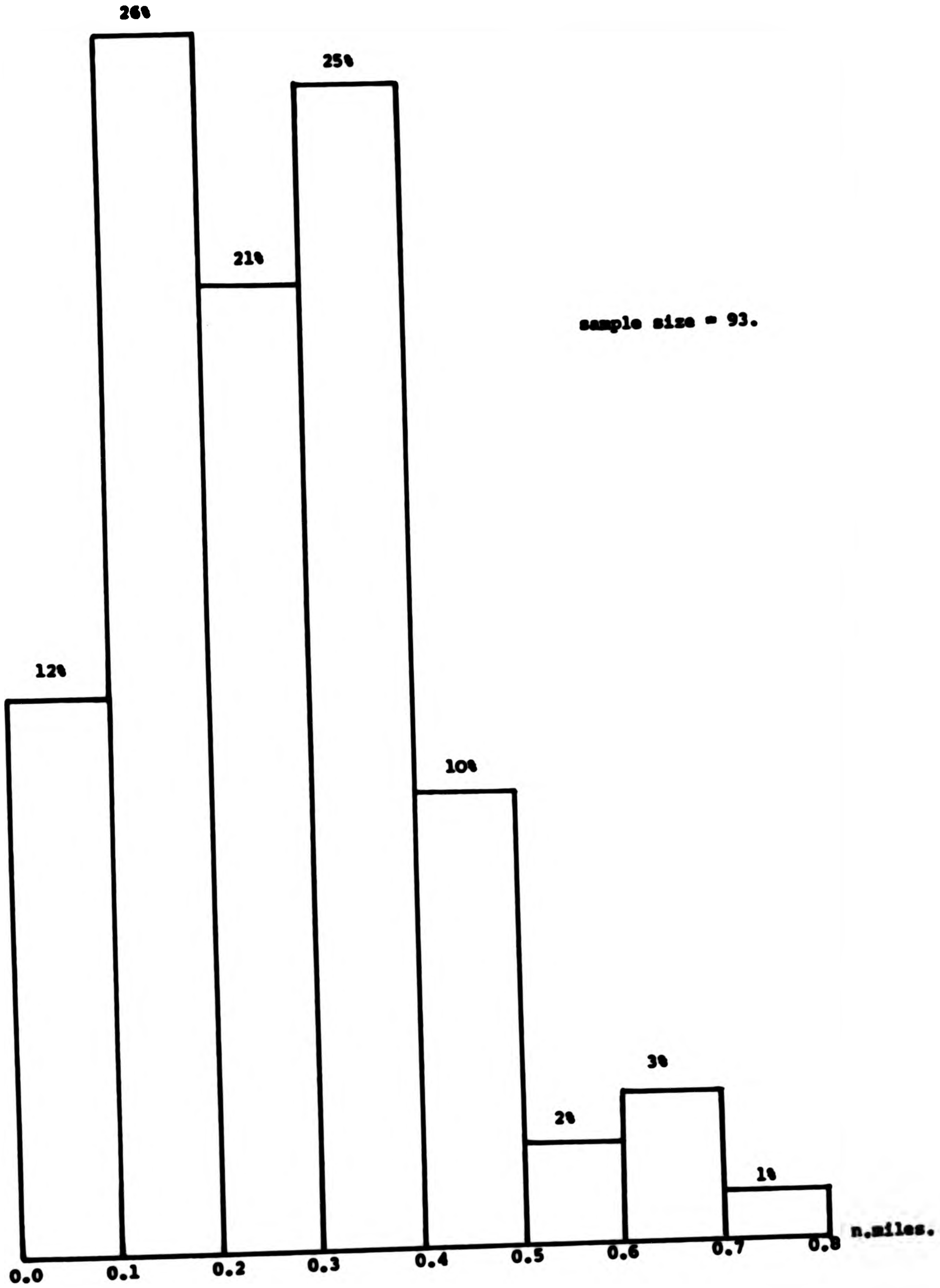

Figure 6.02 Histogram of Expected CPA for Real Life Overtaking Encounters.

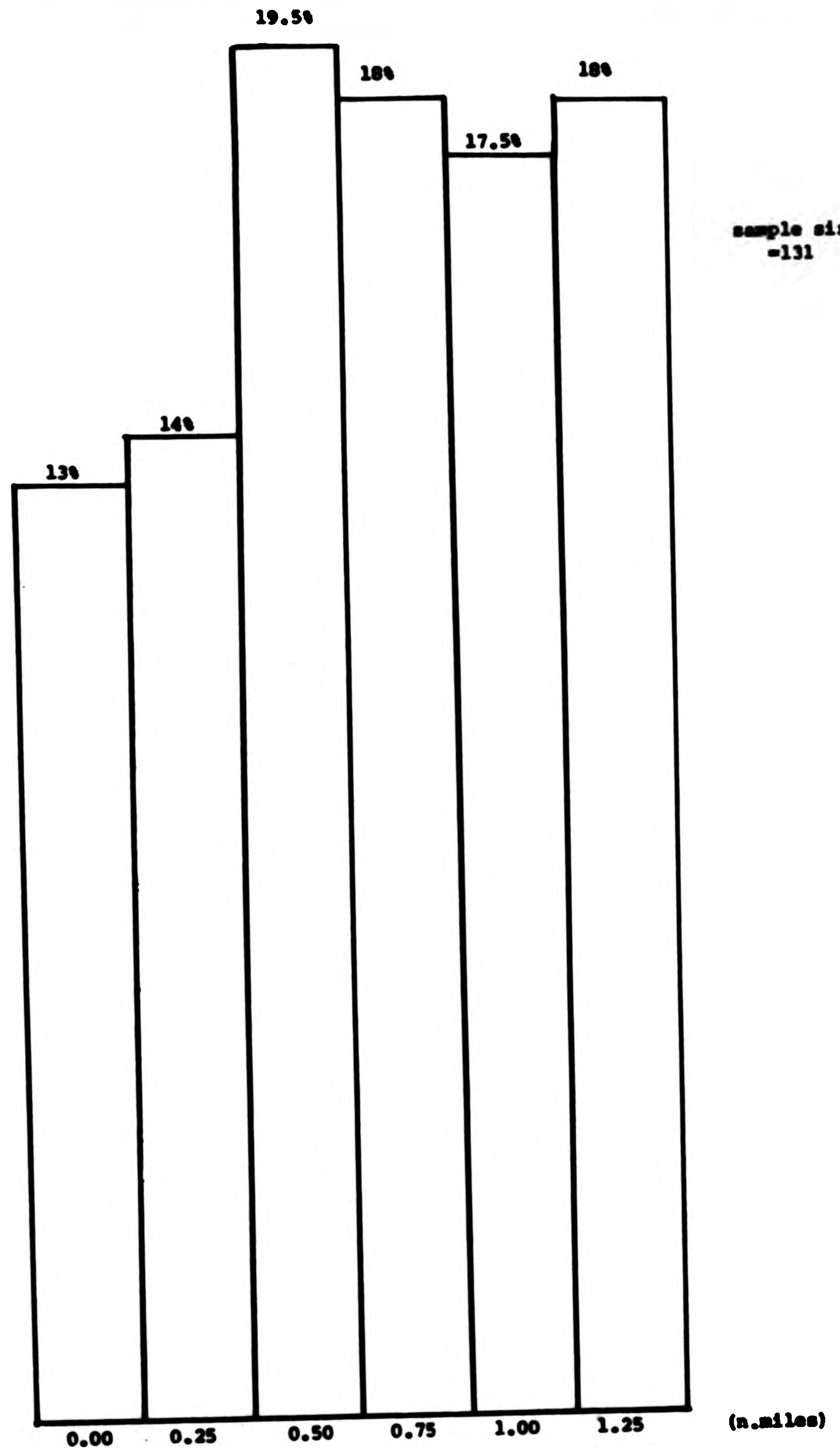

Figure 6.03 Histogram of Expected CPA for Simulator Overtaking Encounters.

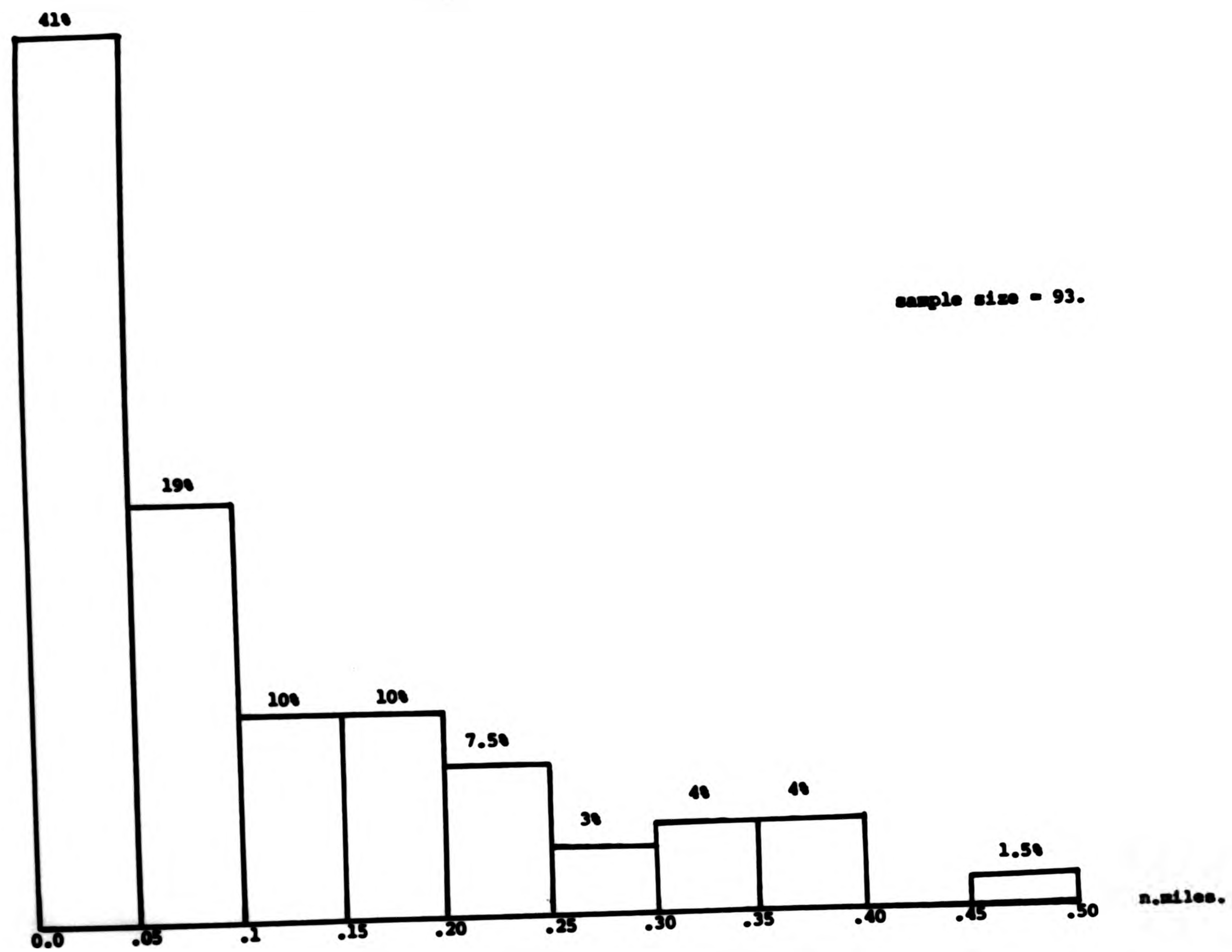

Figure 6.04 Histogram of Expected and Actual CPA differences for Real Life Overtaking Encounters.

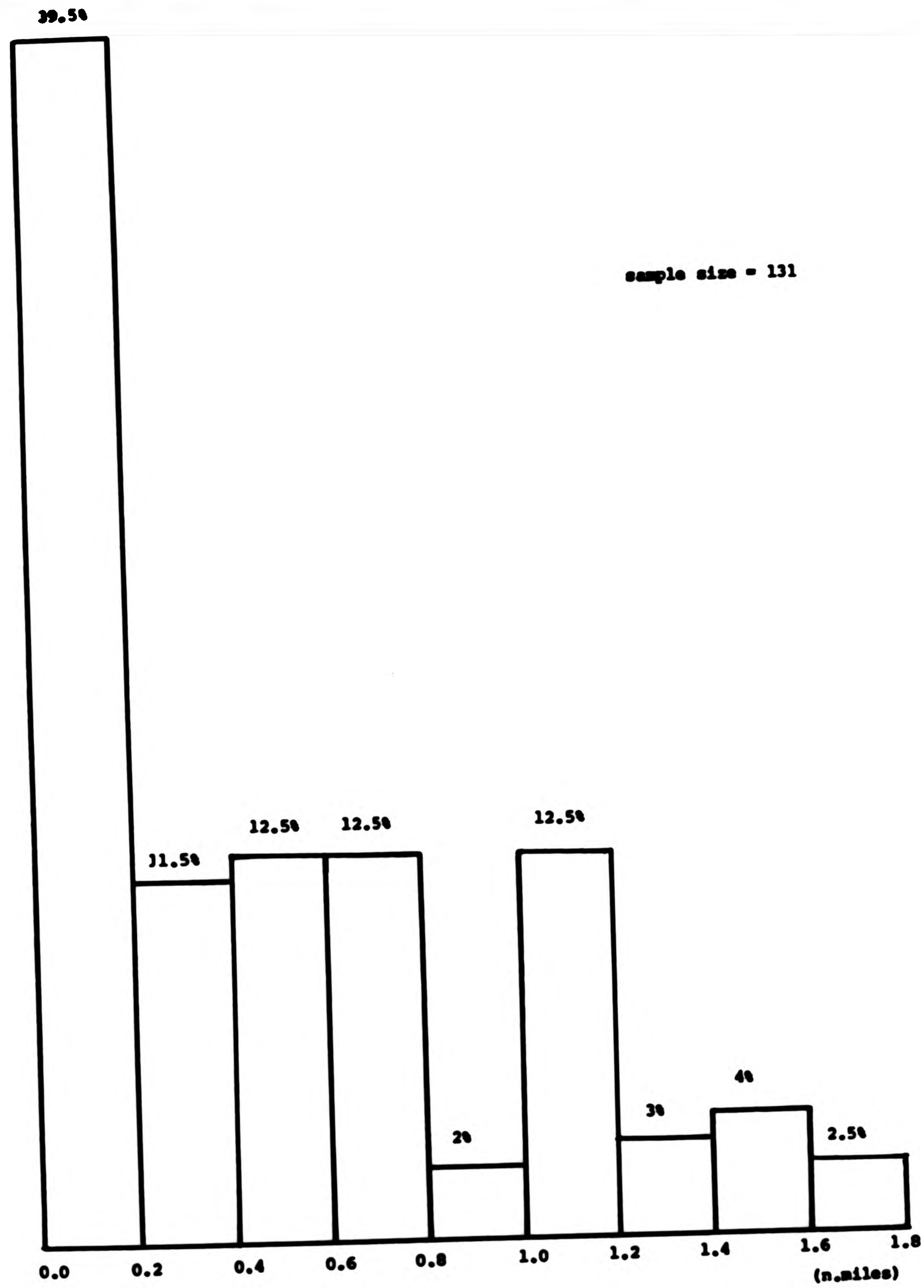

Figure 6.05 Histogram of Expected and Actual CPA differences for Simulator Overtaking Encounters.

real life overtaking encounters is deceptively simil ar. The need to consider the marginal distributions conditional on the expected CPA is apparent. The two data sets were further categorised by the expected CPA. Conditional distributions for expected CPA considered were, 0.0–0.25, 0.26–0.50, 0.51–0.75, 0.76–1.00 n.miles, corresponding to simulator experiment classifications and providing suitable sub class sample sizes. The Mann Whitney U-test procedure has been completed yielding the following results and conclusions for the comparison of real life and simulator actual and expected CPA differences. The test procedure has been applied using the statistical software package 'MINITAB' (Ryan et al 1976). Given the independent samples from the two populations, the real life and simulator data sets, with medians ϵ_1 and ϵ_2 respectively, the null hypothesis is;

$H_0 : \epsilon_1 = \epsilon_2$

with the two sided alternative,

$H_1 : \epsilon_1 \neq \epsilon_2$

A 5% significance level has been used for all the tests and a 95% Confidence Interval for the difference between the medians is given.

