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INTERNATIONAL COLLISION REGULATIONS FOR AUTOMATIC COLLISION AVOIDANCE

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INTERNATIONAL COLLISION REGULATIONS FOR AUTOMATIC COLLISION AVOIDANCE

by

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International collisions regulations for automatic collision avoidance

Chris Perkins
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ABSTRACT

This thesis considers the relationship between collision regulations and an automatic collision avoidance system (ACAS).

Automation of ship operations is increasingly common. The automation of the collision avoidance task may have merit on grounds of reduced manual workload and the elimination of human error. Work to date by engineers and computer programmers has focused on modelling the requirements of the current collision regulations. This thesis takes a new approach and indicates that legislative change is a necessary precursor to the implementation of a fully automatic collision avoidance system.

A descriptive analysis has been used to consider the nature of the collision avoidance problem and the nature of rules as a solution. The importance of coordination between vessels is noted and three requirements for coordination are established. These are a mutual perception of: risk, the strategy to be applied, and the point of manoeuvre. The use of rules to achieve coordination are considered. The analysis indicates that the current collision regulations do not provide the means to coordinate vessels.

A review of current and future technology that may be applied to the collision avoidance problem has been made. Several ACAS scenarios are contrived. The compatibility of the scenarios and the current collision regulations is considered. It is noted that both machine sensors and processors affect the ability to comply with the rules.

The case is made for judicial recognition of a discrete rule-base for the sake of an ACAS. This leads to the prospect of quantified collision regulations for application by mariners.

A novel rule-base to match a particular ACAS scenario has been devised. The rules are simple and brief. They avoid inputs dependent on vision and visibility, and meet all the aforementioned coordination requirements. Their application by mariners to two-vessel, open sea, encounters was tested on a navigation simulator. The experimental testing of such a rule-base is unique.

Mariners were given experience of applying the rule-base in certain circumstances and asked by questionnaire what their agreeable action would be. This was compared with their usual action. While the number of experiments was small, an indication was given of the important issues in applying a quantified rule-base. Aspects identified for further study include the testing of rule-base elements in isolation, and the use of quantified rules in multi-ship and confined water encounters.

LIST OF CONTENTS

CHAPTER 3: AN EXAMINATION OF THE AVAILABLE AND DEVELOPING TECHNOLOGY WHICH MAY BE APPLIED TO THE COLLISION AVOIDANCE PROBLEM

CHAPTER 5: THE DEVELOPMENT OF REGULATIONS COMPATIBLE WITH AUTOMATIC AND MANUAL OPERATION.

CHAPTER 6: EXPERIMENTAL TESTING OF THE COLLISION AVOIDANCE RULE-SETS

CHAPTER 8: CONCLUSION

ABBREVIATIONS

ACAS	Automatic Collision Avoidance System
ACC	Automatic Cooperative Communications
ADS	Automatic Dependent Surveillance
AI	Artificial Intelligence or Artificially Intelligent
ARPA	Automatic Radar Plotting Aid
CAS	Collision Avoidance System
COLREGS 72	International Regulations For Preventing Collisions At Sea, 1972.
cpa	closest point of approach, or distance to closest point of approach.
DSC	Digital Selective Calling
GRT	Gross Registered Tons
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IFF	Interrogation Friend or Foe
INMARSAT	International Maritime Satellite Organisation
M	Nautical Miles
RDRR	Range to Domain/Range Rate
RIN	Royal Institute of Navigation
tcpa	For the purpose of this study: time to closest point of approach; alternative to: time of closet approach
VDU	Visual Display Unit
vhf RT	very high frequency radio telephone
VTS	Vessel Traffic Services

LIST OF TABLES

LIST OF FIGURES

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AUTHOR'S DECLARATION

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2. PERKINS, C.J. International Collision Regulations for Automatic Collision Avoidance, *Poster presented as part of 2nd year PhD report*, 1994, Plymouth. (presented).
3. PERKINS, C.J. and REDFERN, A. Requirements for coordination and the application of an automatic collision avoidance system, *Journal of the Institute of Navigation*, May, 1995.

Signed ....

Date ....

"...if one could rely on accurate information, navigation would be a simple science, where as the art and fascination of it lies in deducing correctly from uncertain clues"

Francis Chichester, The Lonely Sea and the Sky

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The application of automation to ship operation is increasingly common. Arguments can be made for the replacement of manual labour by machine, on grounds of safety and economics. The argument for safety is supported by statistics that purport human error as having a part in the majority of marine accidents[1].

Collisions between vessels at sea continue to occur despite considerable advances in navigation aids and several waves of legislation. The consequences of collision, loss of life and resource, and resultant pollution, have encouraged many parties to work towards a solution to the problem. Most recently work has focused on the partial or full automation of the collision avoidance operation.

The work of computer programmers and engineers has considered the problem one of replacing man by machine within the existing legislative framework[2,3,4,5,6,7]. Analysis described in this thesis will indicate that legislative change is a necessary precursor to the implementation of a fully automatic collision avoidance system. Two published papers by the author[8,9] may be taken as a synopsis of the argument, and will be found in Appendix G.

1.2 AIM OF THE STUDY

The aim of this study is to describe the role of regulations in collision avoidance, and show the relationship between regulations and an automatic collision avoidance system. A further objective is to describe preliminary studies into the acceptability, by human mariners, of quantification in a discrete rule-base.

1.3 METHODOLOGY

1.3.1 Descriptive analysis

A descriptive analytical method has been used to define some aspects of the nature of the collision avoidance problem. This has allowed rules in general, and the International Regulations for Preventing of Collisions at Sea, 1972[10] (COLREGS 72) specifically, to be examined as to their role in collision avoidance.

The collation and description of technology that may constitute a collision avoidance system, have allowed further analysis of the suitability of the COLREGS 72. The requirements implied by the current regulations have been examined against the technological capability of various scenarios. The scenarios include present day manual operation; true artificial intelligence, and expert systems with a variety of supporting sensors. Having indicated that the COLREGS 72 are incompatible with the most likely automatic system, the thesis goes on to consider new rules.

Criteria for the new rules are derived from definitions concerning the role of rules and the limits of a technological scenario that has been assumed. A discrete rule-base has been constructed, drawing on the work of previous researchers where appropriate.

1.3.2 Simulation

The human application of the discrete rule-base has been tested in the course of this research by running collision avoidance exercises with a navigation simulator and practising mariners. Navigation simulation is commonly used and widely accepted as providing useful results when trying to recreate mariners' usual behaviour. In the experiments, mariners were asked to apply the new rules to the circumstances presented to them. A post exercise questionnaire was used to obtain details of the mariners' usual action at sea, and their acceptance of the new rules.

The use of a post-exercise questionnaire to obtain manoeuvre data, rather than taking the actual actions during the simulation exercise is not widely reported. When mariners' "usual" action at sea is compared with work by other researchers it shows a reasonable level of validity. The "new" action data is unique, as is the particular rule-base, and therefore cannot be compared. The level of usefulness and limitations of the data is discussed in the thesis.

1.4 THE STRUCTURE OF THE THESIS

This thesis comprises eight chapters, including this introduction (chapter 1) and the conclusion (chapter 8).

Chapter 2 considers the nature of the collision avoidance problem and solution. Important terms are defined and discussed. The use and role of rules as a solution is examined. The current regulations are critically analysed. The inputs to a collision avoidance system that are implied by the current regulations are noted.

Chapter 3 examines the available and developing technology that may be applied to the collision avoidance problem. Technology is considered under the headings of the human machine; machine sensors; machine processors, and general technology. The technology that may comprise an automatic collision avoidance system is considered.

Chapter 4 examines the relationship between data input and processing, and collision regulations. The requirements of the COLREGS 72 (as considered in chapter 2) are married with the technology available in several scenarios (as described in chapter 3). This analysis indicates the incompatibility of the COLREGS 72 with various technological scenarios, including present manual operation and automatic operation with expert systems.

Chapter 5. The development of regulations that may be compatible with both manual and automatic operations is described. A technological scenario is assumed and rule criteria derived. Relevant work by other researchers is considered.

Chapter 6 deals with the experimental testing of the collision avoidance RULE-SETS. The navigation simulator; human sample; individual exercises, and questionnaire procedure are described.

Chapter 7 describes the experimental results and analysis. The validity of the results is discussed, before making an analysis in general and detail.

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CHAPTER 2

A DISCUSSION OF THE NATURE OF THE COLLISION AVOIDANCE PROBLEM AND SOLUTION

2.1 INTRODUCTION

Defining a problem is usually the key to finding a successful solution. Both theorists and pragmatists have described the collision avoidance problem with methods ranging from mathematics to philosophy. No definitive description appears to have been forthcoming, and if indeed it had, perhaps there would no longer be a problem.

The aim of this chapter is to develop principles from which the problem can be analysed. The place, nature and limitations of rules as a solution will be discussed. Specific reference to the COLREGS 72 will include the data inputs required, and the responsibility implied by the current regulations. The COLREGS 72 will be critically analysed regarding their role in preventing collisions.

2.2 RISK OF COLLISION

2.2.1 Collision occurs when two (or more) vessels try to occupy the same space at the same time.

2.2.2 Collision avoidance is the practice of action that prevents vessels being in the same place at the same time. To take reasoned action before a collision occurs it is necessary to predict that the vessels will be in collision.

2.2.3 Prediction and Risk of collision

The "prediction of collision" is not satisfactory in practice to describe the state when action is necessary to avoid collision, for reasons explained below. The term "risk of collision" encompasses the state "prediction of collision" and describes the circumstances when action to avoid collision is necessary.

2.2.3.1 Interaction

The usual foundation for any prediction comes from extrapolating past and existing observations. In collision avoidance the extrapolation of data may indicate that vessels are passing clear. However, if the passing distance is relatively small, the vessels may be drawn into collision at the last moment by a hydrodynamic effect known as interaction. The effect of interaction does not become apparent until the vessels are very close. It is necessary therefore to pass at a distance at which interaction will not have a significant effect. The prediction process must indicate a particular passing distance rather than simply collision or not.

Due to the effect of interaction it is necessary for vessels to pass with a distance between them if risk of collision is not to exist. Two other factors affect the distance at which vessels must pass when considering risk of collision.

2.2.3.2 Accuracy

The data that is used, and the prediction process, will have limits of accuracy. It is necessary to allow a margin to compensate for the possible inaccuracy of the prediction.

2.2.3.3 Uncertainty

As previously stated, prediction involves the extrapolation of past observations. The future, it may be argued, will be a derivative of the past. This notion allows life to be lived with some order and avoids the need to consider the infinite number of chaotic scenarios that might exist. In reality the future can turn more to the chaotic end of the scale rather than the orderly. The uncertainty of the future requires a particular passing distance to be left between vessels, so that if an unpredicted and adverse turn of events took place, a reasonable chance of avoiding collision by emergency action would exist.

2.2.4 Acceptable risk

When quantifying risk of collision it is necessary to quantify the interaction effect, the prediction accuracy, and the uncertainty. The first two may be quantified. Uncertainty by its nature is impossible to quantify.

If uncertainty were to be quantified then it would first be necessary to quantify what is considered a "reasonable chance" of avoiding collision. That the phrase "reasonable chance," is used, indicates that the elimination of risk is not required, and that there is an acceptable level of risk.

It could be argued that while two vessels exist on the surface of the Earth, risk of collision is greater than zero. It would help minimise the risk if one vessel stayed in port while the other was at sea. It is necessary to weigh the consequences of collision with the need for vessels to travel with their cargoes from one point to another. An acceptable commercial risk and hence passing distance, is delivered by society's values, by various routes.

Statistically, risk of collision increases with the proximity of land and traffic density. This would imply a need for greater passing distances. However in practice, in these areas acceptable passing distances become less; the risk of collision is accepted as being higher.

Goodwin's work on domains[1] suggested that the mariner's concept of acceptable risk depended on a variety of factors. It also indicated that mariners are sometimes forced to accept passing distances which are less than they would like. A general trend showed that larger vessels tried to achieve larger passing distances. This concurs with the notion that with a larger turning circle or stopping distance, the larger vessel will need more room in an emergency. Against the trend, the largest vessels achieved smaller passing distances, perhaps suggesting a upper limit to what could be achieved, or that underlying conditions forced the largest vessels to accept passing distances created by more manoeuvrable vessels.

2.3 ACTION TO AVOID COLLISION

Having determined that there is a need for action to avoid collision (risk of collision exists), it is necessary to find appropriate action.