<u>For $0.0 \leq$ ECPA ≤ 0.25 n.miles.</u>

number of simulator encounters = 35 median = 0.75 n.miles.

number of real life encounters = 48 median = 0.09 n.miles.

A point estimate for $\epsilon_1 - \epsilon_2$ is −0.6 n.miles.

A 95% Confidence Interval for $\epsilon_1 - \epsilon_2$ is (-0.6, -0.9) n.miles.

Test statistic W (given by MINITAB) = 2166.0 which is significant at 0.0 level only, therefore there is no evidence to suggest that the two medians are equal.

For $0.25 < ECPA \leq 0.50$ n.miles.

Number of simulator encounters = 25 median = 0.60 n.miles.

Number of real life encounters = 39 median = 0.04 n.miles.

A point estimate for $\epsilon_1 - \epsilon_2$ is -0.50 n.miles.

A 95% Confidence Interval for $\epsilon_1 - \epsilon_2$ is (-0.2, -0.7)

W = 1124.5 which is significant at 0.0 level only, therfore there is strong evidence to suggest that the medians are not equal.

For $0.50 < ECPA \leq 0.75$ n.miles

number of simulator encounters = 24 median = 0.0 n.miles.

number of real life encounters = 5 median = 0.18 n.miles.

A point estimate for $\epsilon_1 - \epsilon_2$ is 0.0 n.miles.

A 95% Confidence Interval for $\epsilon_1 - \epsilon_2$ is (-0.2, 0.5) n.miles.

W = 365.0 which is significant at 0.795, cannot reject at 5% significance level therefore there is no evidence to suggest that the means are not equal.

For $ECPA > 0.75$ insufficient data has been collected to apply the test procedure.

Of the four tests completed only the comparison for the distributions given an expected CPA of between 0.76 and 1.00 n.miles yielded a non-significant result. This means that there is strong evidence to suggest that the distribution of actual and expected CPA differences given an expected CPA of less than 0.76 n.miles at the time of encounter detection, is statistically smaller for the real life situation than for the simulator situation. However when the expected CPA is greater than 0.75 n.miles at the time of encounter detection, there is no evidence to suggest any difference between the two distributions. This last result has been limited by the relatively fewer number of encounters detected in this category.

(6.7.3) Crossing Encounters

A similar procedure to that outlined in section 6.5.2 has been completed for the comparison between real life and simulator crossing encounters. The histogram of the expected CPA for sampled simulator encounters (Figure 6.06) is again indicative of the experimental design, though it displays a greater range of expected CPA s than the histogram of overtaking simulator encounters, as many of the sampled crossing encounters are a result of vessel progress once the exercise has been initiated. The histogram of expected and actual CPA differences for simulator crossing encounters (Figure 6.07) is as expected positively skewed with a difference of between 0.40 and 0.60 n.miles forming the modal class. For the real life crossing encounters the

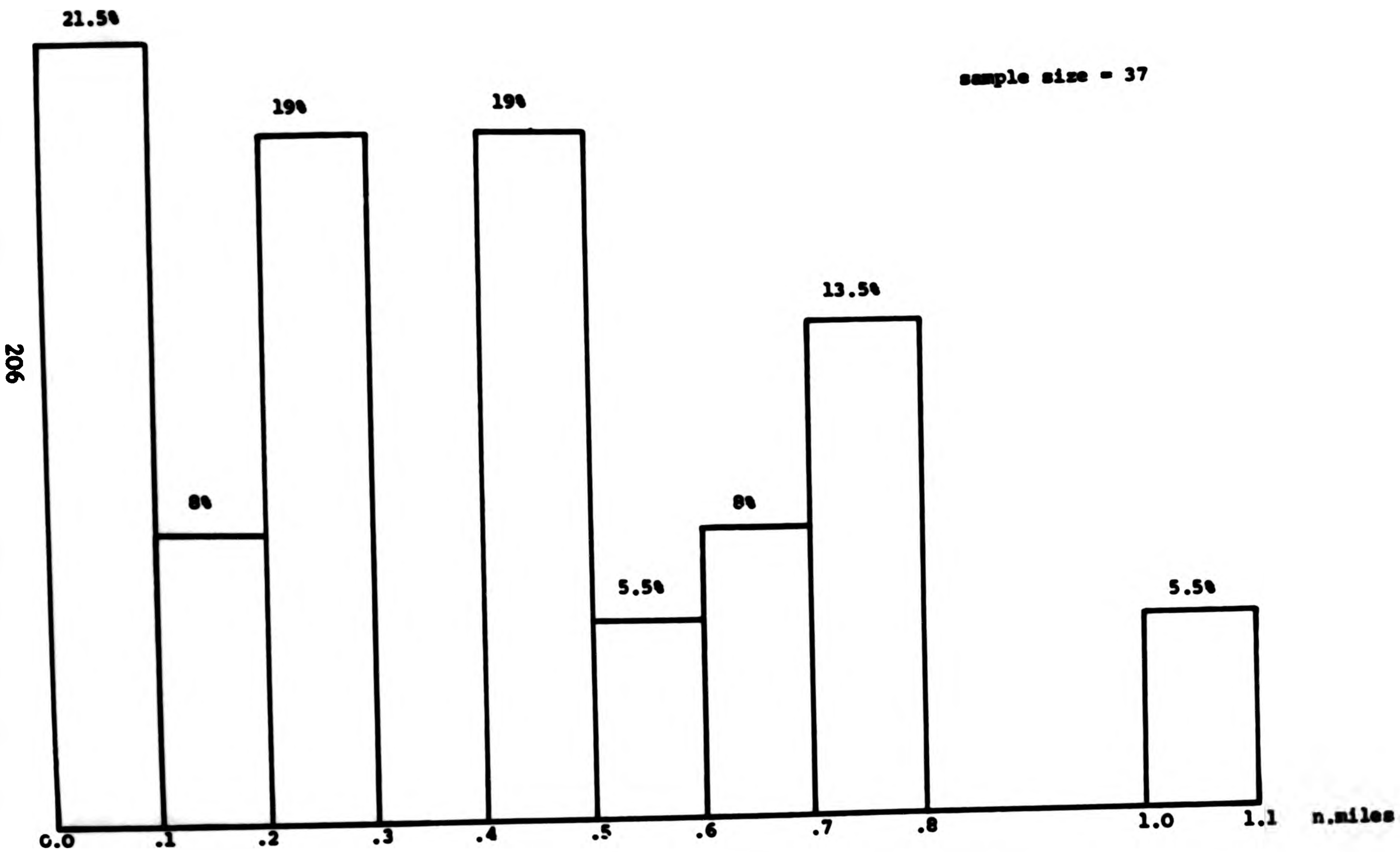

Figure 6.06 Histogram of Expected CPA for Simulator Crossing Encounters.

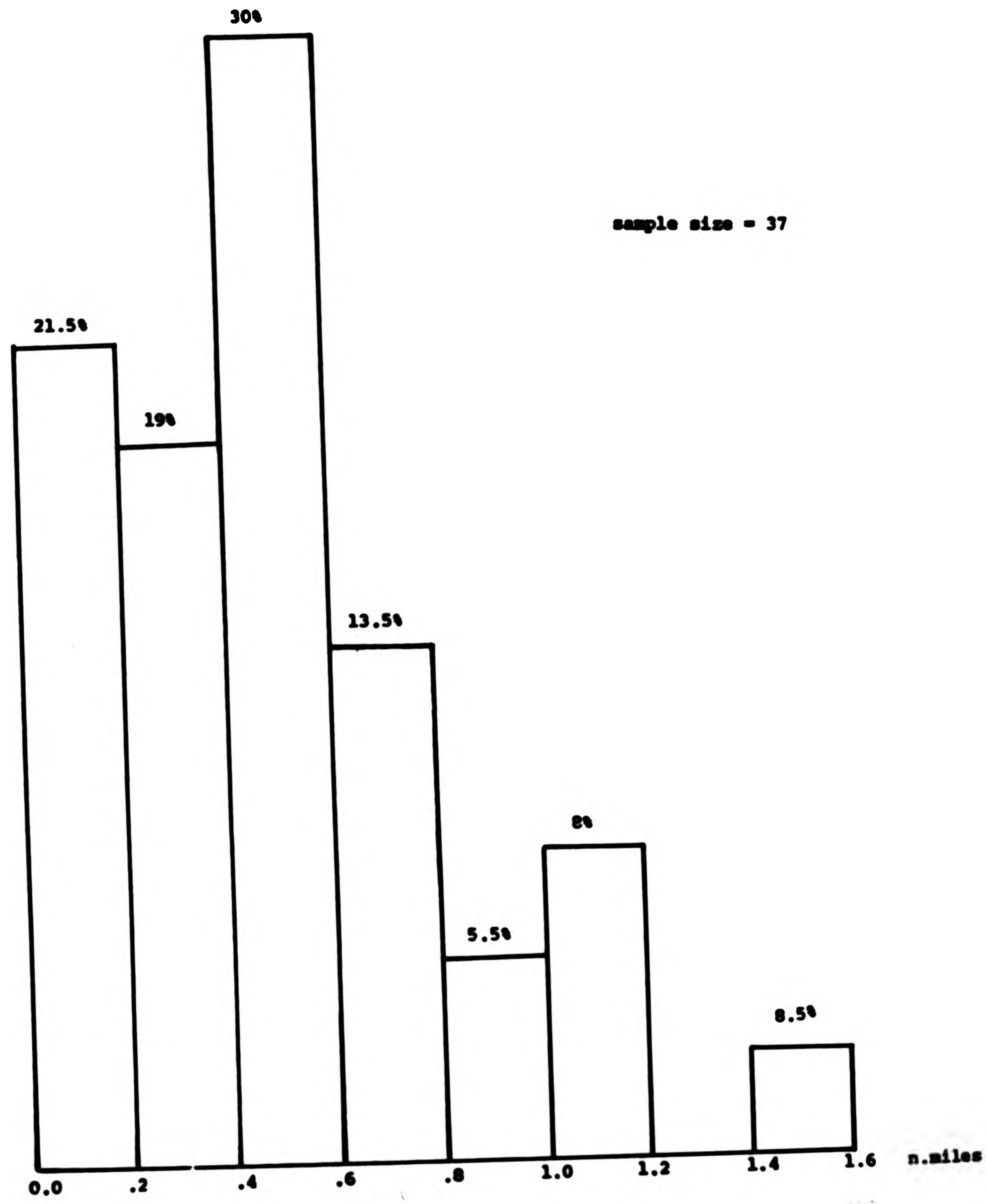

Figure 6.07 Histogram of Expected and Actual CPA differences for Simulator Crossing Encounters.

Histogram of expected CPA's (Figure 6.08) is indicative of the Dover Strait separation scheme while the histogram of expected and actual CPA differences (Figure 6.09) is again positively skewed with a maximum difference of 0.65 n.miles and differences between 0.0 and 0.05 n.miles forming the modal class. The sample sizes for comparison of crossing encounters is smaller than for the overtaking encounter comparison, for this reason the comparison has been completed for two conditional distributions ensuring samples of adequate size. Conditional distributions for expected CPA's were 0.0–0.50 and 0.51–1.5 n.miles, dividing the simulator data set into 55.5% and 44.5% classes with the lower class upper boundary of 0.50 n.miles being the domain size used in the RDRR+ encounter detection method (see chapter four). The Mann Whitney U-test procedure has been completed yielding the following conclusions for the comparison between real life and simulator expected and actual CPA differences.

For $0.0 \leq$ ECPA ≤ 0.50 n.miles

number of simulator encounters = 25 median = .48 n.miles.

number of real life encounters = 52 median = .22 n.miles.

A point estimate for $\epsilon_1 - \epsilon_2$ is -0.30 n.miles.

A 95% Confidence Interval for $\epsilon_1 - \epsilon_2$ is (-0.4, -0.2) n.miles.