2.3.1 Sight-line Rotation

Calvert[2] notes that an essential collision avoidance principle is to maintain or establish sight-line rotation. Sight-line rotation is dependent on vessel separation and both vessels' course and speed. To ensure that net sight-line rotation occurs, both vessels' actions must be considered.

2.3.2 Sight-line rotation by force

Sight-line rotation may be achieved by force if one vessel is faster or more manoeuvrable than the other. The other vessel could try to have a collision but would be unable to force the issue. Kemp[3] has shown that the faster vessel can guarantee collision avoidance by her manoeuvre alone. As the vessels' speeds become closer in value the faster would need to put the other on the beam or abaft the beam to be sure of avoiding collision. As a general practice this approach would be inefficient for progress along a track and is unsuitable for commercial shipping. The other case, a more manoeuvrable vessel, can be best imagined by considering a Greenpeace dory under the bows of a large ship. The dory does not have to be faster than the ship, but can avoid collision by a sudden alteration of course away from the ship's track. The ship is unable to match the rate of change of track and so sight-line rotation is forced. This case is again unsuitable for general commercial practice.

2.3.3 Complementary Action Strategies

Sight-line rotation may be anti-clockwise or clockwise (positive or negative rotation respectively). A net rotation through complementary action may be achieved by various strategies. In a particular encounter:

> [Strategy (i)] both vessels may adopt a convention of positive rotation and manoeuvre accordingly;
>
> [Strategy (ii)] both vessels may adopt a convention of negative rotation and manoeuvre accordingly;
>
> [Strategy (iii)] one vessel will stand-on while the other is responsible for making the manoeuvre and choosing the sight-line rotation sense.

Clearly some form of agreement is necessary to coordinate vessels in this way.

2.3.3.1 Complementary action through natural principles?

Principles of disengagement that may be used in the absence of formal rules have been suggested by Kemp[4] from his experimental evidence. He suggests that three main principles would apply:

"(a) Manoeuvres would be made to pass astern of the vessel being avoided.

(b) Manoeuvres would tend to increase whatever miss distance is originally estimated.

(c) There would be a reluctance to reduce speed."

None of these principles involves any form of coordination between the vessels. Only one vessel can pass astern of the other. Passing astern can be in conflict with increasing the existing closest point of approach (cpa).

If both vessels made a manoeuvre independently of the other, then the result would be non-complementary for 50% of the encounters. If a vessel can observe the action of the other it is possible for her to make her manoeuvre complementary with that of the vessel that manoeuvres first. However, it is not always possible for a vessel to observe the actions of the other, and it is not satisfactory for a vessel to be waiting indefinitely for the other to "show her colours". When the vessels do manoeuvre simultaneously, a cancelling of the effect of the individual manoeuvres may occur.

It is also conjectured that without a form of coordination, the uncertainty in risk of collision may increase, commensurately increasing the accepted safe passing distance. This will mean that to move from a "risk" situation to "non-risk" situation, larger alterations of course and speed are required, which will result in a decrease in the efficiency of shipping.

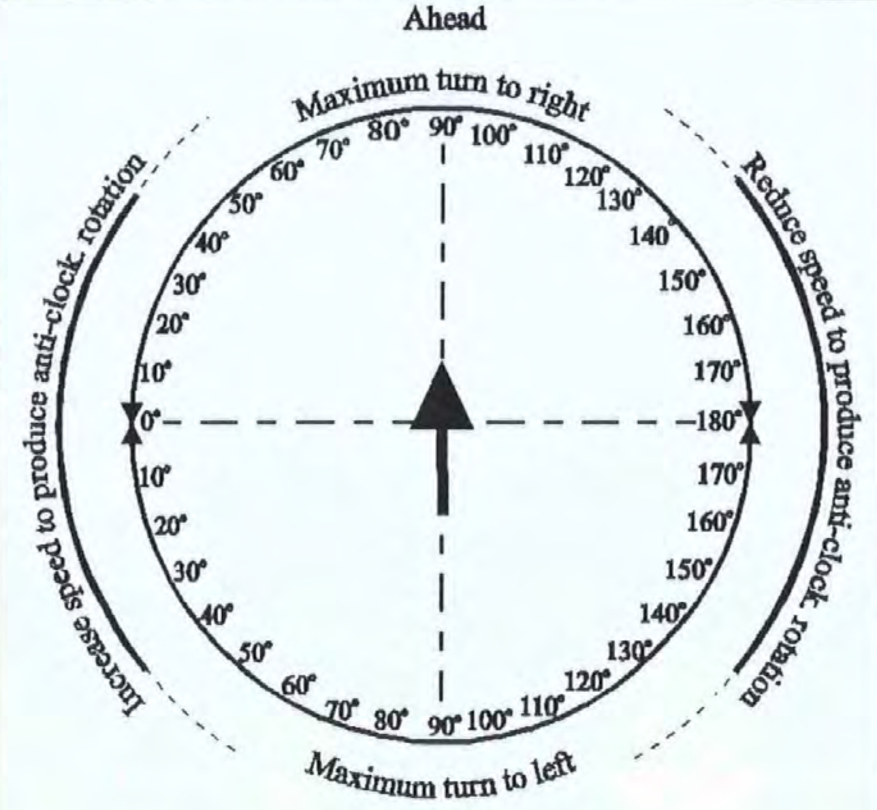
2.4 IMPLEMENTING COMPLEMENTARY ACTION STRATEGY

On examination, the first two complementary action strategies are similar in nature but opposite in sense. The third is different in nature to the first two, and variable in sense.

2.4.1 Strategies (i) or (ii) may be termed dual responsibility, as both vessels are required to manoeuvre. At first sight they appear a very simple and effective strategy for achieving complementary action. The action required under these strategies was considered by Calvert[5,6] and further quantified by Hollingdale[7].

It was shown by Calvert, that for a particular sight-line rotation, the sense of course alteration or speed alteration was dependent on the target's relative bearing. For positive rotation it was shown that with a target forward of the beam an alteration of course to starboard was required. Targets aft of the beam necessitated a port alteration for complementary action. The appropriate speed alterations were an increase if the target was to port and decrease if the target was to starboard. Negative rotation manoeuvres are found by reversing the sense of positive rotation manoeuvres. Positive sight-line rotation is the general theme that runs through the current COLREGS. The following analysis will describe the strategies in positive rotation terms.

An apparent advantage of strategies (i) and (ii) is that having agreed which strategy to operate under, the only information required to apply the strategy is target relative bearing. Another apparent advantage is that it is not necessary to distinguish between vessels, as both are operating under the same rule. Unfortunately, in practice there are some limitations to this strategy.



RELATIONSHIP BETWEEN BEARING OF THREAT AND THE MANOEUVRE WHICH, WHEN EXECUTED BY OWN CRAFT, MAKES THE LARGEST CONTRIBUTION TO THE MISS DISTANCE WITHOUT INFRINGING THE MANOEUVRING AREA OF THE OTHER CRAFT.

Numbers on the inner circle are turns which produce the maximum rate of rotation of the sight-line in the *anti-clockwise* sense. The speed changes shown also produce rotation in this sense. If both craft make the maximum turns, they will be on opposite courses at right angles to the original sight-line. Note that when own craft is not permitted to turn, the turn permitted to the other craft is between 90° and 180°, depending on its aspect.

Figure 2.1
Calvert's analysis
Source: CALVERT, Reference 5.

2.4.1.1 Target on the port beam

Inspection of Calvert's diagrams (Figure 2.1) indicates that when a target is on the port beam, a positive contribution (towards anti-clockwise rotation) cannot be made by course alteration. Hollingdale's quantitative analysis (Figure 2.2) shows that for a target on or near the port beam, course alteration can provide no, or only a small, positive contribution. An increase in speed appears to be the logical action, however in practice, most merchant vessels have only a small reserve of speed, and the increase may take considerable time to be realised.

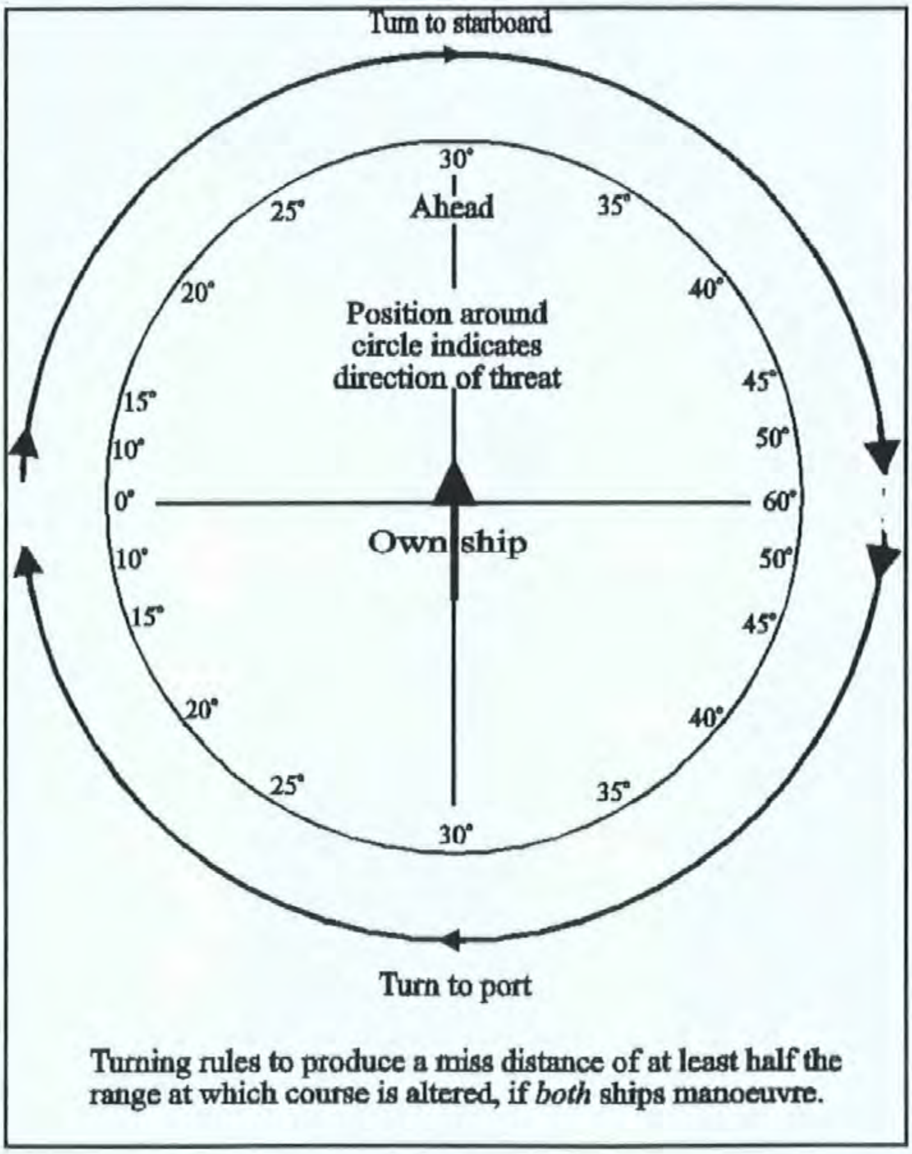


Fig.2.2
Hollingdale's analysis
Source: Hollingdale, Reference 7.

2.4.1.2 Initial negative cpa

A negative cpa is one associated with negative (clockwise) sight-line rotation. If in the first instance risk of collision exists with a negative cpa, that cpa must be overcome by positive action before a positive cpa is built up. If one vessel can only make a small positive contribution, due to having the target on the port beam, or due to having a low speed, or being restricted in her ability to make large course alterations, then action by that vessel alone may not be sufficient to overcome the existing negative cpa. That vessel may have to rely on the target taking action, or take negative, non-complementary action herself to increase the cpa.

If a vessel cannot take the appropriate action as per the strategy, and the cooperation of the target cannot be assured, then a dilemma will exist. The choice is to stand-on until the target manoeuvres or to make a non-complementary manoeuvre oneself. Ideally the target will manoeuvre in good time to clarify the situation. However it is possible for the target to not follow the strategy for various reasons. It is therefore necessary for own ship to know when to manoeuvre as escape action in a non-complementary way. This situation has parallels with strategy (iii).

2.4.2 Strategy (iii) achieves complementary action by requiring one vessel to stand-on holding course and speed, while the other is responsible for choosing the sense of rotation and making a manoeuvre. To operate this strategy it is necessary to be able to distinguish the stand-on vessel from the give-way vessel. Methods of doing so are considered later.

Deferring the method of distinction between the vessels, the advantages of one vessel choosing the sight-line rotation may be shown. Having the choice of rotation means that the most convenient manoeuvre sense may be had. If as with strategies (i) and (ii), one direction is inappropriate, then the other, usually increasing the existing cpa or avoiding crossing ahead, may be used. This strategy allows one vessel to avoid being deviated from her track while the other may choose the most appropriate deviation in the circumstances.

In practice the stand-on vessel may not be as "privileged" as she first appears. If the give-way vessel does not appear to manoeuvre then the stand-on vessel will have to take some escape action. The stand-on vessel cannot make her action complementary with that which the give-way vessel may subsequently take, because there is no convention for sight-line rotation.

From the description of the three strategies it is clear that they have differing strengths and weaknesses. It is important to note that no strategy provides a general complementary solution. When the target appears to be a rogue, anti-strategy escape action may be necessary.

2.4.3 Escape action

Because rogue behaviour does exist anti-strategy action will be necessary. This action though not desirable, is justifiable in the pursuit of the overall aim of avoiding collision. To minimise anti-strategy action due to apparent rogue behaviour, it is necessary to consider the nature of "rogue" vessels.

2.4.4 The nature of the rogue

Rogue behaviour might be considered that which does not implement the complementary action strategy. It stems from different sources. Seven "types" of rogues have been categorised and are described below.

2.4.4.1 Target makes a non-risk assessment

If the target considers that risk of collision does not exist it will not make a collision avoidance manoeuvre. As own vessel does consider "risk" to exist the target appears as a rogue. This type of rogue will appear to be standing on. To avoid this rogue type a mutual perception of risk is necessary.

2.4.4.2 Target is yet to manoeuvre

As the complementary action strategy itself is not concerned with when manoeuvres are to be made, all vessels which are required to manoeuvre, appear to be rogues until they do so. Following this analysis, anti-strategy escape action appears to be justifiable at any time before the target manoeuvres. This approach throws the whole idea coordination away. It appears necessary to make clear, as well as what strategy is being used, the point by which manoeuvres are expected to be made, which will in turn create a basis for when escape action is acceptable. This rogue type appears to be standing on. For coordination a mutual perception of manoeuvre point is necessary.

2.4.4.3 Non-mutual assessment of the strategy requirement

An inadequacy in the accuracy or of the type of data which is available may cause different strategies to be applied by each vessel. This may, depending on exactly what the strategy requirement is, cause the target to appear as a rogue. This type of rogue may appear to be standing on, giving way, or manoeuvring anti-strategy depending on the perceived strategy requirement. To avoid this type of rogue the strategy (and associated rules) must be robust enough to survive likely misperceptions.

2.4.4.4 Target cannot manoeuvre as per the strategy requirement

As described above (2.4.1) it may not be possible for a strategy (i) manoeuvre to be implemented. An obstruction may exist in the direction in which a manoeuvre is required, or given a small initial negative cpa, one vessel may not be able to achieve significant positive rotation without the cooperation of the other being assured. In these cases the target may appear to be standing on, and later may make an anti-strategy manoeuvre.

A strategy (iii) stand-on vessel, may not be able to hold her course and speed, if an alteration for navigational purposes or collision avoidance with a third vessel is necessary. This rogue type will appear to be giving way.

2.4.4.5 Non-detection of own vessel

If the target has not detected own vessel then it will not make any collision avoidance manoeuvre. This type of rogue will appear to be standing on.

2.4.4.6 Ignorance of the strategy requirements

If the watchkeeper on the target vessel is ignorant of the strategy requirements then the vessel may appear to be a rogue. This type of rogue may stand-on, give-way, or manoeuvre anti-strategy depending on the particular strategy requirements.

2.4.4.7 Ignoring the strategy requirements

If the watchkeeper on the target vessel is deliberately ignoring the strategy requirements then the vessel will appear as a rogue. This type of rogue will stand-on, give-way, or manoeuvre anti-strategy depending on the particular strategy requirements.

2.4.5 Coordination requirements

The description of rogue types indicates that to apply a complementary action strategy, it is necessary for the vessels to have a mutual perception of three features. The features are risk of collision, the strategy to be applied, and when manoeuvres are to be made.

2.4.6 Collision avoidance as a game of coordination

Cannell[8] has considered collision avoidance as a "game" of coordination. He states that the solution of a coordination problem may be found in three ways:

" (i) Agreement, specific agreement in an individual case.

(ii) Tacit agreement in a series of similar situations.

(iii) By the obvious salience of a particular solution."

2.4.6.1 Salience

If an encounter has a particularly salient feature which both parties might reasonably be expected to recognise, then this feature may enable coordination. Experiments by Kemp[9] showed that a head-on encounter with a clear initial miss distance held no solution problems for naïve (without seafaring experience) subjects. All subjects altered course to increase the existing cpa. However, when the initial cpa was zero the naive subjects could not find a coordinated solution. It is clear from this that a salient solution can only be found when one exists.

In practice the salience of a solution is open to misperception by both parties, leading to different, conflicting, uncoordinated solutions being found. This is evidenced by a proposal by Corbet[10] for a new head-on rule. The rule hopes to use salience as the solution to encounters. However, recognising the possibility for misperception and hence uncoordinated manoeuvres, the second stage rule is necessary.

Corbet's proposal requires that when vessels are meeting "end-on or nearly end-on" they alter course to increase the existing cpa. A red to red encounter requires vessels to alter to starboard, while a green to green encounter requires vessels to alter to port. If however this action results in one vessel altering to port and the other to starboard, then as per the spirit of the existing crossing rule, the vessel with the other on her starboard side shall either alter back to starboard, or complete a round turn to port, to effect a red to red passing.

Salience does not provide a general solution to the collision avoidance coordination problem for two reasons. One, salient solutions are not available in all cases, and two, the quality and type of information which is available under operational conditions is not adequate to prevent misperceptions of a supposed salient feature.

2.4.6.2 Specific agreement in an individual case

Specific agreement may be reached on how to coordinate action in an individual encounter. A communications channel is required between the two vessels, and/or a third party. Through the communication channel mutual perception of the encounter can be achieved allowing coordination to ensue. This type of coordination has the advantages of circumventing misperceptions due to inaccurate data and processing, and decreasing the uncertainty in risk of collision.

Specific agreement includes the "external overall control of traffic" from Kemp's classification of collision avoidance systems[11], and Corbet's active\directive branch of Marine Traffic Control[12]. It also includes a system where vessels are able to communicate directly with each other. The sound signals as per the current COLREGS for agreeing an appropriate overtaking manoeuvre are an example of such a system. The use of ship-to-ship vhf RT communication enables specific agreement. The future possibility of the mandatory carriage of automatic cooperative communications systems would enhance the opportunity to achieve coordination in this way.

The current technical and administerial situation does not provide a communication channel robust enough for specific agreement to be a present day general solution. It may play a greater role in the future, as the undoubted potential is recognised.

2.4.6.3 Tacit agreement

Tacit agreement requires a previously established convention, i.e. formal rules. Tacit agreement needs no on-line communication channel; formal rules provide the "communication" necessary for coordination in the general case. In effect, before vessels leave port, they have an agreement on how to coordinate action in case of collision risk. The communication element takes place before leaving port, and at sea the agreement is tacit.

Formal rules do however suffer from the potential misperception of the situation, and they may be unsuccessful if applied to extraordinary circumstances.

Given the general inadequacy of salience and the lack of a robust communications channel for specific agreement, tacit agreement through formal rules has been deemed as part of the collision avoidance solution. This thesis is concerned with rules as a solution.

2.5 THE NATURE OF RULES

2.5.1 Rules to meet the coordination requirements

Formal rules may be used to promote coordination between vessels in order to achieve complementary action. There are three requirements for coordination (See 2.4.2) with which the rules may concern themselves. These are establishing a mutual perception of: risk of collision; the strategy to be applied; and when manoeuvres are to be made.

2.5.1.1 A mutual perception of risk of collision

It may be pertinent to consider why vessels may not have a mutual perception of risk of collision. Of the three factors which make up risk of collision, the interaction effect is mutual between the vessels and so should have no bearing. The accuracy of the prediction method will be individual to that used aboard each vessel. Risk assessment by visual observation of target bearing may have a different result and potential accuracy to manual plotting of radar returns, or the continuous automatic plotting carried out by automatic radar plotting aids (ARPA). Non-mutual perceptions may occur due to the accuracy factor.

The uncertainty factor may also cause non-mutual perception of risk of collision. Uncertainty of the future requires a sufficient passing distance to be left in order that a reasonable chance exists of avoiding collision by emergency action. The passing distance required by a larger less manoeuvrable vessel will be greater than that of a smaller more handy vessel. Goodwin's observations[12] indicate that this fact is to a large extent mirrored in practice.

The concept of safety, or what is an appropriate safe passing distance, may be considered as a topic for metaphysical debate. In the absence of specific instruction the watchkeeping mariner must make a judgement. The judgement will be a product of the mariner's experience. The experience may include his formal training in college and the examples of his contemporaries in practice. The experience of individual mariners will not be common throughout the watchkeeping population. The effect of an experience is likely to be individual for individual mariners. A differing concept of safety is inevitable throughout a population of human mariners. This must create the possibility of non-mutual perception of risk of collision.

There is clearly a spread of conceptions of risk of collision across the population of mariners and the circumstances of the case. The role of a rule here would be to change the spread of values to a particular value. Through uniform training a particular conception might be achieved across the human population. The range of values across different circumstances appear to be an inevitable feature of the nature of shipping. A multi-vessel encounter in confined waters may make a particular passing distance impossible to achieve. The value of risk of collision which is acceptable in this case, may be far too small to be acceptable for a two-vessel encounter in open water where achievable passing distances may be great.

A fixed value for risk of collision emphasises the relationship between vessel speed and what can be achieved. A faster vessel will achieve a particular cpa with greater ease than a slower vessel. The slower vessel will have to begin her manoeuvre earlier or make the manoeuvre greater in scale. If due to the strategy to be applied it is necessary for the vessel to overcome an initial cpa before building a new cpa, she may find herself as a rogue type(2.4.4.4). If there were no fixed risk value she could initially stand-on, accepting the passing distance and waiting to see if the target makes a manoeuvre, which she can then complement.

The experimental work in this thesis includes a preliminary investigation of the use of a fixed risk of collision value for two vessel encounters in open waters.

2.5.1.2 A mutual perception of the strategy to be applied

Unless vessels have a mutual perception of the strategy to be applied it appears pointless having a strategy at all. If in all cases strategy (i) is to be applied then there should always be a mutual perception, both vessels always being required to contribute towards anti-clockwise sight-line rotation. If strategy (iii) is always to be applied then the rules may be used to allocate the give-way and stand-on responsibilities. Kemp's classification[14] of collision avoidance systems divides this strategy into two rule types, Hierarchical and Geometrical.

Hierarchical rules differentiate between the vessels by specific characteristics of the vessels. The specific characteristics must be readily and mutually identifiable. Unless a continuous spectrum of identifiable characteristics is available then hierarchical rules can only be supplementary to more general rules.

Geometrical rules use relative bearing as a frame of reference by which to distinguish between vessels. By using target relative bearing and target heading, vessels may be mutually distinguished and awarded differing responsibilities. However, when vessels are meeting on reciprocal courses, they cannot be distinguished in this way.

If the strategies are to be combined in some way then the rules must distinguish between encounters with different strategy requirements.

2.5.1.3 A mutual perception of when manoeuvres are to be made

Previous research[15] indicates that without formal rules, the point at which a manoeuvre is made will vary throughout a population of mariners. If this behaviour manifests itself in a non-mutual perception of when a manoeuvre is to be made, then rogue behaviour will be exhibited(though not intended), which may force anti-strategy action. Rules might be used to indicate when manoeuvres should be made. This in turn may define when it is acceptable to treat the target as a rogue

2.5.2 Other requirements of rules

2.5.2.1 Minimise rogue behaviour

Rogue behaviour undermines the operation of rules. It is therefore important for rules to be such that they minimise rogue behaviour. The rogue which ignores the strategy requirements(2.4.4.7) may be so uncomfortable with the action prescribed by the rule that they feel they must rebel. If the action prescribed leads to an unsafe situation then the rebellion may be justified. If the action prescribed is safe, and is part of the logical coordination of vessels, then the rebellion may lead to a break down of the overall rule strategy.