Test statistic (given by MINITAB) W = 1610.0 which is significant at 0.00 level only, therefore there is no

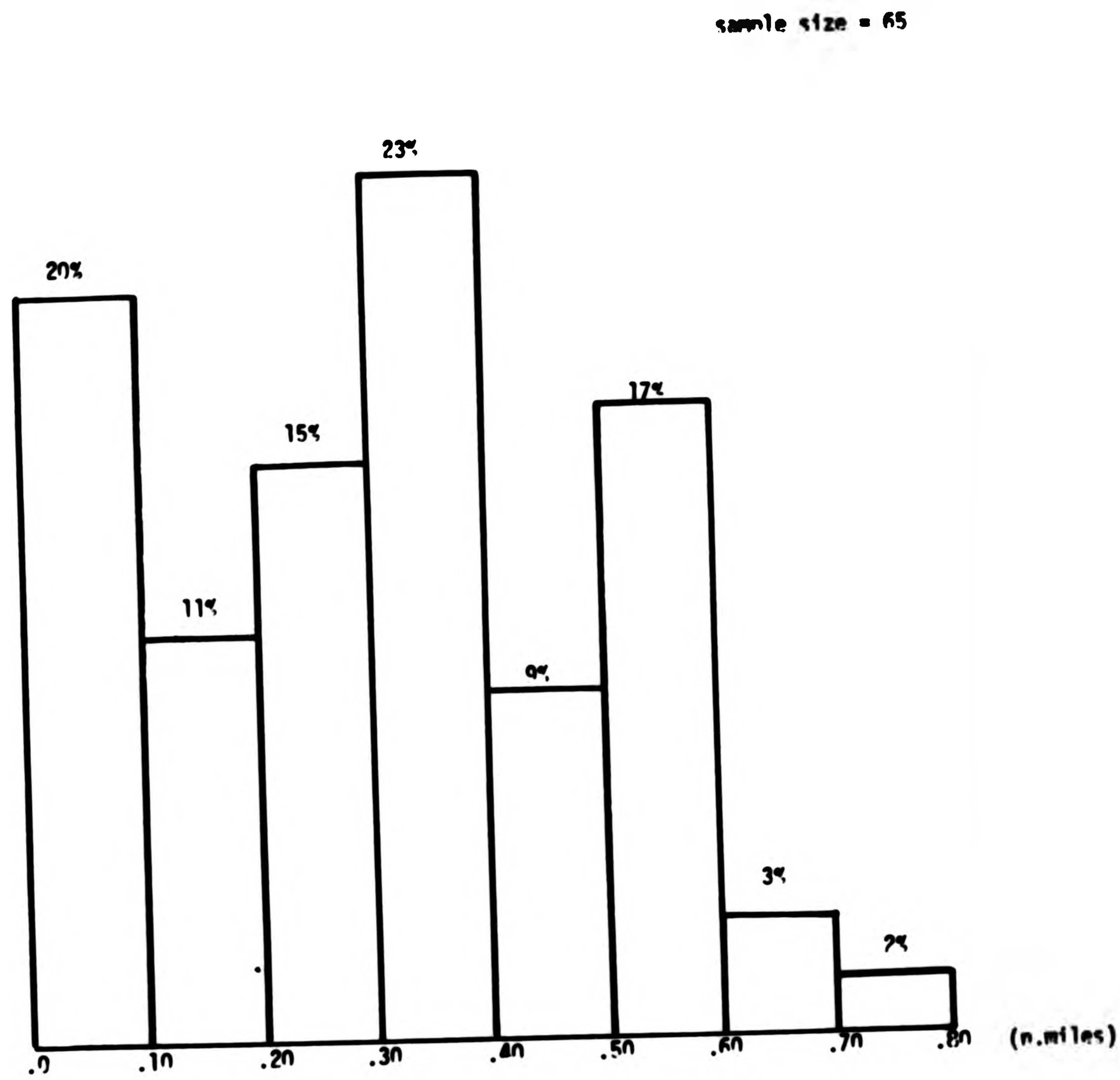

Figure 6.08 Histogram of Expected CPA for Real Life Crossing Encounters.

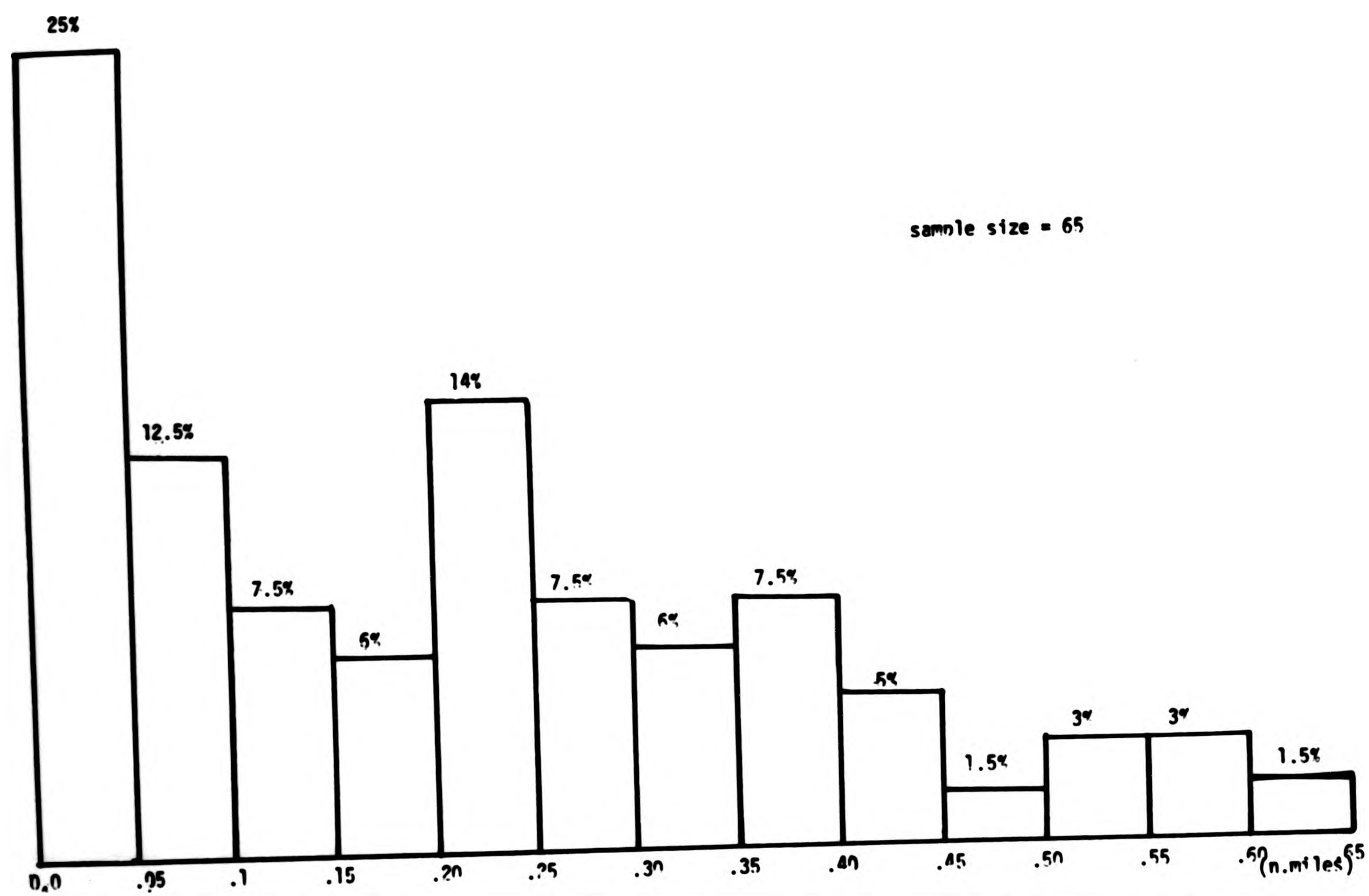

Figure 6.09 Histogram of Expected and Actual CPA differences for Real Life Crossing Encounters.

evidence to suggest that the two medians are equal.

For $0.50 < ECPA \leq 1.50$ n.miles

number of simulator encounters = 12 median = .28 n.miles.

number of real life encounters = 13 median = .04 n.miles.

A point estimate for $\epsilon_1 - \epsilon_2$ is -0.2 n.miles.

A 95% Confidence Interval for $\epsilon_1 - \epsilon_2$ is (-0.4, 0.0) n.miles.

W = 143.5 which is significant at .1739, cannot reject at 5% significance level. Therefore there is no evidence to suggest that the medians are not equal.

The test for expected CPA less than 0.50 n.miles yielded a significant result, implying that a statistical difference between the two distributions. However for an expected CPA of greater than 0.50 n.miles a non-significant result was obtained suggesting that there is no difference for the two distributions given an expected CPA of greater than 0.50 n.miles at the time of encounter detection.

(6.8.0) Conclusions

In this chapter a statistical method for the comparison of behavioural data has been outlined. This method, the Mann Whitney U-test has been applied to navigational data to compare mariners behaviour on a marine radar simulator and in the real life situation. By calculating the expected Closest Point of Approach at the time of encounter detection, data have been classified and results compared.

From the analysis, mariners behaviour on a simulator tends to resemble real life behaviour when the expected CPA is greater than 0.75 and 0.50 n.miles for overtaking and crossing encounters respectively. The implications of these findings are discussed in the final chapter in context of the project evaluation.

Chapter Seven

Conclusions

(7.1.0) Overview

The project has been divided into four main sub-study areas, namely :

i) the transfer of CNIS ADP data to the Polytechnic of North London main frame computer,

ii) the design and implementation of graphically interactive software for the analysis of vessel traffic data,

iii) the development of an automatic encounter detection technique and,

iv) a statistical comparison of mariners behaviour in the real life and simulator situations.

It is convenient to assess the project in context of these study areas.

(7.2.0) Data Transfer

The data transfer concerned copying the CNIS magnetic tape data to the main frame computer system at the Polytechnic of North London.

Once the data transfer was complete software could be developed to analyse these data. The progress of the project through the early stages depended heavily upon the ability to represent successfully these navigational data at the Polytechnic. The copying process was restricted by insufficient and difficult to comprehend documentation, and limited computer experience. The data files consisted of Binary Integer and ASCII (8-bit) code mixed, preventing the files from being read in one unique mode. Modification of the CNIS tape archiving process is highly unlikely, not justifying the cost. It is far easier to adapt a particular host computer's tape reading facility to accommodate this non-standard tape format.

The tape was originally read in ASCII (7-bit) mode, which allowed crude file identification, though corrupting some textual and all binary information. Using PNLCS' tape reading and file inspection programs the file structure was determined and later verified following the graphical software development. Programs were later written using the FORTRAN-77 programming language. These programs helped to present the copied data in a compatible format for analysis.

The tape reading process is totally machine dependent despite FORTRAN-77 being a highly portable and widely supported programming language. Any tape reading procedure will be inherently machine dependent (though some may be suitable for use on several machines). This is because the information has to be 'tailored' so that the host machine can store and access data efficiently. For example both X and Y position/velocity co-ordinates have been combined to form one Dec-10 word to conserve storage requirements. If the data were stored in a different machine such as the Vax-11, which has a word size of 16-bits, this compacting of co-ordinates would not be possible. If the data were indeed copied to a system other than the Dec-10, care should be taken as to how the machine i) stores negative numbers, and ii) records alphanumeric information. The method developed here requires little user input, only the raw data file identifier and output file need to be specified.

With the files successfully identified only the file containing track history information was deemed relevant for this study. An attempt could be made to utilise either the Ship Name file or the Waymark file, but would be of limited use. The Ship Name file contains only information for vessels required to 'report in' to the CNIS and as such is largely incomplete. The Waymark file could be used to analyse the distribution of vessels through a specified gate and as means for absolute position fixing.

If the magnetic tapes needed to be copied to any other machine the tape copying process would have to be reviewed.

However, the work of this study has made this review relatively straight forward as the file structure and tape format have both been verified. The potential use of these data tapes to marine traffic engineering researchers has also been realised providing the impetus for further studies and applications.

(7.3.0) Data Organisation and Interface Design

When faced with the prospect of analysing vast quantities of data it was necessary to organise these data so that access time could be minimised. The software that has been developed to investigate these data is run interactively involving the graphical representation of data. It was because of these facilities, and the need to reduce runtime costs, that an efficient method was required that could scan through the expanded data file. Velocity and position data are analysed in both track history and snapshot mode. The data were organised according to the details given in chapter three. The maximum track history length of 30 minutes could be increased without affecting plotting time, though would require greater computer memory storage space whilst the program is operating. No investigation into the ADP manoeuvre detection technique or the new acquisition register has been made, these could be undertaken if the work were to be extended, though consistant results would not be guaranteed. More efficient ways of storing data may be sought. This could include detailed data structuring when the original track history file were expanded from the magnetic tape, or more efficient methods for storing the data within the program. However since the research project has had many aims, it has not been possible to implement or compare different storage methods. Those employed have been effective in allowing graphical analysis and subsequent behavioural parameter measurement. The greatest problem with the CNIS ADP data has been the seduction of one vessel track by another, rendering further analysis of many vessels behaviour in an encounter impossible. Spaargaren and Tresfon (1978) suggest Kalman filtering and smoothing techniques to minimise seduction problems, and would require a comprehensive investigation. By deleting a vessel reference on seduction and predicting future vessel predictions and/or manoeuvres, it may be possible to plot expected positions and re-assign vessel labels when a lost vessel re-enters the system following its' manual aquisition by the Coastguard.

Interface design has allowed adequate facility to analyse the vessel traffic data recorded by the CNIS ADP data. Detailed description is presented in Chapter Three, with photographs of example output given in Appendix I.

The interface design has been a highly successful part of the project. All of the original goals have been achieved, allowing the later work of this project to be completed. The graphical sections of the programs have been kept independent from the file reading and general calculation so as to facilitate greater portability. If the graphical subroutine library (GINO) or the hardware facilities (SIGMA terminals) were substituted or amended in anyway, the software could be updated to accomodate such changes without disturbing any of the calculative or file reading procedures. Standard FORTRAN-77 code has been used allowing great portability providing the host machine has i) sufficient memory size ii) a Fortran compiler and iii) suitable graphical facilities. Only the file reading process would need to be reviewed, but this would be done as part of the tape reading process anyhow.

If data files were reduced in size, the program could theoretically be operated on a suitable micro computer. This would allow 'desk top' analysis, possibly using 'mouse' supported software and 'pop-down' menus. Access to a tape reader and programs to reduce the size of the data files would still be required, but operation on a micro computer would allow quicker response in interactive analysis as 'time sharing' would not be involved. Application on a micro computer would be a major study, but an interesting extension of this work.

(7.4.0) Automatic Encounter Detection Technique

The automatic encounter detection technique, which extends the RDRR method, has been successful. Using this technique, known as the RDRR+ technique, encounters have been isolated allowing subsequent parameter measurement. The technique brings together two concepts; i) the acknowledgement that different encounter types represent different degrees of danger and ii) the need to consider the time until a critical distance separation value as a threat parameter. The method proved inadequate in detecting all encounters and some situations were falsely detected as encounters mainly due to navigational changes in course and speed by vessels after satisfying encounter criteria and also because the RDRR ratio can assume a critical value when no manoeuvre is necessary. A critical value for the CPA was added as a satisfying condition to greatly reduce this false detection.