Kemp[16] suggested that rules should require action which is as close to that if there were no formal rules. Mariners would be most likely to follow rules demanding action of this sort, and rogue behaviour would therefore be minimised. On the other hand Schauer[17] notes that a rule's role may be to turn natural behaviour to normal behaviour. If natural behaviour involves a wide spectrum of action, then creating a norm by rule enforcement will entail considerable changes to what individual mariners would naturally do. There is a compromise to be had between achieving a normal behaviour, and creating a rule which will be followed.

2.5.2.2 Robustness over likely misperceptions

The need to have a mutual perception of various features in an encounter has been discussed above. Despite the need, and rules devised to emphasise the need, misperceptions can occur due to the inherent limitations of data and processing accuracy. Because misperceptions will occur it is desirable to have rules which are "robust". By this it is meant that if a particular feature is misperceived then the resulting behaviour will have a minimal effect on the overall application of the strategy.

2.6 THE LIMITATIONS OF RULES

2.6.1 Two vessel strategy

So far, when discussing the ways in which the three complementary action strategies may be implemented, encounters between two vessels only have been considered. It is clear that the addition of a third vessel in risk of collision can cause any simplicity in either of the strategies to collapse. A vessel could be obliged to alter to starboard for one vessel and to port for the other. A vessel could be obliged to stand-on for a vessel, while give-way to another.

2.6.2 Confined waters

The discussion of strategies has also assumed that there is open water all around. In some circumstances this is the reality. In seeking port however, vessels must travel in the vicinity of land, shoal water, floating navigational aids and other shipping in general. This reality can create a problem in implementing strategy (i) or (iii). A requirement to turn in a particular direction may not be possible due to the obstruction. A stand-on vessel may need to manoeuvre to avoid the obstruction.

2.6.3 Circumstances of the case

It is clear that the circumstances in a collision avoidance scenario extend beyond a single vessel or a vessel creating risk of collision. It may be argued that in the general case the circumstantial variables are infinite. The possibility of creating rules which account for all circumstantial variables can only be considered alongside the concept of a supreme being. Even given such rules not even the fastest computer, let alone mere mortal man, could begin to apply them. To apply them on-line at sea requires stepping from the improbable, to the impracticable, to the impossible.

The rules which mortal men may conceive must be specific in nature. The inevitable general application of rules means that whether following a rule produces a useful outcome depends on the circumstances of the case. Rules of increasing complexity may be written trying to encompass the circumstantial variables. At some point the ability of the operator to apply the rules as prescribed will fail to be adequate. A compromise between circumstance encompassing complexity, and operational application ability, must be made.

2.7 THE INTERNATIONAL REGULATIONS FOR PREVENTING COLLISIONS AT SEA, 1972

2.7.1 Development

A British Royal Commission of 1831 proposed that steamers navigating in rivers should keep to the starboard side, hence creating a port to port passing[18]. This principle was developed into rules of increasing complexity. Annex B of the International Conference on the Safety of Life at Sea 1948 was entitled "Regulations for Preventing Collision at Sea". These regulations came into force in 1954.

By this time, the collision regulations entailed various concepts and procedures. Responsibility for action was determined by encounter types, which were described in terms of encounter geometry and vessel classification. Special light, shape and sound signals were used to help determine the type of encounter. Vessels were usually assigned roles as the give-way or stand-on party.

The post war use of marine radar emphasised the question "Did the steering and sailing rules apply when vessels were not in sight of one another?" The 1960 SOLAS convention Annex B made it clear that different rules applied depending on whether or not vessels were in sight.

The improper and inappropriate use of radar had led to several well publicised "radar assisted collisions" as they were called. The 1960 rules tried to address the need for radar to achieve its potential. An annex concerning the use of radar information as an aid to avoiding collision was attached to the rules. An implied reference to radar and radar plotting is found in Rule 16c[19]. By the 1972 conference, radar was included in the body of the rules, and there was an implied reference to ARPA.

2.7.2 The requirements of the current collision regulations

The current regulations entail an amalgam of strategies (i) and (iii). When vessels are "not in sight" of one another strategy (i) is generally promoted (exceptions are considered in 2.7.4.2). When vessels are "in sight" then strategy (iii) is used with one exception. When two power driven vessels(equal hierarchy) are meeting on reciprocal or nearly reciprocal courses, then strategy (i) applies. The mixing of the two strategies and the use of the give-way stand-on concept of strategy (iii) leads to the regulations requiring a variety of data inputs.

2.7.2.1 Target vessel being in or not in sight

Having detected a target it is necessary to decide whether the target is in sight or not, the rules being different for the two cases. If the target is in sight, responsibility is divided according to geometry and vessel classification. If the target is not in sight, responsibility for action is given to each vessel, and in most cases strategy (i) is applied.

Section II of the steering and sailing rules (Rule 11, 12, 13, 14, 15, 16, 17, 18) apply to "vessels within sight of one another". Section III (Rule 19) refers to the "Conduct of vessels in restricted visibility". Rule 19(a) states "This Rule applies to vessels not in sight of one another when navigating in or near an area of restricted visibility".

Rule 3(k) states that "Vessels shall be deemed to be in sight of one another only when one can be observed visually from the other".

Rule 3(l) states that "The term "restricted visibility" means any condition in which visibility is restricted by fog, mist, falling snow, heavy rainstorms, sandstorms or any other similar causes".

In order to apply the rules of Section II or Section III correctly, it is necessary to have as inputs one, the existence or lack of visual detection of a target, and two, the existence or lack of visibility restricting phenomena.

2.7.2.2 Target in sight

If the target is in sight, and risk of collision is deemed to exist, responsibility for action must be found. To do this it is necessary to know the target relative bearing, target aspect, and target type and condition compared to own vessel type and condition.

Responsibility by geometry

Three encounter types exist according to geometry:

Overtaking, Rule 13;

Head on, Rule 14;

Crossing, Rule 15.

This results in five possible scenarios for own vessel:

being overtaken by target;

target crossing from port;

overtaking the target;

target crossing from starboard;

head on.

The first two scenarios require own ship to stand-on. The third and fourth require own ship to give-way, while the fifth possibility splits the responsibility between the two vessels, the manoeuvre specified as an alteration to starboard.

In order to differentiate between the five scenarios it is generally, necessary to know the relative bearing and the aspect presented by the target. In the first instance, relative bearing divides the situation into four as shown in Figure 2.3. If the target is in section one, own is being overtaken by the target, and no reference to target aspect is necessary. If the target is in section two, three or four, it is necessary to know target aspect in order to distinguish between the remaining four scenarios.

N.B. Target aspect is a product of target relative bearing and target heading.

Responsibility by classification

If by geometry, the encounter is not an overtaking scenario then, it is necessary to refer to Rule 18, Responsibilities between vessels. This rule sets up a crude pecking order between broad classes of vessels. For example Rule 18 (a):

A power-driven vessel underway shall keep out of the way of:

(i) a vessel not under command;

(ii) a vessel restricted in her ability to manoeuvre;

(iii) a vessel engaged in fishing;

(iv) a sailing vessel.

The rule goes on, requiring a sailing vessel to keep out of the way of numbers (i), (ii) and (iii); and a vessel engaged in fishing to keep out of the way of the first two. If both vessels are power driven then the geometrical rules complete the division of responsibility. An encounter between two sailing vessels is dealt with specially by Rule

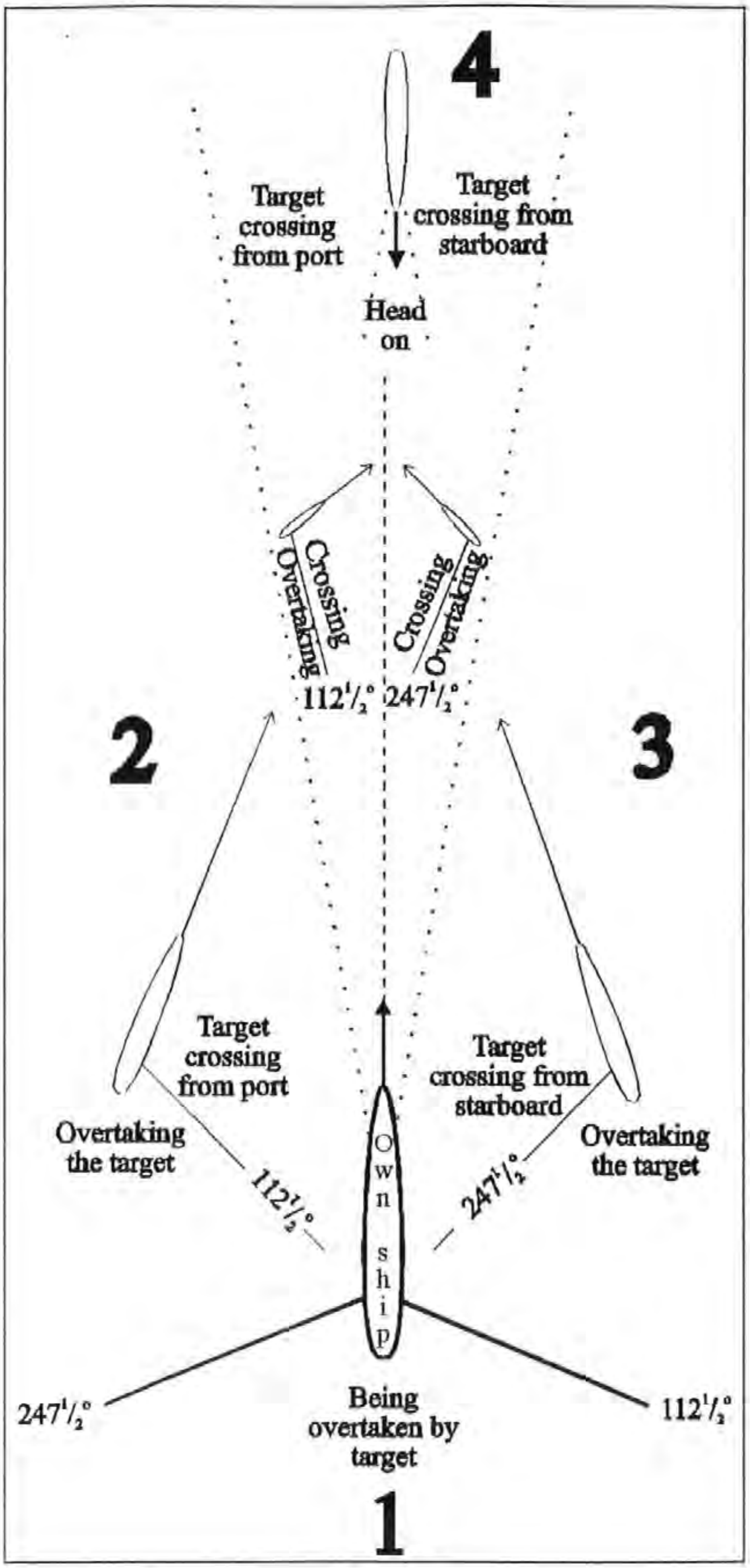


Fig. 2.3
Encounter scenarios by geometry in the COLREGS 72
Source: Author

12, using wind direction as a frame of reference by which to divide responsibility. The regulations do not concern themselves with the division of responsibility for encounters by vessels of the same class, except power -driven and sailing vessels as mentioned.

To obey Rule 18 it is first necessary to know own-ship's class and target class. Target class is indicated by day from general appearance, specific prescribed shape and sound signals, and by night from the display of specific lights and again sound signals.

2.7.2.3 Target not in sight

If the target is not in sight then Rule 19 applies. Part (d) of Rule 19 requires that certain actions shall so far as possible be avoided. These actions are dependent on whether the target is forward of the beam or abeam\abaft the beam. The input required is target relative bearing.

Part (d)(ii) of Rule 19 makes a distinction between a vessel forward of the beam being overtaken or otherwise. The required input here is target aspect(heading and bearing).

2.7.2.4 The give-way stand-on concept

In many circumstances the current regulations for vessels in sight of one another require a vessel to "keep out of the way of the other". This is termed the "give-way" vessel, the other the "stand-on" vessel. In general the former has a largely free choice of what evasive action to take, the latter being required to "keep her course and speed".

The give-way stand-on concept works well in the first instance. If however the stand-on vessel finds it necessary to manoeuvre, then the freedom of action initially granted to the give-way vessel makes the achievement of complementary action difficult.