The utility of such an automatic encounter technique has been realised and is an essential research tool. Much laborious work is eliminated by employing the technique, freeing the researcher to progress and complete a detailed statistical study of collision avoidance behaviour. The algorithmic nature of the technique allows it to be included in an interactive analysis program such as the one developed as part of this study. The model could be adapted to account for other factors such as vessel and traffic flow characteristics, but such inclusion would necessarily compound the computation probably rendering the technique too complex to be used interactively. In its present form the model is an invaluable research tool and is optimal given the constraints of computation time and successful identification.

The implementation of such a technique to operate in real time at a monitoring station depends on the development of monitoring system technology (in particular the elimination of tracking/seduction errors), the reduction of errors inherent in the model and the broa d acceptance of computer technology as an aid in the marine navigational field. Even if all the errors could be eliminated, its application as part of a real time navigation monitoring aid would be hindered by the general non-acceptance of computer technology in the navigational field.

Non-acceptance of computer technology is noted by Pask and Curran (1982): 'For sometime it has been accepted that checkers and chess programs can play faster and more reliably than the human player who wrote them. It still seems alarming, though, to say the same thing about medical diagnoses. However, some of them perform consistantly better than the consultants whose expertise was used to compile their data bases. Since data bases are written so that mistakes are prevented from being repeated, their performance can continually be updated and improved'.

A discussion on the acceptance of a computerised detection technique may seem hypothetical since no suitable technique exists but this non-acceptance does represent a major obstacle in the possible development of one.
This is not to say that the automatic detection method could ever replace the job of a monitoring station duty officer, but could relieve him of much routine work to devote more attention to communication and other activities.

Inadequacies inherent with the model are well recognised, not all reality can be modelled in terms of numbers and symbols open to logical manipulation. Hoos (1982) defines the model as 'a symbolic representation of something, and, like all representations, it is subject to distortions, prejudgements, and limitations of vision and wisdom of its creator'. The RDRR+ model is not prescribed as an all purpose 'watchkeeper' but at the least can aid the researcher when analysing navigational data.

(7.5.0) Statistical Comparison

The marine radar simulator has two distinct uses. These are i) as a training tool, providing the mariner with a monitored programme in a relatively inexpensive form, and ii) as a readily available source of navigational data for research studies.
These two uses require different investigative methods for

validation. The work of this project has sought to validate the use of a marine radar simulator as a research tool. This investigation, has been concerned with how well mariners' behaviour when operating a simulator represents behaviour in a real life situation. For this validation it was decided following on from work completed by Goodwin (1975) and Curtis and Barratt (1981) that specific parameters measured on real life and simulator data sets would be compared. These parameters were to be chosen so that they described, as best as possible, mariners' behaviour in a collision avoidance situation.

Given the restrictions imposed by the simulator data set a single parameter has been compared between the two data sets. This parameter, the difference between the expected CPA at the time of encounter detection and the actual CPA, accounts for any action taken by the mariner due to collision avoidance consideration. The degree of action taken is reflected in the magnitude of this parameter and will depend upon conditions when the encounter is first detected. It is for this reason that the parameter chosen for comparison has been made conditional upon the expected CPA at the time of encounter detection. This second parameter takes into consideration the rate of approach and the distance separation which are accounted for by the RDRR+ technique for automatic encounter detection. Other factors such as traffic density, weather conditions and vessel handling characteristics are not accounted for. This is because this information has not been available and would require a comprehensive study following on from Holmes' work (1979) to determine the effect these factors have upon mariners action in an encounter. However, since Dover Strait data have been compared with restricted seaway simulator exercise data the differences between these factors across the two data sets have been minimised.

The statistical comparison between mariners behaviour on a radar simulator and in the real life situation has not been as comprehensive as originally planned. The main constraint has been the availability of suitable simulator data. For direct comparisons to be made, the analyst must be involved in the experimental design, which has not been possible here for reasons explained in chapter six. The results obtained have not validated the use of the simulator as a research tool though this is inconclusive. The simulator can be regarded as a 'poor visibility' scenario whilst the real life data has been collected from clear visibilty conditions. Consequently the findings that greater evasion action is taken in the simulator situation is not surprising. The fact that comparable results were obtained when the expected point of approach at the time of encounter detection was relatively large confirms this. Also the comparison has not accounted for differing angles of approach, which for the simulator data is a result of experimental design.

The simulator must monitor subject performance so that the training program may be amended and progress monitored. Derived data can be used for validation studies and to modify the training program. The system of obtaining data from plots is adequate but not ideal. For further studies the collection of data in the form of discrete position information recordings is essential.

Veenman and Verhage (1983) completed an inquiry into simulator training using the bridge manoeuvring simulator at the Royal Netherlands Naval College. In conclusion to the inquiry the role of the simulator is clearly defined. Veenman and Verhage see the simulator as essential in eductional capacities including the practising of the rules of the road, developing a professional attitude towards watchkeeping and general exercises in navigational techniques. Ship manouevring models with a large number of parameters and expensive accessories are not recommended. These conclusions are certainly stressing the training capacity of the simulator and although an investigation into the results would aid the researcher, it is unlikely that this would be top of the manufacturers list of facilities if they were to follow these suggestions.

This study has stressed the need for direct simulator data access to enable the researcher to concentrate on analysis rather than data collection methodology. To ignore the potential of these data sources for research is an oversight and work such as Goodwin (1975) and Curtis and Barratt (1981) have shown that the simulator can be used for reserach into mariners behaviour and not as Veenman and Verhage suggest, for training purposes only. A methodology for comparison studies has been detailed and if work were to continue a method for direct simulator data collection should be developed allowing the comparison of more detailed behavioural parameters, using the software developed within this project for real life data collection and exploration. The findings of the comparison do not fully validate the use of the simulator, but it is suggested the work be extended using the detailed methodolgy as a foundation for this study.

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Appendices

Appendix I

Photographs of Software Display

The following photographs have been taken of the graphical display of the developed software package which allows graphical analysis of the CNIS ADP data and the automatic detection of real life ship encounters.

Figure A1

A plot of the approximate area of coverage is shown with the English and French coastlines clearly visible. Vessel identifying labels have been drawn by vessel positions. The blue box to the top right of the viewing screen encloses an area to be surveyed for possible encounters. The menu display shows MENU1 with the cursor positioned by the labels option.

Figure A2

The encounter table is displayed over the plotting screen referencing the next five stored encounters. The menu display is MENU1 with the cursor positioned by the encounters option. The digit 7 by this option represents the total number of detected encounters during the last search.

Figure A3

Shows a displayed encounter involving vessels with identification 981 and 21. MENU2 is displayed giving range, Closest Point of Approach and RDRR (optional) information.

Figure A4

Shows the quick access MENU3. The vessel with identification 21 at time 05 16 has been set as a reference point.

Figure A5

Shows MENU4 which displays speed and angular information.

Figure A6

Showing MENU5 allowing the user to specify domain sizes and RDRR+ parameter values.

Figure A7

MENU6 is displayed which allows the user to produce a relative plot of a detailed encounter.

Figure A8

MENU7 is displayed, again presenting the user with vessel behaviour information.

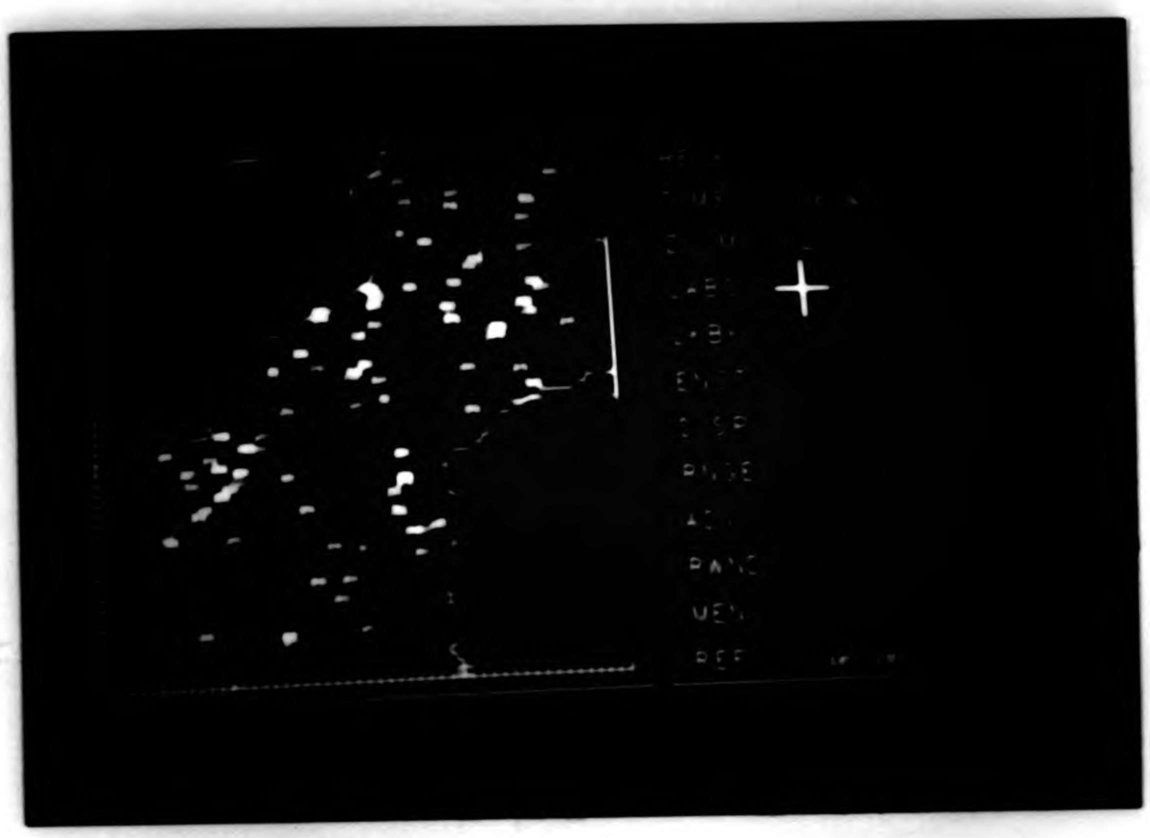
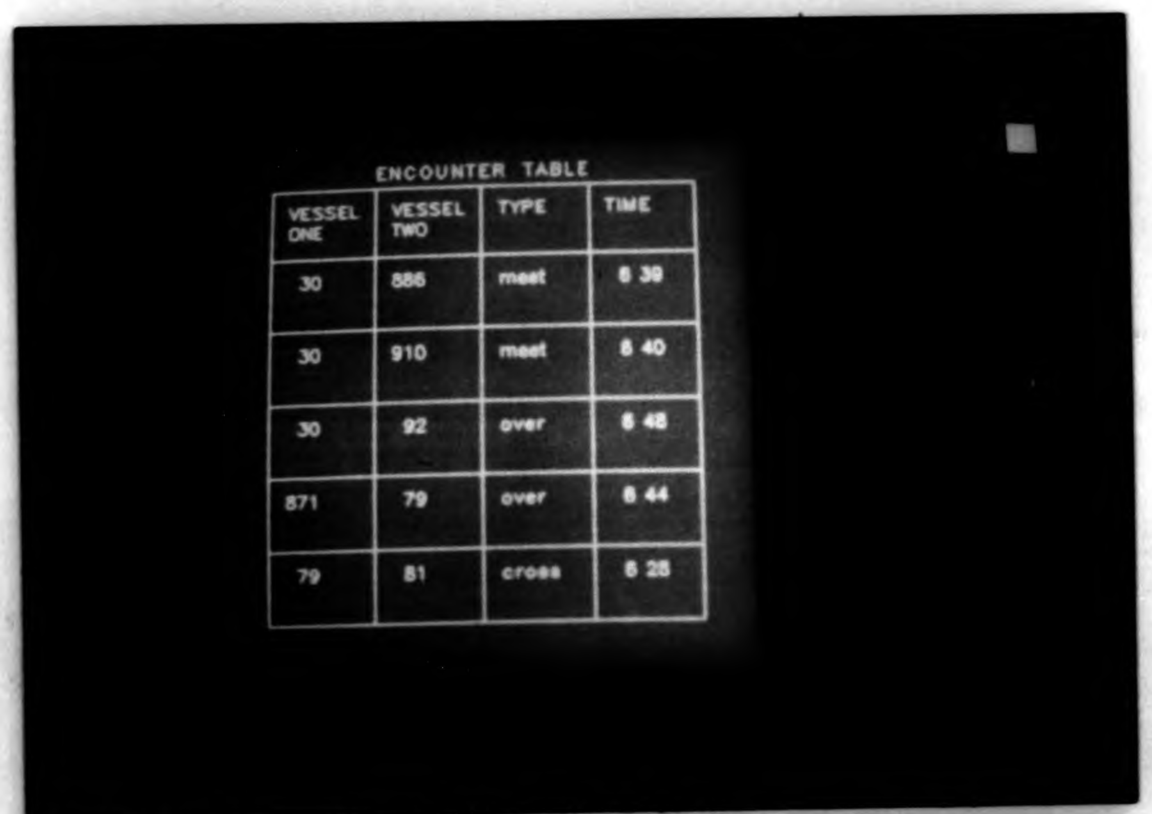


Figure A1.



ENCOUNTER TABLE

VESSEL ONE	VESSEL TWO	TYPE	TIME
30	886	meet	8 39
30	910	meet	8 40
30	92	over	8 48
871	79	over	8 44
79	81	cross	8 28

Figure A2.

Figure A1.