It is not desirable for any vessel to keep her course and speed indefinitely, while standing into danger. It is also not desirable to have the breakdown of the give-way stand-on concept, leaving difficulty in achieving complementary action. The regulations permit [R.17(a)(ii)] and later require [R.17(b)] the stand-on vessel to manoeuvre if, she perceives that the action of the give-way vessel is inappropriate with respect to the regulations [R.17(a)(ii)], or inadequate for avoiding collision [R.17(b)]. The action required of the give-way vessel must therefore be such to avoid the stand-on vessel having these perceptions. Rule 16 requires the give-way vessel to so far as possible take "early and substantial action to keep well clear".

For the give-way vessel to take action "early" enough to satisfy the stand-on vessel it is necessary to know the limit of the stand-on vessel's manoeuvring point. This might be considered as the vessel's arena as described by other researchers[20]. It is necessary to communicate manoeuvres to the stand-on vessel. For this reason "substantial" manoeuvres are required in order that they may be observed. Observation under current operation/regulations is by visual means (supplemented by radar). The need to keep "well clear" indicates that the stand-on vessel must perceive the action as providing a safe passing distance. It is necessary for the give-way vessel to have knowledge of what the stand-on vessel will accept as a safe passing distance. This might be considered as the stand-on vessel's domain.

In order to obey Rule 16 the give-way vessel must know the target's(stand-on) arena and domain, and target's method of observation or perception. The inputs required by Rule 17, the stand-on vessel, are own domain and arena.

2.7.3 Summary of inputs required by current regulations, Rules 13 to 19.

From the previous discussion inputs required by the current collision regulations can be derived. These are shown in Table 2.1

	Rule number						
Required inputs	13	14	15	16	17	18	19
Target bearing	✓	✓	✓				✓
Target heading	✓	✓	✓				✓
Target classification						✓	
Target domain				✓			
Target arena				✓			
Target perception method				✓			
Own classification						✓	
Own domain					✓		
Own arena					✓		
Existence/lack of visual detection of target	✓	✓	✓	✓	✓	✓	✓
Existence/lack of visibility restricting phenomena	✓	✓	✓	✓	✓	✓	✓

Table 2.1
Summary of inputs required by the current regulations. Rules 13 to 19

2.7.4 COLREGS 72 and the coordination requirements

Formal rules may be used to promote coordination between vessels. It is interesting to consider whether the COLREGS 72 meet the coordination requirements which were identified.

2.7.4.1 A mutual perception of risk of collision

The current regulations do not provide a definitive measure for a mutual perception of risk of collision. The closest that the regulations come to quantifying risk of collision is in Rule 7(d)(i) "...risk shall be deemed to exist if the compass bearing of an approaching vessel does not appreciably change". Rule 7(d)(ii) indicates the limitations of risk assessment through observation of bearing change, "...risk may sometimes exist even when an appreciable bearing change is evident..."

Rule 16 requires that action should be so as to "keep well clear". This, it is supposed, recognises the need to create an apparent mutual perception that a safe passing distance is being achieved. The need certainly exists if coordination is to be achieved, the regulations however do no more than indicate the need.

2.7.4.2 A mutual perception of the strategy to be applied

To ensure a mutual perception of the strategy to be applied it is necessary for each vessel to be able to differentiate between encounters with different strategy requirements. The current regulations use a mixture of strategy (i) and (iii). The requirements of strategy (i) are simple while the requirements of strategy (iii) will depend on which vessel is assigned give-way or stand-on responsibility. In general Rules 11 to 19 specify the strategy to be applied.

The major difference in strategy occurs over vessels being in or not in sight. "It is conceivable that instantaneous sighting may not occur, even if both vessels are keeping an efficient visual look-out, due to such factors as differing intensities of navigation lights or to patches of low fog obscuring the bridge of one vessel but not her masthead lights. A vessel must comply with the Rule which relates to the situation which applies at the particular instant."[21] Given that operational factors force this rule boundary open to non-mutual perception it would be desirable for it to be robust.

A vessel operating under Section II(vessels in sight) may expect a particular target to stand-on to her give-way manoeuvre. The target, operating under Section III(vessel not in sight), is not required to stand-on. This type of encounter is prone to non-complementary action. In a crossing case the proscribed action for the give-way vessel under Rule 15 may help to keep action complementary with a vessel operating under Rule 19. In the overtaking case there is no such proscribed action for the give-way vessel.

<u>No strategy at all</u>

Rule 19(d)(ii) requires that when a target is abaft the beam alteration of course towards the vessel should be avoided. This implies that for a target on the port side, abaft the beam, the preferred action is to turn to starboard. This action, although reducing the rate of approach, is not always complementary with the action required of the target vessel which may in any case regard itself as an overtaking vessel with little restriction on altering to port. In this case the current rules do not promote a complementary strategy at all.

As already mentioned, when vessels, except for power-driven and sailing vessels, of the same status (as described by Rule 18) meet, the COLREGS 72 do not offer a strategy.

2.7.4.3 A mutual perception of when manoeuvres are to be made

The current regulations do not state quantitatively when manoeuvres are to be made. In the 1960 rules, the stand-on vessel was required to hold her course and speed until she "finds herself so close that collision cannot be avoided by the action of the give-way vessel alone"[22]. This rule tried to avoid unnecessary cancelling action by making the stand-on vessel leave her escape action to the last moment. Action at the last moment however, will have its least effect. Also, leaving action until the give-way vessel cannot avoid collision by her action alone, may still result in collision if the stand-on vessel was less manoeuvrable than the give-way vessel in the first place. It is clear that this rule was too stringent for use in practice. The 1972 revision of the rules expanded the stand-on vessel's option by allowing her to "take action to avoid collision by her manoeuvre alone, as soon as it becomes apparent to her that the vessel required to keep out of the way is not taking appropriate action in compliance with these Rules"[R.17(a)(ii), 1972]. The phrase "as soon as it becomes apparent" is not defined in the regulations, hence encouraging escape action more than under the 1960 rule.

It has been implied from the regulations (2.7.2.4), that Rule 16 requires the give-way vessel to have as an input, knowledge of the arena of the stand-on vessel. This knowledge would allow the give-way vessel to make her manoeuvres appear as if there was a mutual perception of when manoeuvres were to be made. Operational technology does not allow the give-way vessel to know the stand-on vessel's arena. In practice the give-way mariner must guess this information. Until a manoeuvre is made the stand-on mariner must guess whether his opposite number is a rogue, or his opposite number considers the arena yet to be infringed.

For the give-way - stand-on concept to succeed a mutual perception of satisfactory give-way manoeuvres is necessary. It may be argued that the stand-on vessel needs to appreciate the give-way vessel's perception of her(stand-on) domain and arena. This type of circular argument may exist at sea today in the absence of other criteria, or the ability to agree criteria.

2.7.5 COLREGS 72 and responsibility

It has already been noted that it is impossible to write rules which can account for all possible circumstances. That the basic coordination requirements are not met by the COLREGS 72 is symptomatic of that fact.

2.7.5.1 The ordinary practice of seamen

The current regulations avoid infinite complexity by using the concept of the "ordinary practice of seamen". Rule 2(a) requires precautions in line with the ordinary practice of seamen to be taken. The current regulations as written do not explicitly indicate how the navigator should behave. They are limited to the following:

-the regulations indicate some of the factors that should be considered for vessel navigation and collision avoidance;

-in some instances they assign responsibility to one vessel for keeping out of the way of the other, and in one instance they describe the sense of course alteration for both vessels;

-in some instances they proscribe manoeuvres.

The regulations themselves do not entail a complete rule-base. They lack various instructions which include:

-a strict definition of risk of collision;

-the sense of course alteration in many cases;

-the extent of course or speed alteration;

-the timing of course or speed alteration.

In law the ordinary practice of seamen is deemed to cover the detail of the "missing parts".

In practice the mariner must interpret undefined phrases in the regulations. The interpretation is affected by the training and experience of the mariner. A mariner's training, in college, may have exposed him to some pertinent case law, and at sea, exposed him to the accepted practice of his more experienced contemporaries. A mariner's experience of collision avoidance will affect his conception of safety.

2.7.5.2 The mariner and the law

In law, the "missing parts" of the collision regulations are given quantification when cases of collision come to court. Inspection of case law will show what is an acceptable passing distance, for risk of collision not to exist, in a particular set of circumstances. The distance will vary depending on the circumstances, but it will not vary depending on the particular mariner being tried. There are absolute values for risk of collision and by these the mariner will be judged. The same argument applies to the point at which manoeuvres are to be made.

In court, the effect of circumstantial variables are considered retrospectively to one particular collision. The deliberation is carried out by several men with advisors, over a period of hours or days. At sea, to comply with the law, the individual mariner must make a correct judgement as to the effect of the circumstantial variables, on-line, over a period of minutes.

2.7.5.3 An absolute rule system

The generality of rules has caused Schauer[23] to note that "...accepting a regime of rules necessitates tolerating some number of wrong results - results other than those which would have been reached by the direct and correct application of the substantive justifications undergirding the rule". The current regulations imply this limitation of rules and yet will not accept a number of wrong results.

Rule 2(a) states that "Nothing in these rules shall exonerate any vessel, or the owner, master or crew thereof, from the consequences of any neglect to comply with these Rules or of the neglect of any precaution which may be required by the ordinary practice of seamen, or by the circumstances of the case".

Rule 2(b) states that "In construing and complying with these Rules due regard shall be had to all dangers of navigation and collision and to any special circumstances, including the limitations of the vessels involved, which may make a departure from these Rules necessary to avoid immediate danger".

Rule 2 makes it clear that the mariner is required to know when the general rules are going to give Schauer's wrong result, and act upon that in order to avoid collision. The mariner is also required to find a solution to the collision avoidance problem in all "special circumstances". The regulations appear not to give the mariner any reprieve in the event of collision.

The COLREGS are worded and constructed such that in the event of a collision the judicial system can find the mariner at fault. Human error or incompetence is the apparent reason for the collision. This concept of guilt regardless of circumstances, presents a high level of personal accountability, and is laudable in that it probably promotes a high level of personal responsibility. However, this approach has been criticised for inhibiting the use of regulations to truly aid the mariner. The regulations have been described as being drawn up to suit the purposes of lawyers rather than mariners, distinguishing responsibility for collision rather than maximising operational guidance.

2.8 SUMMARY AND CONCLUSION

Prediction of collision has three influencing factors: interaction; prediction accuracy and uncertainty. Risk of collision is defined as the state when action to avoid collision is necessary. The idea of acceptable risk indicates that risk cannot be eliminated.

Action to avoid collision has been described in terms of sight-line rotation. The ability to force sight-line rotation lies with faster and/or more manoeuvrable vessels. General practice requires manoeuvres to be complementary. Three strategies for complementary action have been identified. Natural principles appear limited in their ability to achieve complementary action.

An examination of the complementary action strategies indicates that none offers a general solution. In the face of an apparent rogue, anti-strategy escape action may be necessary.

A consideration of possible rogue types shows that apparent rogue behaviour may be minimised by attaining a mutual perception of three aspects of an encounter. The "coordination requirements" are for vessels to have a mutual perception of: risk of collision; the strategy to be applied, and when manoeuvres are to be made.

Tacit agreement is recognised as the coordination solution which envelopes formal rules. The use of rules to achieve the mutual perception of the coordination requirements is considered. The enforcement of a fixed value for risk of collision or when manoeuvres are to be made demands a spread of conceptions across the population of mariners to be melted into one. A mutual perception of the strategy to be applied requires that rules distinguish between encounters with different strategy requirements. Rules must also be robust over likely misperceptions.

Limitations of the simple strategy rules are clear when encounters involve more than two vessels or confined waters. Rules which can be successfully applied in all circumstances would be infinitely complex. A compromise is necessary between rule complexity and ease of application.

Major inputs required by the COLREGS 72 have been identified. The COLREGS 72 do not meet the coordination requirements of providing a mutual perception of risk of collision or when manoeuvres are to be made. The present regulations do consider strategy although they are incomplete and are not always robust across rule boundaries. In one instance they promote non-complementary manoeuvres.

The COLREGS 72 and present judiciary imply that nothing in the rules will be a defence of the mariner in the event of a collision. The regulations and judicial system appear as an absolute rule-base, being suitable for application in all circumstances. The mariner may be held responsible for collision in any case.

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CHAPTER 3

AN EXAMINATION OF THE AVAILABLE AND DEVELOPING TECHNOLOGY WHICH MAY BE APPLIED TO THE COLLISION AVOIDANCE PROBLEM.

3.1 INTRODUCTION

This chapter considers the technology which may support or make up a collision avoidance system. Technology will be discussed in terms of sensors and processors. The chapter is divided into sections considering the human machine; machine sensors; machine processors and general supporting technology. Technological scenarios for an automatic collision avoidance system will be considered. Consideration will be given to likely political-technological development.

3.2 A COLLISION AVOIDANCE SYSTEM

Marine collision avoidance has hitherto been considered as a manual task, with the human watchkeeper using various technological tools as aids to the operation. This thesis considers the possibility of automatic collision avoidance, using no human input at all. The familiar model of the human watchkeeper, surrounded by his aids to navigation, may not bear analytical comparison with a model of an automatic system.

A simple conceptual model of a collision avoidance system (CAS) has been devised which should encompass the elements of both manual and automatic operation. A deeper examination may indicate that reality is more complex than the model. For our initial purposes the model is adequate, providing form for collision avoidance systems whatever their nature.

In general a system exists within an environment. For the system to interact within the environment it must have a sensor element which will create data from the environment. It must also have a control element with which to input a change to the environment. Between the sensor and control, data will be processed in some way by a processor element.

Environment → | Sensor → Processor → Control | → Environment

Fig.3.1
Conceptual model of a collision avoidance system
Source: Author

At a simple level the collision avoidance system consists of the human eye sensor, the human brain processor, and a rudder angle alteration control. In this thesis we are concerned with the sensor and processor. The main task of the control functions, altering course and adjusting speed, are already highly automated on many ships, and are suitable for overall automatic operation.

3.3 THE HUMAN MACHINE

Sensors

3.3.1 The human eye

Seeing is the physical recording of the pattern of light energy received from the surrounding world.[1] The process of human vision is effortless, and yet for most people it provides the input by which to create a model of the outside world. It should be noted however that seeing is only the use of the eye as a sensor, giving distorted two dimensional images. Vision involves the processing of this data by the brain, giving an interpretation of what we see. The human brain is the primary organ of vision. The ease by which the eye sensor gathers information has made it fundamental to collision avoidance.

Visual target detection is dependent on electromagnetic radiation (in the visual spectrum) reflected or radiated from a vessel, reaching the eye. Daylight is reflected from effectively all bodies. At night there is less if any, natural light to be reflected, making visual detection less likely. Artificial light may be reflected from bodies, or radiated directly from lamps.

Having left the target the light must travel to the eye. Unless travelling in a vacuum the light will suffer some form of attenuation increasing with distance. The further the target, the more the signal will be degraded. In practice, good atmospheric conditions will allow a target to be perceived at the geometrical limit of line of sight.

Atmospheric conditions become degraded as aerosols become more prevalent. Aerosols such as small water droplets, fog and mist; larger water droplets, rain, hail and snow; and sand, all attenuate the light signal. Aerosols may absorb and scatter the light before it reaches the eye, preventing visual perception.

3.3.2 The human ear

Hearing is the physical collecting of ambient sound energy. The ear is the human sensor for sound energy. Like light the sound signal is attenuated over distance. In practice the appreciation of sound is limited due to the relatively small distances over which it can travel without significant distortion. The direction of a sound source is also difficult to ascertain with accuracy. In collision avoidance sound as an input is limited to specific signals made under convention by vessels, and voice reception from other vessels via radio communication.

Processor

3.3.3 The human brain

The human brain is central to controlling almost all human activity and is party to the very sense of consciousness and being. This organ is complex and its processes are only partially understood. The inputs and outputs of the brain are electrical and chemical signals. For our purposes the brain's actions will be considered in terms of the result of its actions, rather than the mechanism of the action itself.

3.3.3.1 Vision

As stated above, vision is a function of the brain processor. Light initiates a reaction by cells in the eye which is interpreted by the brain, presenting some concept of the outside environment. For the purpose of collision avoidance, vision involves the detection and non-detection of other vessels. If a vessel is detected then it may have relevant attributes which can be recognised. These include aspect; type, size, colour; special shape signals, and lights at night. Vision is also used for sensing the data provided by machine sensors and processors.

3.3.3.2 Intelligence and reasoning

A collision avoidance system requires a processing element. In the manual system the human brain is the primary processor. The brain exhibits the concept of intelligence, perhaps the highest level of processing. Although intelligence has a dictionary definition it has no agreed scientific meaning and is not described by quantitative natural laws.

The capabilities that may be expected through intelligence have been described by Fischler and Firschein[2] in the following list.

> "<u>Attributes of an intelligent agent</u>
> We expect an intelligent agent to be able to:
> - Have mental attitudes (beliefs, desires, and intentions)
> - Learn (ability to acquire new knowledge)
> - Solve problems, including the ability to break complex problems into smaller parts
> - Understand, including the ability to make sense out of ambiguous or contradictory information
> - Plan and predict the consequences of contemplated actions, including the ability to compare and evaluate alternatives
> - Know the limits of its knowledge and abilities
> - Draw distinctions between situations despite similarities
> - Be original, synthesize new concepts and ideas, and acquire and employ analogies
> - Generalise (find a common underlying pattern in superficially distinct situations)
> - Perceive and model the external world
> - Understand and use language and related symbolic tools".

Given what appears to be a most comprehensive list of capabilities, it is at first sight difficult to conceive what the intelligent agent could not do. What the list does not imply is the standard or level of the abilities. The list does recognise that there may be limits to knowledge and abilities. An intelligent agent only has to give an example of the attribute, not show success in all applications of the attribute.

Whether the human has intelligence attributes to the level which will achieve collision avoidance will depend on the detail of the collision avoidance scenario. On the whole, under current conditions, it appears that the human mariner is successful in avoiding collision. Collisions do occur however and a contributory cause may be inadequate processing ability.

3.3.3.3 Learning

A particularly significant aspect of human intelligent behaviour is the ability to learn. The human brain appears to be able to modify behaviour according to experience. This means that the human processor can constantly evolve, adapting itself in order to be successful in its environment.

3.3.3.4 Biological vulnerability

The functioning of the human brain and therefore the level of operational intelligence may be affected by chemical and electrical signals received at the brain. Signals may be induced from pain, stress, fatigue, illness and disease, and drugs. Some drugs may, at least in the short term, enhance the brain functioning. Most other factors, including other drugs tend to detract from the brain's ability. The variability of human operational intelligence creates the chance of a usually adequate watchkeeper making an inadequate decision.

3.4 MACHINE SENSORS

3.4.1 Primary Radar

Primary radar(radar) is compulsory on merchant vessels greater than 1600 GRT[3]. Target range and bearing may be obtained by the reception of a transmitted signal which is subsequently reflected from the target. Detection by radar is not always possible.

The detection of a target by radar is not guaranteed for various reasons. The transmitted signal must make it back to the scanner. During travel between scanner, target, and back to scanner, the signal may be attenuated by various aerosols, particularly rain.

The signal will be diminished as it is reflected from a target. For a target with poor reflecting properties the signal returned may reduce to zero. Signal reflection depends on the aspect presented, shape, texture, material and size of the target. Large metal vessels generally make better radar targets than small wooden or plastic craft.

Having returned to the scanner the signal will register. However for the return to be recognised as a target it has to be discernible from other returns known as clutter. Clutter is the name for unwanted random echoes. Sea clutter is caused by radar reflection from sea waves and is most prevalent to windward near to the vessel. Clutter by precipitation, particularly rain, forms as random echoes on the screen, wherever rain is falling. In any type of clutter, despite filtering techniques, a target with a weak response may not be detected at all.

3.4.1.1 Radar image processing

A simple radar image processing technique has been reported on by Japanese researchers. An attempt to estimate gross tonnage, shape and aspect of radar targets was made. It was reported that the aspects of vessels could be ascertained with "relative certainty".[4]

3.4.2 Vhf RT

3.4.2.1 Voice

Very high frequency radio telephone (vhf RT) allows voice communication between suitably equipped vessels. Communication range under normal atmospheric conditions is usually line of sight of aerials. This technology has the potential to allow an interactive exchange of data between vessels. The vessels may confirm each others perception of the situation and discuss and agree what action is to be taken. However there are several operational limitations to the general use of this sensor.

It is not always possible to determine with certainty that the vessel which is observed is the same as that which is responding to a vhf RT communication. Vessel identification is simple when reference can be made to a mutually perceived reference point such as a buoy. This explains the successful and everyday use of vhf RT in buoyed rivers and port approaches and in particular the Great Lakes, USA. When in more open waters, it may not possible to confirm the identity of an observed target. In this case a vhf RT communication has the potential to be misleading and dangerous. The United Kingdom Government Merchant Shipping Notice (M.845) warns of this problem.

Language comprehension is another limitation for verbal communication in an international setting. Successful vhf RT communication also needs both parties to be cooperative. Both must have suitable equipment and both must be using it correctly.

3.4.2.2 Data

Digital Selective Calling (DSC) techniques allow efficient communication of data on vhf RT frequencies. Particular recipients may be automatically addressed, giving a level of security. Communication speeds are much quicker than voice for comparable levels of information. This relieves pressure on the finite capacity of radio frequencies.

3.4.3 Satellite communications

Voice and data transmissions may be made through satellite communications systems. Communication is limited only by line of sight of terrestrial aerial to satellite to terrestrial aerial.

Coverage by Inmarsat geostationary satellites is up to 70° latitude. Transmission times are almost immediate and free of interference.

3.4.4 Automatic cooperative communications

Automatic cooperative communication(ACC) is defined as the automatic exchange of information between parties. The concept of automatic identification of vessels has long been muted. The proponents of this concept have indicated benefits for collision avoidance and efficient Vessel Traffic Services(VTS). It is for the sake of improved VTS capability that automatic information exchange is now becoming a reality in specific localities. Discussion is currently concerned with the wider application of such technology to aid all appropriate aspects of maritime safety.

3.4.4.1 VTS and ADS

Recent stranding incidents [EXON VALDEZ, BRAER[5]] and "hit and run" collisions [OCEAN HOUND[6]] have caused public discussion about the requirement for an efficient ship reporting scheme. The expansion of VTS as a tool to aid vessel safety requires commensurate improvements to the traffic image that is presently available[7]. The concept of ADS(Automatic Dependent Surveillance) provides the appropriate improvement.

ADS is a conceptual name for a system which will monitor the movements of vessels. The vessel automatically transmits its identity; course; speed; position and other information to a Marine Traffic Control centre. In Valdez, Alaska, ADS is being installed for the monitoring of tankers in Prince William Sound.[8] Trials of an Automatic Vessel Monitoring System are being carried out by the Swedish Maritime Administration[9,10].

The technical specification of particular systems varies. The positioning element is usually provided by GPS. Communications can be achieved through the space segment giving world-wide coverage or by terrestrial means depending on operational requirements. The actual data which is communicated appears to be at least vessel identity and position.

3.4.4.2 ADS technology for automatic ship to ship communication

The type of technology which underpins ADS could equally be applied to effect automatic communication directly between vessels. The system tested by the Swedish Maritime Administration allows ship to ship as well as ship to shore data exchange.

3.4.4.3 Radar transponders for automatic ship to ship communication

The earliest calls for the automatic identification of vessels were made with radar transponders in mind. Developed in the 1939-45 war, interrogation friend or foe (IFF) transponders were first used to identify "friendly" aircraft from less cooperative targets. This system required very large radar scanners and sophisticated radar processing equipment for the shore based stations. It is considered that the system is unsuitable for ship to ship use because of its limited capacity and does not allow data transfer other than identification. The expense of shore stations and the "environmental eyesore" of the large aerials makes this an unlikely candidate even for simple ship to shore identification.[11]

A more probable system would have secondary radar transponders operating with a dedicated channel between the accepted maritime radar bands.[12,13] This type of system appears to have suitable capacity although data transfer is, as with IFF, limited. Shore based surveillance costs using such technology may be prohibitive.[14]

The use of modified search and rescue transponders is being considered. Data transfer will be limited as with the other radar based systems.[15]

3.4.4.4 Scope of application

The application of an automatic cooperative communication system is dependent on political factors. Successful implementation of a system requires a policy which ensures the carriage of commensurate equipment on board participating vessels. For general collision avoidance the nature of shipping requires that policy formulation is by international agreement.

At present it is commonly assumed that not all craft would be expected or required to participate in "the" system. It may be thought unnecessary, impractical or impossible for small craft, yachts, fishing vessels or primitive vessels to be equipped. These assumptions may not be true in the future or the present.