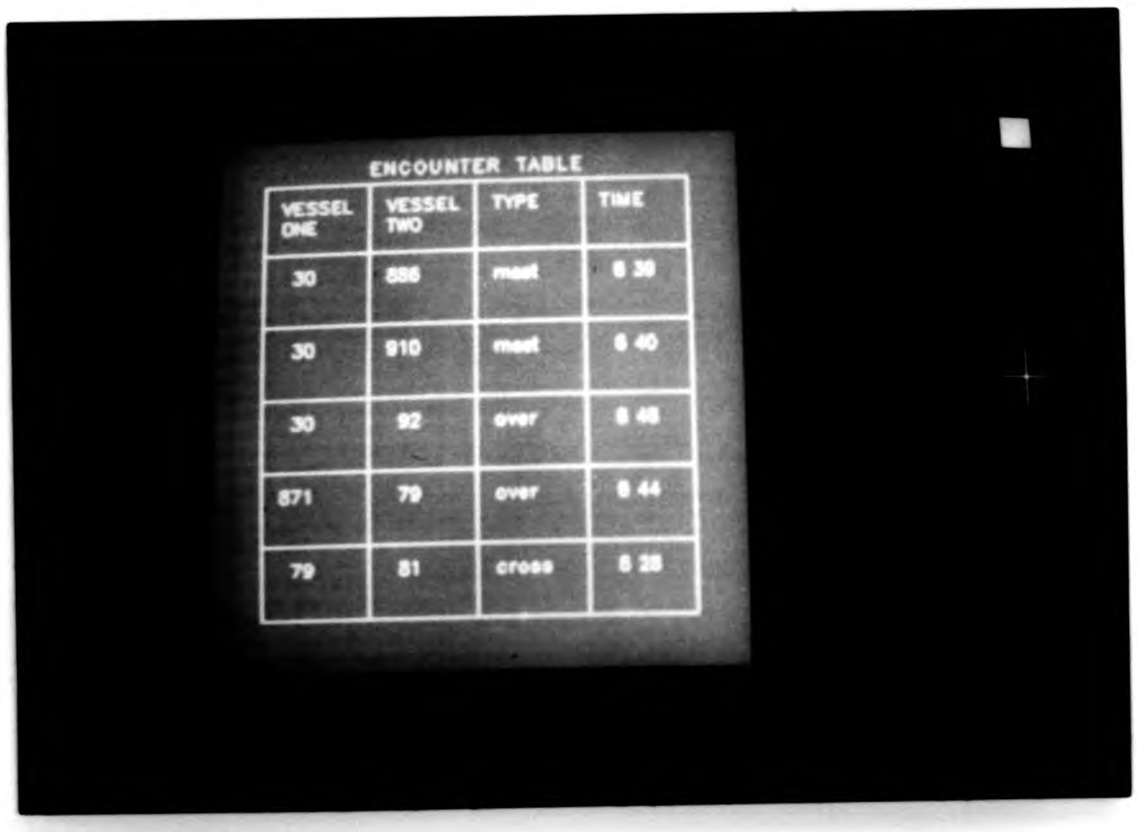


Figure A2.

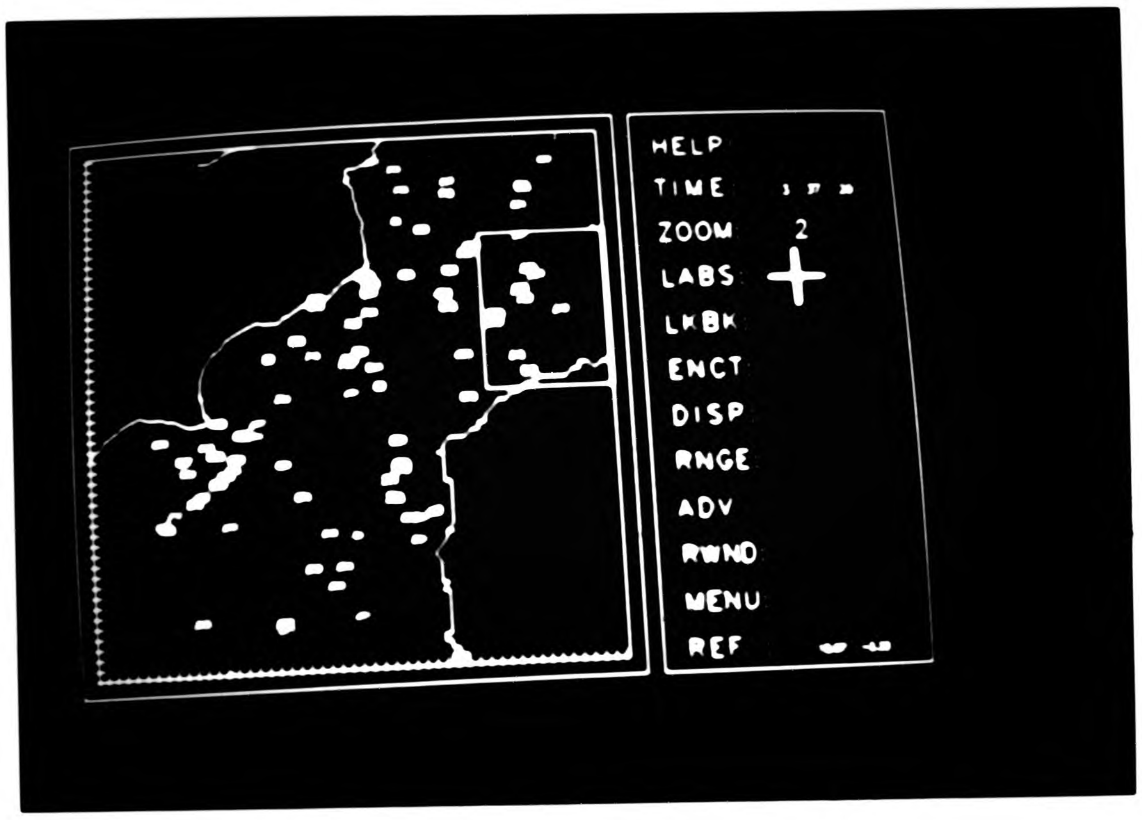


Figure A1.

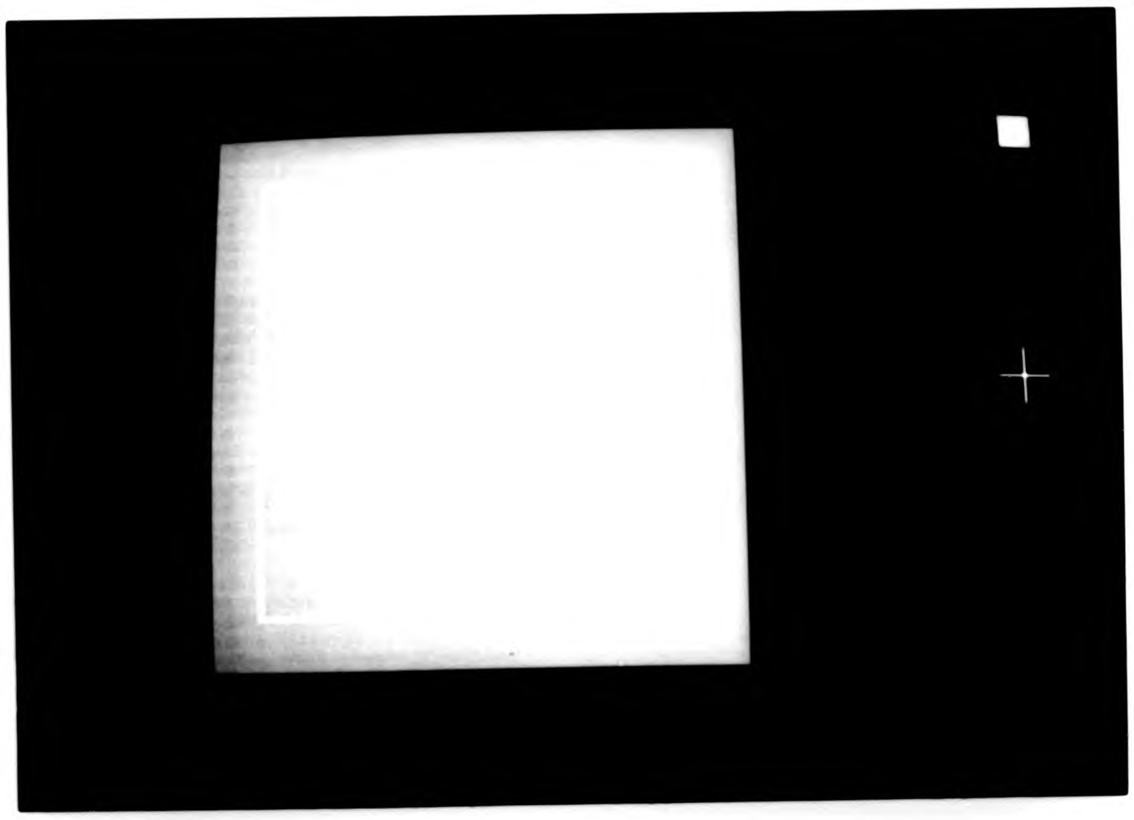


Figure A2.

Figure A3.

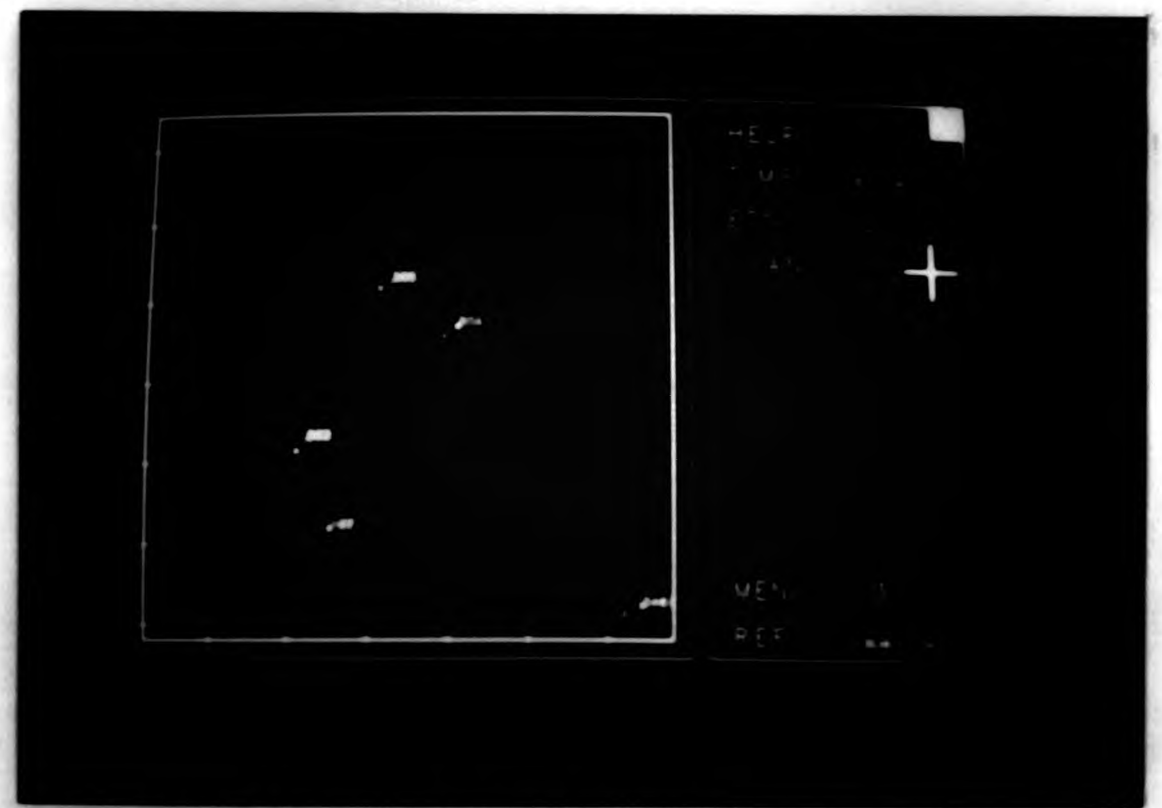


Figure A4.

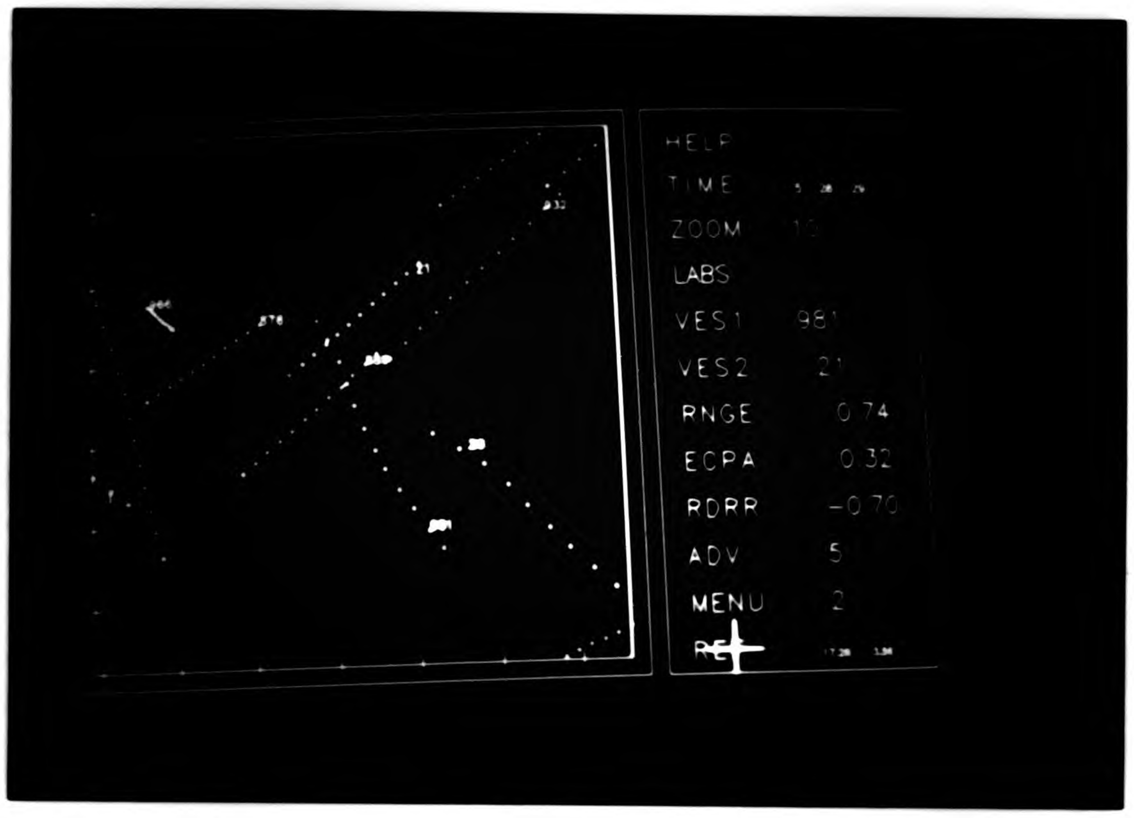


Figure A3.

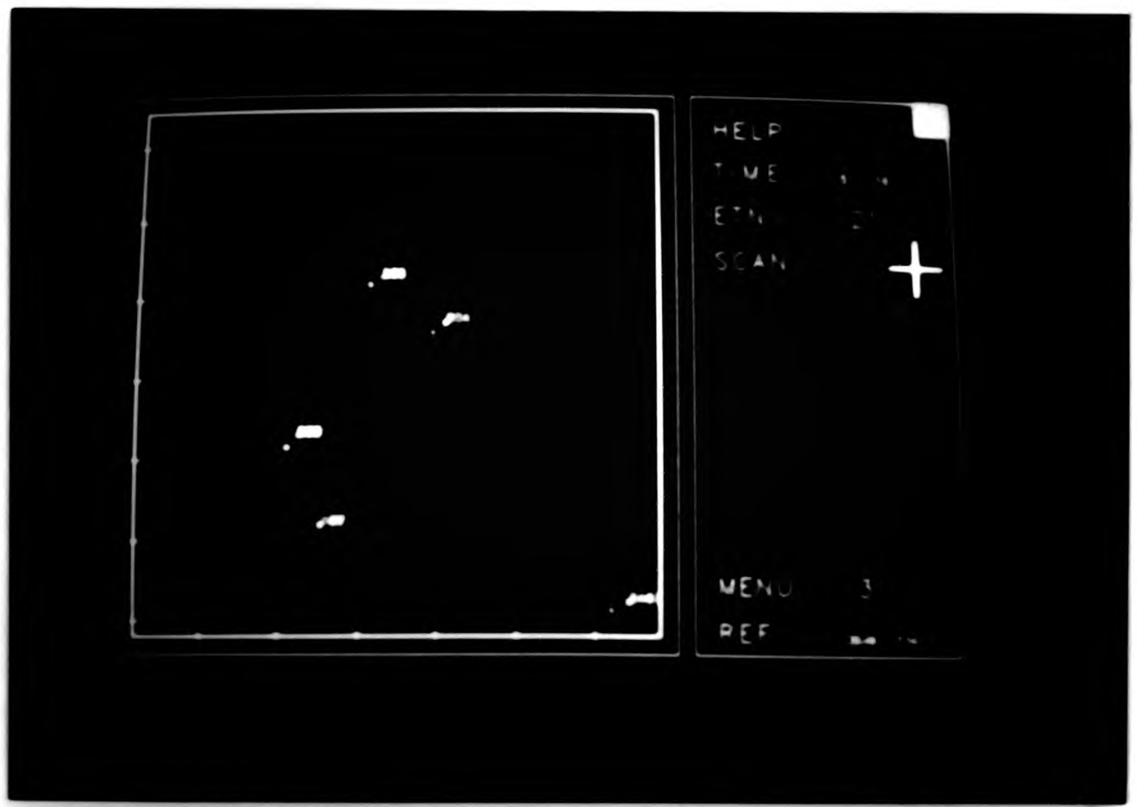


Figure A4.

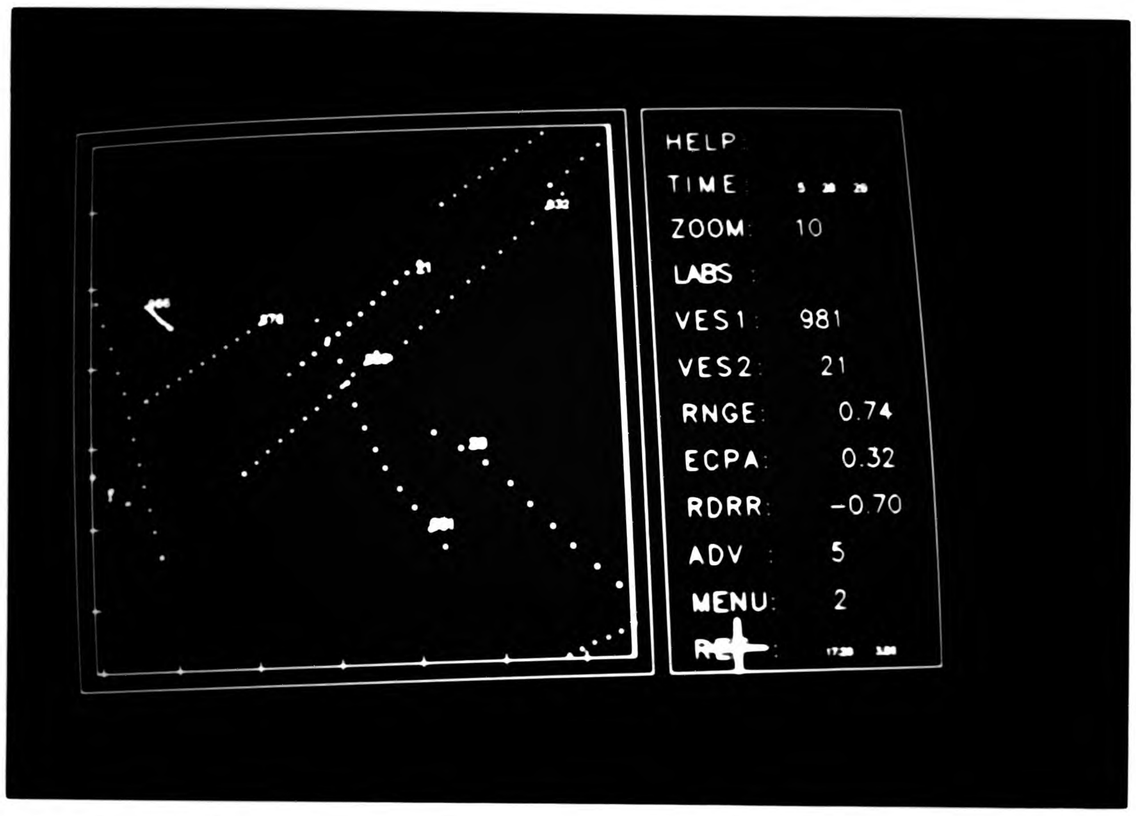


Figure A3.

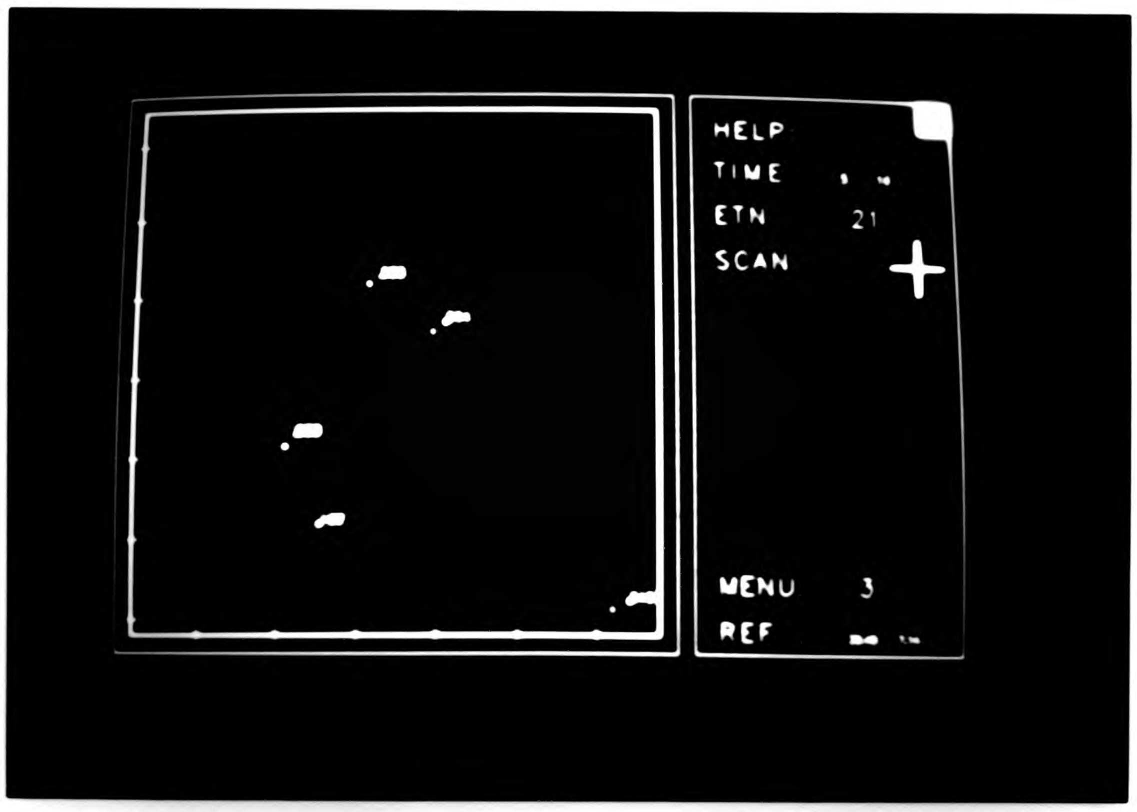


Figure A4.

Figure A5.

Figure A6.

Figure A5.

Figure A6.

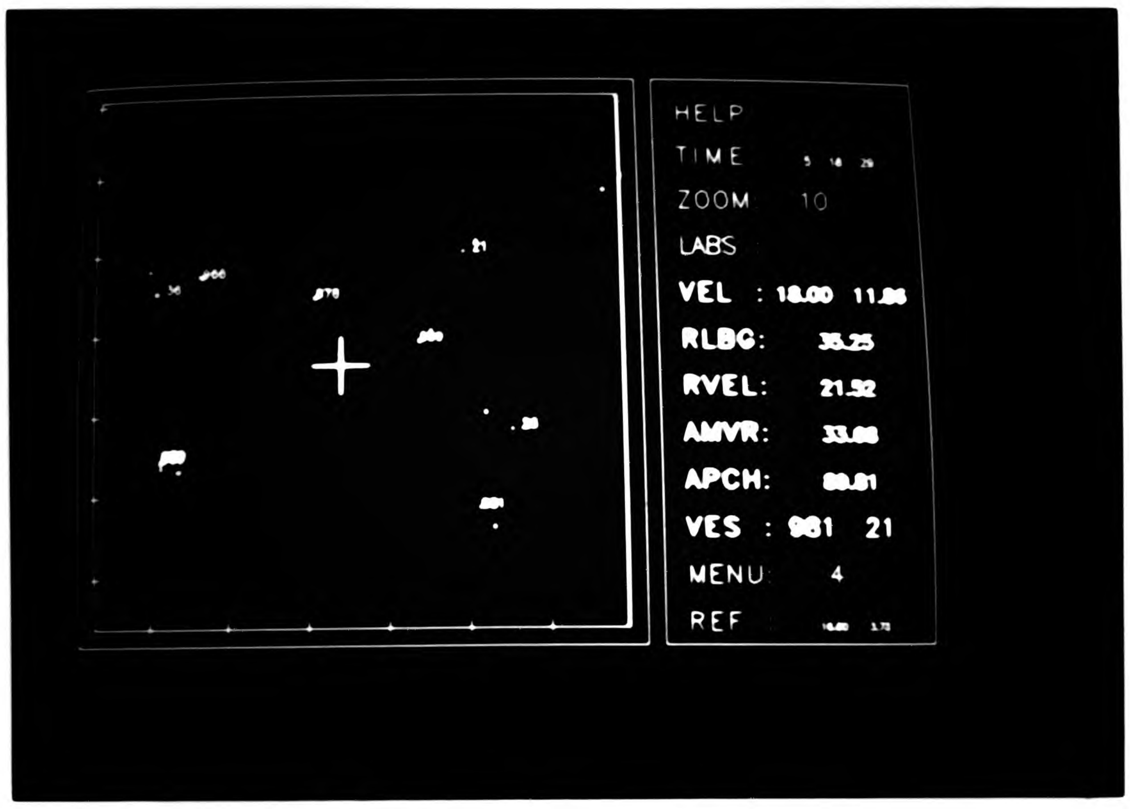


Figure A5.

Figure A6.

Figure A7.

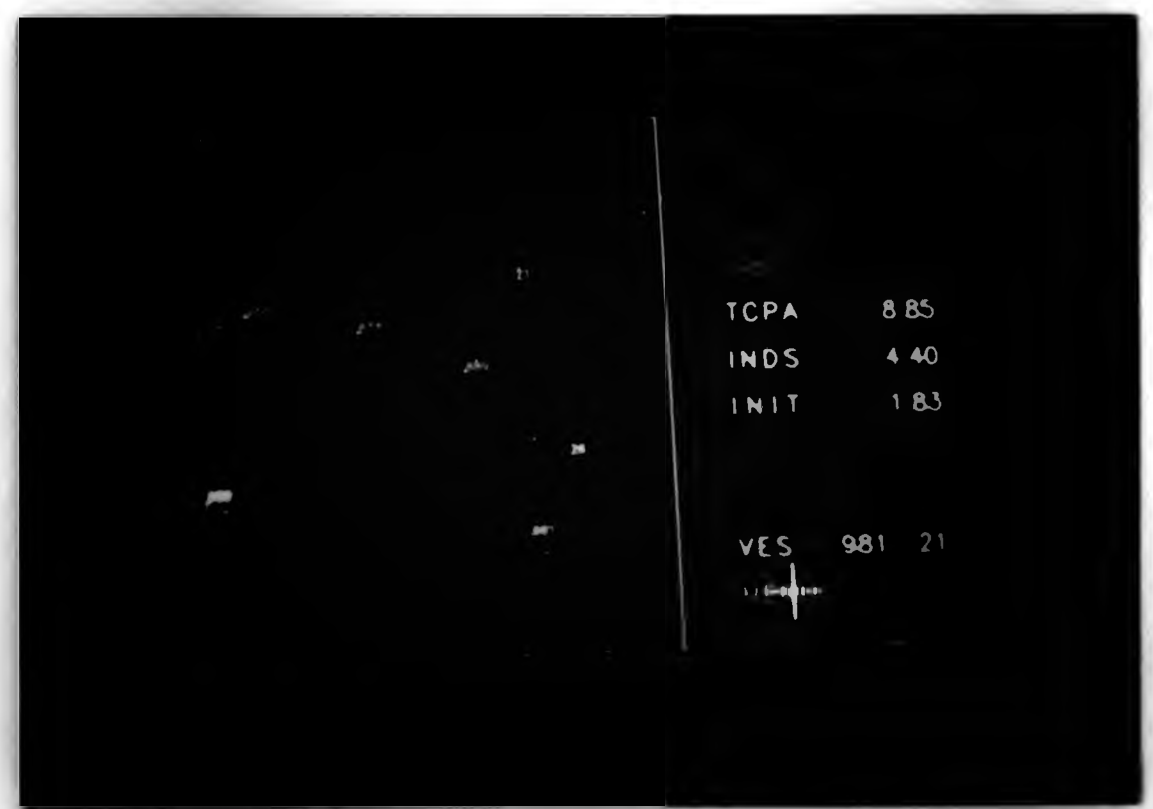


Figure A8.

Figure A7.

Figure A8.