Necessity

The present demand for identification and monitoring systems stems from large ship strandings and "hit and run" collisions. This evidence leads to the call for larger vessels and vessels with environmentally sensitive cargoes to be participants of the communication system. If however the technology is to be extended to include ship to ship communication for the benefit of general collision avoidance, then it is necessary to include as many craft as possible.

Possibility

Whether it is physically possible to install a system on a particular craft depends on the specific technology in use. The problems associated with small low tech craft are that of available space, and providing a dry environment and electrical power. The proliferation of portable and even hand-held equipment indicates that these problems are no longer fundamental.

Practicality

Given that it is physically possible to install the system on a small craft, it remains to consider whether craft owners and operators could be persuaded, or forced, to install and use the equipment. Many small craft already carry the component parts of a potential system; vhf RT and an electronic positioning system. GPS is likely to attract the massive land market making the basic technology low cost to manufacture. Given a statutory requirement the market for the whole sea-borne system will be great. The cost of a basic version of the user equipment is likely to be commensurate with commonly carried existing instruments. Even if the cost of equipment remained a barrier to small craft users a solution may exist in government subsidies "for the common good" or with equipment hiring arrangements. The policing of a statutory carriage requirement would be simple because rogue vessels would not be indicating a transponder signal.

3.4.4.5 General benefits and opportunities

The benefits of such technology would depend on the specifics of the system. The ability for vessels to share and exchange information on-line at sea may revolutionise the nature of the collision avoidance operation. The way would be open to use Cannel's "specific agreement" solution to the coordination problem (2.4.6.2).

The information required for the sake of VTS operations may be similar to that wanted to aid collision avoidance. Vessel position is essential for both operations. Vessel identification, course and speed, vessel manoeuvre actions and vessel classification (as per collision regulations) are useful. A sophisticated benefit of automatic information exchange is the potential to be always able to indicate and agree action.

Action might be indicated by transmitting rate of turn information as measured on the vessel. The ability to agree to specific action or to agree a common perception of the situation might relegate the collision regulations along with their inevitable weaknesses to limbo. Misperception due to the inevitable accuracy limitations of individual measurements would be irrelevant if specific agreement could be made. It could be possible to meet all coordination requirements (2.4.5) in all circumstances.

3.4.5 Machine vision

The fundamental role of vision in so many human operations has driven research to mimic human vision. In collision avoidance the aim may be to extract the equivalent information as is obtained through human vision (3.3.3.1). An attempt to do this has been made although the level of success was not reported.[16] In general the progress made in machine vision has been slower that anticipated by early workers. It has been realised that vision is part of intelligent processing, bringing with it all the complex issues that surround intelligence. "...vision poses such difficult problems that AI (sic Artificial Intelligence) today is much closer to developing systems which could serve as physicians or lawyers than to building robots that could replace gardeners or cooks."[17]

3.5 MACHINE PROCESSORS

Machine processors may play the role of primary or sub-processor in a collision avoidance system. The primary processor is involved with the final decision sent to the control mechanism. A sub-processor will present data/information to the primary processor. Automatic radar plotting aids (ARPA) and an advisory expert system are sub processors. Automatic expert systems and the human brain are primary processors.

3.5.1 Automatic radar plotting aids

The systematic plotting of target range and bearing allows information to be created. Simple relative plotting gives the relative track of the target. This allows the closest point of approach (cpa) of the target to be identified and measured, and the time to the cpa (tcpa) to be measured. The addition of own vessel course and speed during the plotting period, allows the target heading, speed and aspect to be calculated. This process has been automated by the development of the ARPA.

ARPA can acquire and track many targets at once, maintaining an accuracy far higher than that of manual operation. However it is inherent in the plotting method, manual or automatic, that the result is based on historic data. If either vessel manoeuvres, particularly the target vessel, then the processed information data becomes more inaccurate, suffering a time lag which will diminish only after both vessels have had a steady velocity for a few minutes.

The use of ARPA is increasingly common on commercial vessels. Development in processor technology has made equipment smaller and more affordable. In the near future the installation of ARPA will become practical on all vessels which currently carry radar.

3.5.2 Expert systems

"An expert system uses a compilation of knowledge of one or more expert persons and through a computer program, performs the decision making as if the expert person were actually performing the task".[18] This branch of artificial intelligence (AI) has been applied to collision avoidance by several parties.[19,20,21,22,23,24] So called expert watchkeeper behaviour has been modelled by the computer program. The expert system aims to produce expert behaviour solutions to the collision avoidance problem.

Early work in the general field of expert systems produced programs for identifying molecular compounds from analytical data (DENDRAL); choosing appropriate anti-bacterial treatment given patient symptoms (MYCIN), and evaluating probable mineral ore potential given geological data (PROSPECTOR).[25] These consulting type systems had data entered to them manually. The data being input would not change within the time that it took to produce an answer. A collision avoidance expert system must work on-line receiving a constant stream of data. In order for the system to work effectively, machine sensors are used to continuously input relevant data.

Although expert systems have been classed as artificial intelligence they do not exhibit all the attributes of an intelligent agent(3.3.3.2). Expert systems are domain dependent and limited in their field of usefulness. Expert systems as they are currently constructed are restricted to operating with the knowledge embedded in their program; they do not have the ability to acquire new knowledge or learn new skills and techniques. They may be powerful in their field but remain strictly finite in application.

3.5.2.1 Advisory expert systems

A prototype expert system for pilotage has been developed.[26] Most expert systems written for collision avoidance have been "marketed" as advisory systems. This mode of use would present the human watchkeeper with collision avoidance advice probably via a computer screen. The advisory mode of operation is attractive because it might be implemented as an aid to navigation without reference to legal constraints. Responsibility is supposed to remain with the watchkeeper, deferring limitations of the machine sensors, which feed the expert system.

Although appearing to offer the abilities of both man and machine the advisory system scenario will have problems when trying to combine the abilities of man and machine. If the machine recommends a manoeuvre which does not concur with the man's reckoning then the man must rationalise the two differing ideas. This is an additional task for the human watchkeeper. It may be an impossible task unless the machine manoeuvre is supported by reasoning in human reasoning terms. The expert system does not reason in the same way as the human; "In our current state of knowledge, we know as much (or as little) about the reasoning in the brain as we do about the location and functioning of the human soul".[27] This aspect of advisory systems requires further investigation. There may be a place for advisory systems, but the information and the way in which it is presented, will be critical to successful use.

3.5.2.2 Automatic expert systems

The automatic expert system will automatically activate any control function required. No human input is involved.

3.5.3 Artificial intelligence

When discussing intelligence in the case of the human (3.3.3.2), it was noted that a simple definition of intelligence was not available. As artificial intelligence might have the same defining features of human intelligence albeit without the human, the absence of a simple definition remains. Intelligence appears to be a principal characteristic of human behaviour. The ability to recreate such a phenomenon is expected to be one of fascination. But despite undoubted interest and resources being directed to this field results have been limited.

All early work in AI was domain specific. Domain specific programs are typified by expert systems as already discussed. They may show success in emulating apparently intelligent human behaviour, solving often complex problems. They are also limited to a narrow field or domain. The latest generation of chess computers are now regularly beating the best human chess players. But apply the chess machine to deciding when it is safe to cross the road, or how to get to the chip shop, and it will be useless. The machine lacks a form of common sense.

The need to give AI machines some form of common sense has been recognised for many years. In 1960 a prospectus for a machine named "advice taker" was published. "...the advice taker will have available to it a fairly wide class of immediate logical consequences of anything it is told and its previous knowledge. This property is expected to have much in common with what makes us describe certain humans as having common sense".[28] Twenty eight years later in 1988, the original writer commented, "The advice taker prospectus, ambitious in 1960, would be considered ambitious even today and is still far from being immediately realisable".[29] It appears that the machine with common sense eludes us, and that we are domain dependent for now.

If a program were truly domain independent it would probably meet the list of "attributes of an intelligent agent". Given there is no simple definition of intelligence it is no wonder that there is as yet no truly artificial intelligence. This may relieve devout theologians and remain a puzzle for philosophers.

3.5.3.1 Machine learning

The artificially intelligent machine is significantly different to the knowledge based expert system by way of its ability to learn. Where as the expert system performance is fixed, the learning facility of the intelligent system results in an evolving, active level of performance.

3.6 GENERAL TECHNOLOGY

3.6.1 GNSS positioning

A Global Navigation Satellite System(GNSS) is highly likely to be the primary source of positioning information for vessels in the future. The United States GPS programme has proven the potential for global coverage with positioning accuracy of metres. Current reservations over reliance on GPS are related to the political control of the system rather than the fundamental technical infrastructure.

GPS is operated by the US Department of Defense primarily as a military system. Concern that military interests would not always be compatible with commercial user interests were realised during the recent Gulf conflict.[30]

The tactical advantage of controlling GPS only exists while the system offers a unique service. The availability of the Russian Federation's GLONASS[31] will diminish the special place of GPS. GLONASS is remarkably similar to GPS offering global coverage and accuracy of a few metres. Integrated GPS/GLONASS receivers are being developed.[32]

There is work currently under way, driven by the aviation industry, to put GNSS firmly in place for international civilian/commercial use and control.[33,34] The cooperation of INMARSAT as a body through which to administer the system is being considered. INMARSAT appear to be active in the satellite navigation arena.[35] A GNSS is highly likely to exist under civilian international control in the future.

GNSS and collision avoidance

Collision avoidance in open waters is concerned with relative positioning of vessels, while in constricted waters it is necessary to also position vessels relative to additional vessels and navigational limits. GNSS could meet the positioning requirements of open and constricted water collision avoidance. This is likely to be the long term source of position data used in automatic cooperative communication systems.

3.6.2 Event recording and reporting

The aviation industry has made use of Flight Data Recorders since the late 1950's and cockpit voice recorders subsequent to this.[36] The automatic recording of various flight parameters and speech in the cockpit, has aided the task of accident investigators. The so called "black box" is designed to survive the effects of most aviation accidents. The replaying of the recorded data can help reconstruct the events and circumstances leading to an accident.

The mandatory carriage of such equipment of marine vessels is yet to materialise despite recent application to one particular fleet.[37] Course recorders have been available for many years, however their use remains arbitrary. The benefits of event recording for accident analysis has been recognised.[38] It is technically possible to collect data automatically from an event recorder by satellite communications.

It is thought that the mandatory carriage of event recorders could have an influence on collision avoidance behaviour. In the event of a collision, or a near miss, or any perceived rule infringement, the facts of the case will be evident from the recordings. At present the facts of an incident are only established when a collision occurs, and then from subjective memories of the officers concerned. An automatic event recorder provides objective truths easily, enabling near misses and rule infringements to be investigated. In the event of objective criteria being encompassed into regulations, proscribed action could be detected automatically. The ability to police inappropriate behaviour in this way is likely to make mariners more compliant with rules.

3.6.3 Simulation for watchkeeper training and examination

The use of navigation simulators for watchkeeper training in collision avoidance and general navigation is well established. Recently, consideration has been given to using the simulator as an examination tool.[39,40] While collision avoidance training may be carried out on a simulator the subsequent examination for certificates of competency has remained a matter of written and oral interrogation. A pilot study for the United States Coast Guard has developed a PC based examination, presenting collision avoidance scenarios, with automatic scoring as an objective. In order to score the candidate's action automatically it is necessary to quantify acceptable collision avoidance parameters in a given circumstance. It is suggested that this is tantamount to giving judicial quantification in the collision regulations.

3.6.3.1 Autonomous targets

Initially in navigation simulators a target's interaction was dependent on on-line instructor input. This limited the number of targets which could be handled in a realistic manner. Software has been developed which allow targets to operate autonomously.[41] This is another example of prior quantification being given to collision avoidance parameters.

3.7 AN AUTOMATIC COLLISION AVOIDANCE SYSTEM

An automatic collision avoidance system (ACAS) by definition involves no on-line human activity. This precludes the use of the elements described in 3.3 "The human machine". The machine sensors and processors which have been described allow us to envisage ACAS which vary in sophistication; the highest order appearing to mimic all human functions. The use of technology in collision avoidance will depend on political and technical development. Figure 3.2 illustrates an estimate of possible political/technical development. A number of ACAS scenarios are described below for consideration in the next chapter.

3.7.1 True artificial intelligence

The highest level of technical development is concerned with true artificial intelligence. AI processing and machine vision may allow machines to mimic human functions. All other technological development is considered subsidiary to AI and is likely to be extant. This scenario is considered as the most extreme and futuristic. Technical progress is slow: the political aspect has not been considered, although this may be the greatest hurdle.