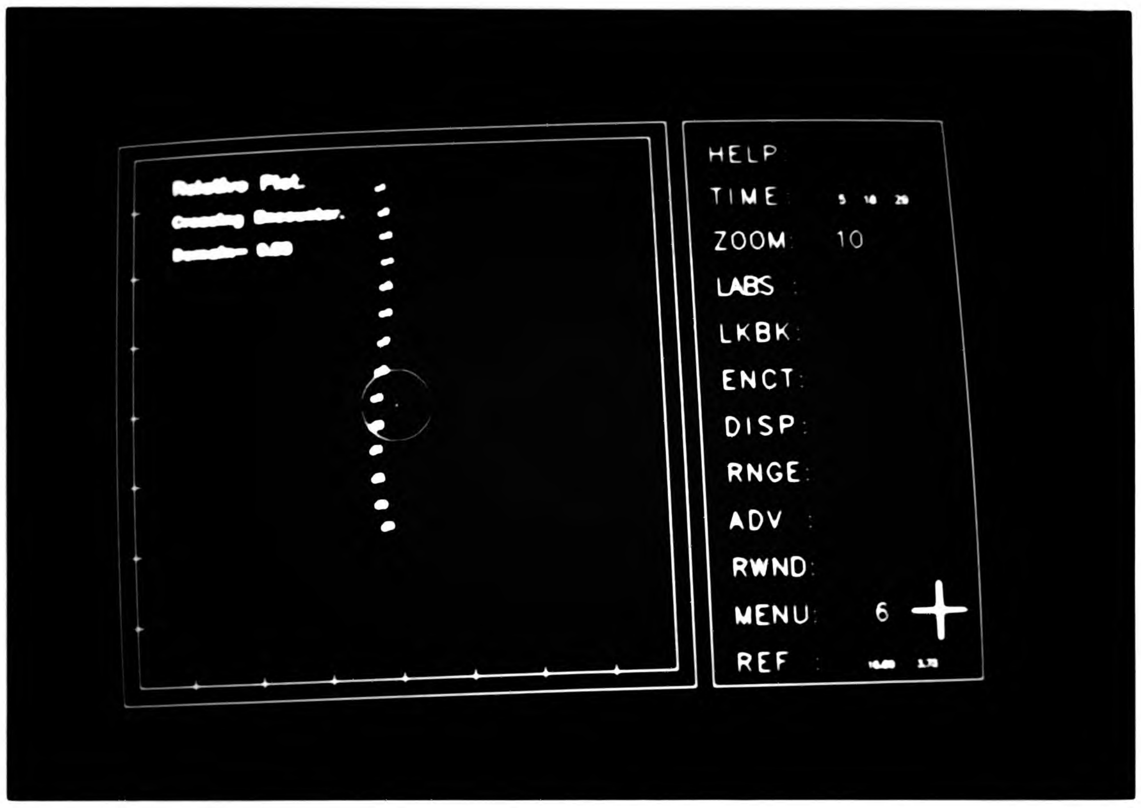


Figure A7.

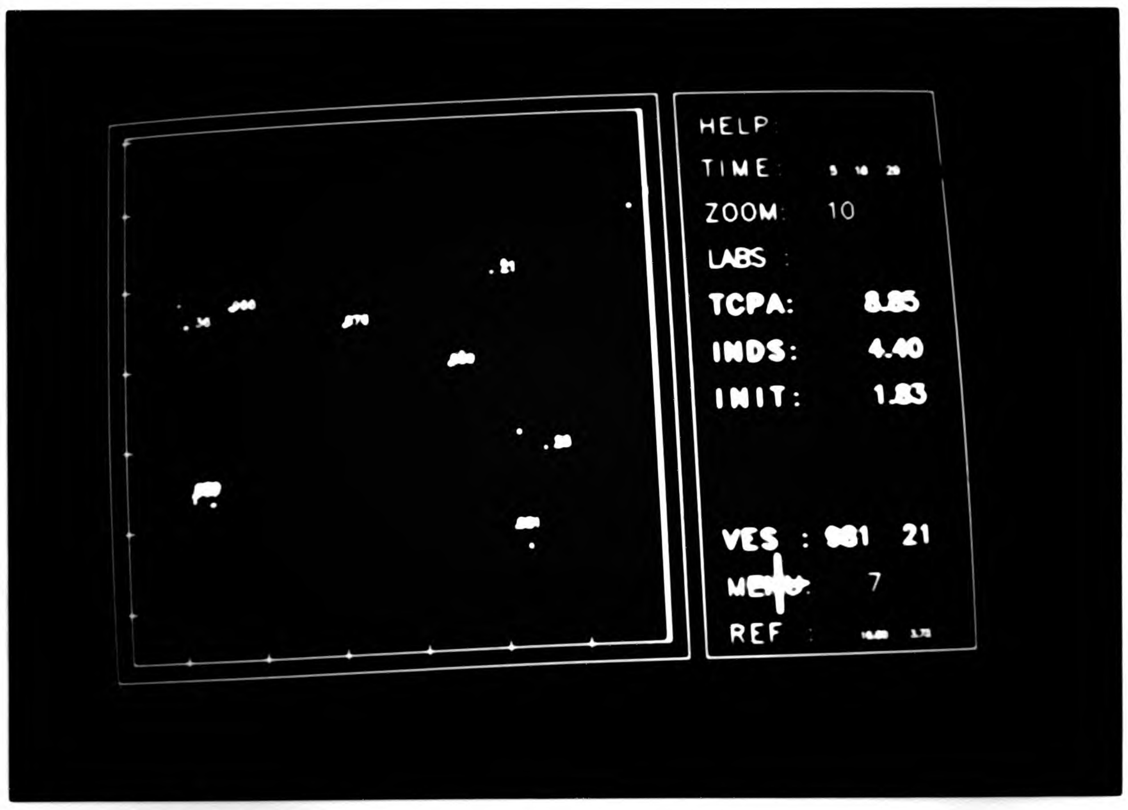


Figure A8.

Appendix II

Track History File Format

FILE HEADER

Word	no. of words	Content
1	1	Record type-1
2	1	1 for archived file.
3	4	snapshot time of first entry (see note one).
7	2	Year, Month (ASCII).
9	4	time of last entry
13	1	next available record no.
14	1	record no. of last non zero entry.
15	1	no. of records allocated.
16	4	time of 1st record.
20	1	record no. of 1st record.
21	4	time of 5th record.
25	1	record no. of 5th record.
26	4	time of 6th record.
etc.		

121	4	time of 89th record.
125	1	record no. of 89th record
126	3	zero.

Track Snapshot

A track snapshot consists of,

a snapshot header

a table of new tracks

LT2 table

a table of label changes

LT1 table.

These are written continuously, ignoring record boundaries. The last record is padded with zeroes.

Word	no. of words	Content
snapshot header		
1	1	record type-2
2	4	time of snapshot.
6	1	record number

		of next typed record.
7	1	record number of previous record.
8	1	no. of words in new track table.
9	1	no. of words in LT2
10	1	no. of words in label change table.
11	1	no. of words in ltl
12	1	overflag for new tracks. 0-no overflow. 1-overflow.

<u>New Track Table</u>

13	upto 19	each word contains ETN of a new track.
	upto 400	LT2 table.
i	upto 140	Label changes.
j	upto 2000	LT1 table.

padded to the end of physical record (ie. to a multiple of 128).

Note 1 : Times are four words, ASCII characters.

1 : dd day of month.

2 : hh hour.

3 : mm minute.

4 : ss second.

The format of the waymark snapshots and label files are not of immediate interest to the project so a detailed description of their structure is not included.

Track Tables

The track tables allows for upto 400 tracks. The main array holds track data exactly as received from the ADP system. A second array is one word per track and holds the category / classification data.

Main Track Table LT1

Each track occupies five words.

Word 1 : Status and track number.

Word 2 : X position.

Word 3 : Y position.

Word 4 : X velocity.

Word 5 : Y velocity.

The X and Y position are in units of 1/200 nautical miles.

The X and Y velocity are in units of 1/200 Knot for ships and 1/50 for aircraft.

Status and track number are :-

Bit 15 : Zero on 1 minute scans, set for 1/2 minute scans.

Bit 14 : Zero for ships, set for aircraft.

Bit 13 : Set if bad echo.

Bit 12 : set if target manoeuvring.

Bit 11 : Spare.

Bit 10 : Set if new track number.

Bits 9 - 0 : Track number (1-999).

Note : The position grid is 320 nautical miles square. The track number held within word 1, is the External Track Number (ETN).

<u>Secondary Track Table.</u>

One word per track.

Bits 14-10 : Zero if not in a category, otherwise the category letter (1=A, 2=B, etc.)

Bits 9-6 : Zero if not classified, otherwise the class code.

Bits 5-3 : Zero if position as received from ADP. Non zero if position predicted.

Bits 2-1 : Unused.

Bits 0 : Set if MAREP.

Word 1 of the second array corresponds to Words 1-5 of the first array. Word 2 corresponds to words 6-10 etc.

Much of the data copied from tha CNIS magnetic tape were not of immediate importance to this particular project. Therefore a computer program has been designed which scans through the Track History File identifying all the component records. The Label Table LT1 was copied along with the date and time of each snapshot, all else was discarded. Care had to be taken when scanning through the file as many records are padded to a word multiple of 128 so as to pad the records to their physical length.

Appendix III Data Tables

Table A1.

Real Life Meeting Encounters

	ECPA (n.m.)	CPA (n.m.)	RELVEL knots	APCH (Degrees)	ECPA-CPA (n.m.)
1	0.07	0.24	21.90	146.76	0.21
2	0.07	0.27	35.91	151.20	0.20
3	0.33	0.24	5.56	184.77	0.00
4	0.53	0.51	29.88	137.31	0.00
5	0.24	0.57	35.03	219.66	0.23
6	0.64	0.40	28.26	158.43	0.00
7	0.00	0.25	32.57	180.23	0.25
8	0.75	0.61	30.08	198.07	0.00
9	0.14	0.26	21.89	187.51	0.12
10	0.16	0.58	23.56	185.04	0.10
11	0.22	0.24	16.46	178.07	0.12
12	0.20	0.26	12.85	130.75	0.06
13	0.39	0.46	37.46	174.79	0.07
14	0.38	0.38	35.57	174.00	0.00
15	0.39	0.48	37.46	174.79	0.09
16	0.38	0.38	35.37	173.99	0.00
17	0.47	0.52	12.21	165.52	0.05
18	0.53	0.62	27.47	195.45	0.09
19	0.12	0.24	8.16	124.91	0.12
20	0.15	0.63	34.74	178.18	0.48
21	0.07	0.34	30.86	155.49	0.27
22	0.07	0.37	38.95	177.58	0.30
23	0.20	0.52	28.69	129.78	0.32
24	0.24	0.26	15.15	47.71	0.02
25	0.08	0.11	15.23	50.33	0.03
26	0.04	0.63	34.74	178.18	0.57
27	0.03	0.22	24.79	171.36	0.19
28	0.12	0.22	22.67	179.18	0.10
29	0.37	0.39	20.56	196.53	0.02
30	0.31	0.49	15.09	155.65	0.18
31	0.33	0.63	40.14	201.52	0.30
32	0.14	0.38	36.71	203.63	0.24
33	0.10	0.12	26.42	162.40	0.02
34	0.14	0.32	19.76	214.05	0.18
35	0.10	0.38	35.13	174.97	0.28
36	0.28	0.29	21.37	216.19	0.01
37	0.14	0.21	40.98	151.87	0.07

Table A2.

Real Life Overtaking Encounters

	ECPA (n.m.)	CPA (n.m.)	RELVEL (knots)	APCH (Degrees)	ECPA-CPA (n.m.)
1	0.26	0.28	12.59	5.01	0.02
2	0.35	0.39	3.94	1.95	0.04
3	0.37	0.22	4.56	2.07	0.00
4	0.14	0.49	18.96	10.42	0.35
5	0.15	0.29	4.67	1.92	0.14
6	0.66	0.57	4.99	11.24	0.00
7	0.29	0.49	20.21	18.48	0.20
8	0.11	0.12	3.02	0.58	0.01
9	0.16	0.23	0.77	0.41	0.13
10	0.21	0.29	3.26	3.89	0.08
11	0.40	0.45	9.46	11.18	0.05
12	0.15	0.11	5.97	18.29	0.00
13	0.26	0.41	10.22	20.92	0.15
14	0.21	0.50	14.82	59.04	0.39
15	0.13	0.24	5.62	25.04	0.11
16	0.30	0.31	16.73	37.44	0.01
17	0.83	0.68	13.73	40.16	0.00
18	0.24	0.52	11.98	55.36	0.28
19	0.70	0.60	14.54	49.22	0.00
20	0.65	0.98	16.76	71.29	0.33
21	0.42	0.46	3.47	4.99	0.04
22	0.11	0.26	19.41	53.54	0.15
23	0.31	0.29	6.10	18.01	0.00
24	0.38	0.37	11.26	33.44	0.00
25	0.47	0.64	3.62	6.09	0.17
26	0.35	0.50	2.13	5.59	0.15
27	0.07	0.52	5.99	1.94	0.45
28	0.31	0.32	20.89	32.47	0.01
29	0.02	0.24	5.11	4.10	0.22
30	0.15	0.28	5.65	0.10	0.13
31	0.48	0.63	7.84	4.63	0.15
32	0.10	0.19	5.45	2.85	0.09
33	0.14	0.29	12.78	8.24	0.15
34	0.16	0.28	5.18	3.91	0.12
35	0.26	0.35	9.31	8.21	0.09

Table A2. Continued

Real Life Overtaking Encounters

	ECPA (n.m.)	CPA (n.m.)	RELVEL (knots)	APCH (Degrees)	ECPA-CPA (n.m.)
36	0.41	0.52	10.62	27.46	0.11
37	0.04	0.35	5.96	4.17	0.31
38	0.10	0.13	5.45	2.85	0.03
39	0.02	0.36	12.83	1.03	0.34
40	0.33	0.39	9.04	3.81	0.36
41	0.52	0.76	22.74	76.16	0.24
42	0.54	0.72	6.51	16.92	0.08
43	0.34	0.34	9.40	2.56	0.00
44	0.26	0.27	9.12	3.14	0.01
45	0.15	0.23	1.16	0.43	0.08
46	0.08	0.26	0.98	0.19	0.18
47	0.35	0.36	11.92	36.57	0.01
48	0.07	0.07	8.06	64.49	0.00
49	0.31	0.31	8.16	27.36	0.00
50	0.30	0.31	10.85	1.37	0.01
51	0.19	0.22	2.82	2.52	0.03
52	0.04	0.12	10.33	16.68	0.08
53	0.33	0.40	12.24	8.90	0.07
54	0.38	0.44	3.85	6.00	0.06
55	0.10	0.37	5.01	18.93	0.27
56	0.42	0.49	3.30	0.21	0.07
57	0.22	0.24	10.85	1.37	0.02
58	0.20	0.39	5.85	8.69	0.19
59	0.69	0.32	5.45	2.85	0.13
60	0.26	0.34	9.12	3.14	0.08
61	0.21	0.28	6.81	7.14	0.07
62	0.37	0.38	10.34	1.65	0.01
63	0.23	0.18	3.86	3.47	0.00
64	0.16	0.17	4.42	1.74	0.01
65	0.35	0.36	15.02	1.55	0.01
66	0.19	0.25	14.91	7.78	0.06
67	0.12	0.21	11.64	0.06	0.09
68	0.14	0.12	5.64	5.74	0.00
69	0.27	0.34	11.28	5.67	0.07
70	0.00	0.03	7.23	0.48	0.03

Table A2. Continued

Real Life Overtaking Encounters

	ECPA (n.m.)	CPA (n.m.)	RELVEL (knots)	APCH (Degrees)	ECPA-CPA (n.m.)
71	0.42	0.48	4.28	4.83	0.06
72	0.25	0.33	5.87	3.03	0.08
73	0.35	0.67	5.43	13.16	0.32
74	0.19	0.22	12.98	14.46	0.03
75	0.41	0.45	4.59	3.99	0.04
76	0.13	0.16	10.37	2.83	0.03
77	0.38	0.40	5.18	3.71	0.02
78	0.02	0.26	3.15	4.52	0.24
79	0.12	0.49	2.38	10.67	0.37
80	0.00	0.25	2.53	6.65	0.25
81	0.20	0.36	6.78	10.88	0.16
82	0.09	0.31	6.43	6.70	0.22
83	0.33	0.32	5.94	1.58	0.00
84	0.48	0.56	7.83	25.44	0.12
85	0.39	0.63	6.47	22.13	0.24
86	0.33	0.32	5.94	1.58	0.00
87	0.24	0.09	8.02	5.09	0.00
88	0.24	0.29	4.71	3.45	0.05
89	0.17	0.21	5.01	3.22	0.04
90	0.36	0.57	4.99	11.24	0.21
91	0.31	0.34	5.21	1.44	0.03
92	0.19	0.19	6.47	16.90	0.00
93	0.17	0.27	4.90	2.09	0.10

Table A3.

Real Life Crossing Encounters

	ECPA (n.m.)	CPA (n.m.)	RELVEL (knots)	APCH (Degrees)	ECPA-CPA (n.m.)
1.	0.36	0.39	21.62	89.22	0.03
2	0.09	0.21	19.81	82.62	0.12
3	0.60	0.64	23.11	102.05	0.04
4	0.23	0.25	19.81	118.27	0.02
5	0.77	0.72	17.40	103.16	0.00
6	0.01	0.44	22.66	102.69	0.43
7	0.50	0.60	23.31	134.01	0.10
8	0.31	0.69	25.79	138.98	0.36
9	0.06	0.29	19.98	118.04	0.23
10	0.14	0.54	21.16	78.86	0.40
11	0.24	0.60	17.95	108.74	0.36
12	0.13	0.27	20.48	90.18	0.14
13	0.59	0.59	17.93	73.34	0.00
14	0.28	0.78	17.50	97.46	0.50
15	0.51	0.51	12.23	144.75	0.00
16	0.14	0.45	14.24	71.42	0.31
17	0.28	0.32	12.72	30.48	0.04
18	0.13	0.28	17.01	71.29	0.15
19	0.32	0.30	11.07	60.99	0.00
20	0.61	0.76	23.17	94.86	0.15
21	0.06	0.33	22.62	93.22	0.27
22	0.38	0.41	12.54	128.77	0.03
23	0.22	0.42	23.16	97.36	0.20
24	0.57	0.65	16.05	57.70	0.12
25	0.09	0.68	20.16	102.39	0.59
26	0.31	0.60	21.58	93.80	0.29
27	0.34	0.69	18.89	71.31	0.34
28	0.19	0.55	25.94	104.23	0.34
29	0.41	0.56	16.84	65.39	0.15
30	0.09	0.70	18.07	78.49	0.61
31	0.33	0.65	30.30	108.17	0.32
32	0.24	0.53	26.67	97.24	0.29
33	0.32	0.54	22.19	97.78	0.22
34	0.35	0.55	23.33	97.62	0.20
35	0.52	0.76	22.74	76.16	0.24

Real Life Crossing Encounters

	ECPA (n.m.)	CPA (n.m.)	RELVEL (knots)	APCH (Degrees)	ECPA-CPA (n.m.)
36	0.01	0.45	18.96	78.66	0.44
37	0.58	0.58	22.96	143.50	0.00
38	0.15	0.23	23.50	98.85	0.08
39	0.56	0.80	15.65	80.55	0.24
40	0.08	0.40	13.85	34.33	0.32
41	0.37	0.42	18.30	82.43	0.05
42	0.49	0.52	25.50	102.28	0.03
43	0.41	0.51	24.81	109.50	0.10
44	0.31	0.70	22.54	281.53	0.39
45	0.48	0.30	22.86	152.53	0.18
46	0.56	0.64	6.02	58.48	0.08
47	0.23	0.45	8.26	55.86	0.22
48	0.52	0.60	5.43	35.61	0.08
49	0.22	0.42	5.45	24.66	0.22
50	0.40	0.61	6.20	38.36	0.21
51	0.04	0.61	25.42	102.43	0.57
52	0.01	0.49	18.96	78.66	0.48
53	0.06	0.56	14.57	88.26	0.50
54	0.57	0.57	21.70	69.61	0.00
55	0.36	0.53	29.32	126.35	0.17
56	0.25	0.51	24.31	123.57	0.26
57	0.39	0.25	22.11	120.92	0.00
58	0.14	0.41	19.31	71.42	0.27
59	0.44	0.49	14.92	118.15	0.05
60	0.07	0.12	8.06	64.49	0.05
61	0.24	0.54	26.67	97.24	0.30
62	0.31	0.15	8.16	27.36	0.16
63	0.05	0.13	22.73	103.23	0.08
64	0.38	0.51	13.50	109.51	0.13
65	0.89	0.60	23.11	99.34	0.01

Table A4.

Simulator Crossing Encounters

	ECPA(n.m)	CPA(n.m)	DIFF(n.m)
1	0.10	0.82	0.72
2	0.24	0.98	0.74
3	0.13	1.05	0.92
4	0.71	0.97	0.26
5	0.06	0.42	0.36
6	0.68	0.98	0.30
7	0.26	1.42	1.16
8	0.00	0.47	0.47
9	0.06	0.29	0.23
10	0.47	0.79	0.32
11	0.26	0.45	0.19
12	0.48	0.65	0.17
13	0.71	1.48	0.77
14	0.42	0.90	0.48
15	0.28	0.76	0.48
16	0.52	0.52	0.00
17	0.76	1.09	0.33
18	0.46	0.66	0.20
19	0.47	0.57	0.10
20	0.71	0.57	0.00
21	0.20	0.62	0.42
22	0.22	0.62	0.40
23	0.11	1.09	0.98
24	0.20	1.28	1.08
25	0.71	1.47	0.76
26	0.01	0.52	0.51
27	0.00	0.47	0.47
28	0.60	1.00	0.40
29	0.00	1.00	1.00
30	0.47	0.96	0.49
31	1.01	1.01	0.00
32	1.00	1.00	0.00
33	0.01	1.59	1.58
34	0.66	1.14	0.48
35	0.00	0.66	0.66

Table A4. Continued

Simulator Crossing Encounters

	ECPA(n.m)	CPA(n.m)	DIFF(n.m)
36	0.57	0.57	0.00
37	0.48	0.90	0.42
38			
39			
40			

Table A5.

Simulator Overtaking Encounters

	ECPA(n.m)	CPA(n.m)	DIFF(n.m)
1	0.50	1.00	0.50
2	0.50	1.50	1.00
3	0.50	0.80	0.30
4	0.75	0.75	0.00
5	0.75	0.75	0.00
6	0.75	1.00	0.25
7	1.00	1.00	0.00
8	1.00	1.00	0.00
9	1.00	0.75	0.00
10	0.50	0.55	0.05
11	0.50	0.75	0.25
12	1.25	1.25	0.00
13	1.25	1.25	0.00
14	1.25	1.25	0.00
15	0.75	0.75	0.00
16	0.75	0.75	0.00
17	0.75	0.75	0.00
18	1.00	1.25	0.25
19	1.00	1.50	0.50
20	1.00	1.50	0.50
21	1.25	1.25	0.00
22	1.25	1.25	0.00
23	1.25	1.25	0.00
24	1.00	1.00	0.00
25	1.00	1.00	0.00
26	1.00	2.00	1.00
27	0.75	0.75	0.00
28	0.75	0.75	0.00
29	0.75	1.25	0.50
30	0.50	1.25	0.75
31	0.50	1.25	0.75
32	0.50	1.35	0.85
33	1.25	1.25	0.00
34	1.25	1.35	0.10
35	1.25	1.45	0.20

Simulator Overtaking Encounters

	ECPA(n.m)	CPA(n.m)	DIFF(n.m)
36	0.75	1.25	0.50
37	0.75	1.50	0.75
38	0.75	1.50	0.75
39	0.50	0.60	0.10
40	0.50	1.50	1.00
41	0.50	1.50	1.00
42	1.00	1.00	0.00
43	1.00	1.60	0.60
44	1.00	2.50	1.50
45	1.25	1.50	0.25
46	1.25	1.50	0.25
47	1.25	1.60	0.35
48	0.50	0.50	0.00
49	0.50	0.50	0.00
50	0.50	1.25	0.75
51	0.75	0.75	0.00
52	0.75	1.00	0.25
53	0.75	1.00	0.25
54	1.25	1.25	0.00
55	1.25	1.23	0.00
56	1.25	2.25	1.00
57	1.00	1.00	0.00
58	1.00	0.50	0.00
59	1.00	1.50	0.50
60	1.00	1.00	0.00
61	1.00	1.75	0.75
62	1.00	1.60	0.60
63	0.75	0.75	0.00
64	0.75	0.75	0.00
65	0.75	0.60	0.00
66	0.50	0.50	0.00
67	0.50	1.10	0.60
68	0.50	1.50	1.00
69	1.25	1.25	0.00
70	1.25	1.25	0.00

Table A5. Continued

Simulator Overtaking Encounters

	ECPA(n.m)	CPA(n.m)	DIFF(n.m)
71	1.25	1.25	0.00
72	1.25	1.25	0.00
73	1.25	1.25	0.00
74	1.25	0.75	0.00
75	0.50	0.50	0.00
76	0.50	3.00	2.50
77	0.50	1.10	0.60
78	0.75	0.75	0.00
79	0.75	1.25	0.50
80	0.75	2.00	1.25
81	1.00	1.00	0.00
82	1.00	1.00	0.00
83	1.00	1.00	0.00
84	1.00	2.00	1.00
85	1.00	1.50	0.50
86	0.75	0.75	0.00
87	0.75	1.50	0.75
88	0.75	1.75	1.00
89	0.50	1.50	1.00
90	0.50	1.60	1.10
91	0.50	0.75	0.25
92	1.25	1.25	0.00
93	1.25	2.25	1.00
94	1.25	1.25	0.00
95	0.25	0.75	0.50
96	0.25	0.77	0.52
97	0.25	1.00	0.75
98	0.00	0.60	0.60
99	0.00	1.40	1.40
100	0.00	1.75	1.75
101	0.25	1.25	1.00
102	0.25	1.25	1.00
103	0.25	1.50	1.25
104	0.00	1.15	1.15
105	0.00	0.01	0.01
106	0.00	0.01	0.01

Simulator Overtaking Encounters

	ECPA(n.m)	ECPA(n.m)	DIFF(n.m)
107	0.25	0.50	0.25
108	0.25	0.75	0.50
109	0.25	1.25	1.00
110	0.25	0.80	0.55
111	0.25	0.80	0.55
112	0.25	1.10	0.85
113	0.00	0.60	0.60
114	0.00	0.25	0.25
115	0.25	1.25	1.00
116	0.25	0.25	0.00
117	0.25	1.50	1.25
118	0.25	2.00	1.75
119	0.25	0.75	0.50
120	0.25	0.75	0.50
121	0.00	0.60	0.60
122	0.00	1.60	1.60
123	0.00	0.50	0.50
124	0.00	1.50	1.50
125	0.00	1.50	1.50
126	0.00	1.50	1.50
127	0.00	0.75	0.75
128	0.00	1.25	1.25
129	0.00	0.80	0.80
130	0.50	0.75	0.25
131	0.50	0.80	0.30

Appendix IV

List of Abbreviations

ADP	Automatic Data Processing
APCH	Angle of Approach
ARPA	Automatic Radar Plotting Aid
ASCII	American Standard Code for Information Interchange
BMT	British Marine Technology
CLP	City of London Polytechnic
CNIS	Channel Navigation Information Service
CPA	Closest Point of Approach
DSIS	Dover Strait Information Service
DTI	Department of Trade and Industry
ECPA	Expected Closest Point of Approach
ED	Encounter Distance
ETN	External Track Number
IMO	International Maritime Organisation
IMCO	Inter-governmental Consultative Organisation
Knots	Nautical miles per hour
MDD	Minimum Decision Distance
MSS	Minimum Separation Standard
N.M.	Nautical Miles
NMI	National Maritime Institute
N.Miles	Nautical Miles
NPL	National Physical Laboratory
PAI	Problem Area Identifier

PNL	Polytechnic of North London
PNLCS	PNL Computer Services
RELVEL	Relative Velocity
RDRR	Range to Domain over Range Rate
RDR +	RDRR+
SAR	Search and Rescue
SDD	Strategic Decision Distance
SSS	Strategic Separation Standard
TDD	Tactical Decision Distance
TSS	Tactical Separation Standard
VLCC	Very Large Crude Carrier
VHF/DF	VHF Direction Finding
VTS	Vessel Traffic Systems

Statistical Expressions

δ	X-component of relative velocity as a random variable
$\bar{\delta}$	mean value of δ
γ	Y-component of relative velocity as a random variable
$\bar{\gamma}$	mean value of γ
$\sim$	a random variable has a stated distribution
E( )	Expected value
Var( )	Variance
$Nor(\mu, \sigma^2)$	Normal Distribution with mean μ and variance σ^2

Two events A and B are Independent implies P(AB) P(A)x P(B).

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END