3.7.2.1 Expert systems with future technology (except AI)

Radar image processing is available. Automatic cooperative communications are available. In this scenario ACC is at its most sophisticated allowing intentions and agreements to be made ship to ship. This is the second most futuristic scenario after that of true artificial intelligence. The sophistication of the ACC could be used to supplant the use of rules, moving towards "specific agreement" as a coordination solution.

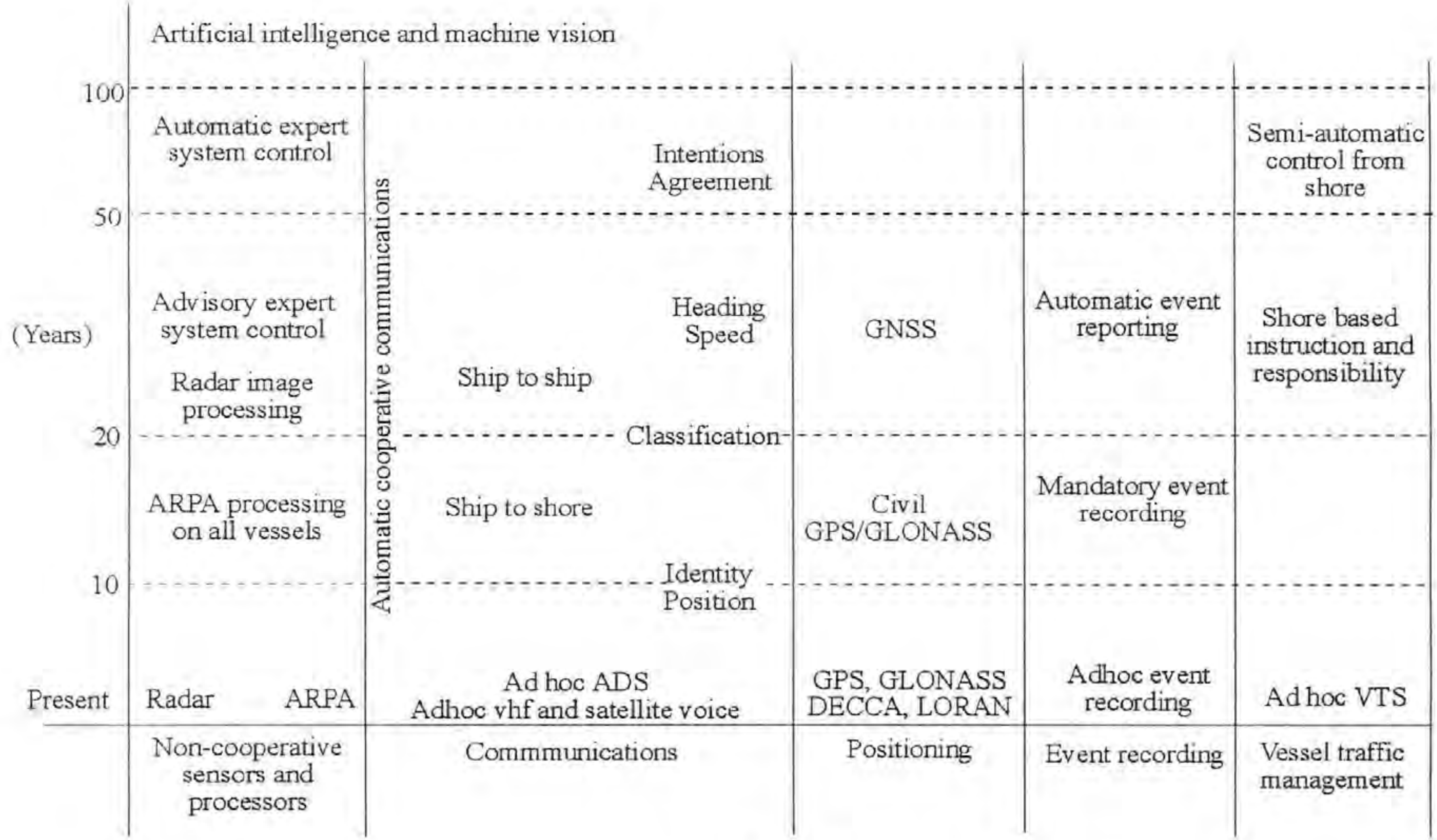

Fig3.2
Political - Technological development : a forecast

Source: Author

3.7.2.2 Expert systems, current technology and basic ACC

This scenario includes current radar and ARPA technology as well a simple ACC system. The ACC allows the communication of vessel position; identity; classification; heading and speed.

3.7.2.3 Expert systems and current technology only

This, the simplest of scenarios, is akin to immediately implementing an automatic expert system, without any advances in supporting technology. Radar and ARPA are available.

3.8 SUMMARY AND CONCLUSION

A collision avoidance system may be considered as having three elements: sensor; processor, and control.

The human "machine" has the eye and ear as sensors, and the brain as a processor. The eye is the sensor which allows the brain to create vision. A target visually detected may have recognisable attributes such as aspect, type, special shape signals, and lights at night. Visual detection may be impaired by fog, mist, rain, hail and airborne snow and sand.

The human brain exhibits the concept of intelligence. This infers a highly sophisticated level of processing. The ability to learn is a particular aspect of intelligence which the human exhibits. The operation of the brain may be adversely affected by pain, stress, fatigue, illness and disease. Drugs can have both beneficial and detrimental effects on the brain's processing ability.

Primary radar is well established for marine use. Range and bearing of targets can be obtained. Small targets, and targets in the presence of rain or steep waves, may not be detected. Experimental work on radar image processing may lead to the instant acquisition of target aspect. ARPA, well established on large vessels, is likely to be available in the near future to any vessel with the capability of carrying a radar.

Vhf RT is commonly used to aid collision avoidance but is limited by the need to identify the target and by language comprehension. Digital selective calling enables efficient data transmission and opens the way for greater user capacity. Satellite communications are developing rapidly. They provide secure, interference free transmission of voice and data. Instant communication is almost global.

The concept of automatic cooperative communications is rapidly becoming a reality. Potential benefits to enhance the traffic image for VTS and collision avoidance are being realised. The actual technology to be used is being debated. Radar transponder type technology is one option although this appears limited in data transfer capacity. Systems using GPS positioning, and vhf RT or satellite DSC communications appear the most likely option. System capability begins with providing target position, increasing in sophistication to identity; classification; heading; speed; intentions and agreement. Future developments may make this type of technology available on all craft.

Machine vision for collision avoidance has been attempted. Success was not reported. It is thought that this technology will only be realised in the long term future along with general truly intelligent machines.

Several parties have applied expert systems to collision avoidance. Expert systems are domain dependent and do not demonstrate true intelligence. The use of expert systems in an advisory mode must deal with the problem of forcing the mariner to rationalise his own and the machine's conflicting opinions.

Despite continual and widespread research, the idea of a truly intelligent machine remains solely a concept for now. An artificially intelligent machine is significantly different from an expert system because of its ability to learn. The expert system's program and ability is fixed, while a learning machine may evolve.

The benefits of world-wide high accuracy instantaneous position fixing have been realised by GPS and GLONASS. The requirements of the aviation industry are likely to drive a civil GNSS to reality. The action by INMARSAT to augment the existing system may be seen as a step in that direction.

Voyage event recorders are not mandatory but are on a limited trial at present. As well as being useful in reconstructing accident events, data could be used to indicate near misses and other rule infringements. This may have an influence on mariner behaviour.

An automatic collision avoidance system may be envisaged in a variety of technological guises. True artificial intelligence including machine vision implies the ability to mimic human behaviour. This scenario is very futuristic. Expert system type processors are more likely to be the processor in the first ACAS.

The level of technology which can support the processor will vary according to technical and political advances. In particular, the extent to which automatic cooperative communication systems are developed, will have considerable effect on the data available to the processor.

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CHAPTER 4

AN EXAMINATION OF THE RELATIONSHIP BETWEEN DATA INPUT AND PROCESSING, AND COLLISION REGULATIONS

4.1 INTRODUCTION

This chapter examines the relationship between data input and processing ability, and collision regulations. In particular the COLREGS 72 will be analysed with respect to current manual operation and the four ACAS scenarios outlined in chapter 3. Analysis of the data input requirements will consider the scenarios concurrently thus:

current manual collision avoidance;

true artificial intelligence (3.7.1);

expert systems with future technology (except AI) (3.7.2.1);

expert systems, current technology and basic ACC (3.7.2.3);

expert systems and current technology only (3.7.2.3).

The processing ability requirements demanded by the COLREGS 72 from the human processor were covered in (2.7.5). This chapter will consider the compatibility of expert system and true artificially intelligent processing with the current collision regulations.

4.2 THE COLLISION AVOIDANCE SYSTEM AND THE RULES

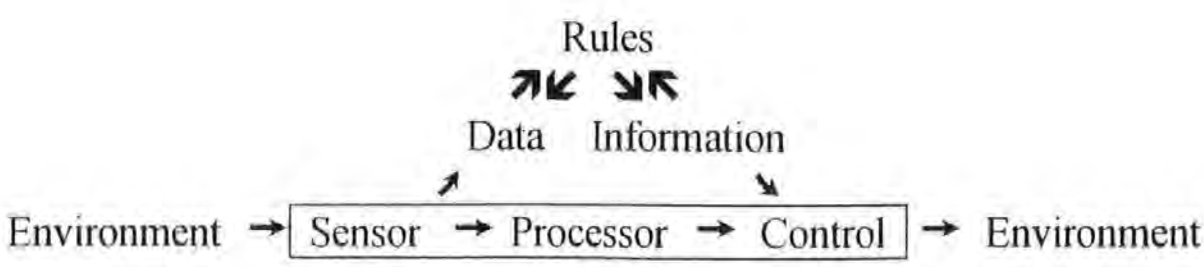

Figure 4.1
The relationship between the collision avoidance system and rules
Source: Author

There is a relationship between the rules governing an operation and the operational technology. The connection between the two has been described in the conceptual model as data and information. Data is provided by the CAS sensor. Information output by the processor represents processing ability. It can be shown that rules have data and information requirements. For a motorist to comply with a speed limit rule he must have as a data input his own speed, and have the processing ability to compare this with the limit. The information produced will instruct the control function to maintain speed or slow down. It is necessary for governing rules and operational technology to be compatible, if the rules are to be effective.

4.3 DATA PROVISION FOR THE COLREGS 72

4.3.1 Current manual collision avoidance

The way in which the technology of current manual operation meets the major COLREGS 72 input requirements is summarised in table 4.1.

	Operational technology			
Major inputs	Human vision	Human processing	Radar	Arpa
Target bearing	✓		✓	
Target heading	✓			(✓)
Target classification	✓			
Target domain				
Target arena				
Own classification		✓		
Own domain		✓		
Own arena		✓		
Existence of visual detection of target	✓			
Existence of visibility restricting phenomena	✓			

Table 4.1
Major inputs of COLREGS 72 against current manual operation

4.3.1.1 Target domain and arena

In chapter 2 it was stated that the COLREGS 72 imply a need to know the target domain and arena. There is however no operational technology which will make that input. In practice the human processor has to make a judgement to quantify the values. The regulations encourage action to "keep well clear" and to be taken "early", in order that the issues are mutually perceived.

4.3.1.2 Own inherent processor knowledge

Own classification, domain and arena are all deemed to be part of the knowledge which is inherent in the processor. Own classification is an integral part of the vessel's operation and will therefore be known to the mariner. Own domain and arena are a product of human processing which defies simple explanation. They are dependent on other input variables, but for practical purposes appear as inherent to the processor.

4.3.1.3 Manual radio communication

Manual radio communications, terrestrial or satellite based, could provide many of the major inputs. It has not however been included as operational technology as shown in Table 4.1. The general use of such communications is not practical due to language and identification problems. It is also considered that such communication is used primarily to reach specific agreement, rather than provide the data for a rule based tacit agreement.

4.3.2 True artificial intelligence

When a truly intelligent machine exists for collision avoidance then all other technology may be assumed to be available. This scenario is illustrated in Table 4.2. Machine vision exists and all the major input requirements could be met. There is no reason why an automatic system of this type could not comply with the present regulations on the grounds of input provision.

Major inputs	Operational technology					
	Radar	Arpa	Machine processor	Automatic Cooperative Communications	Advanced radar	Machine Vision
Target bearing	✓			✓		✓
Target heading		(✓)		✓	✓	✓
Target classification				✓		✓
Target domain				✓		
Target arena				✓		
Own classification			✓			
Own domain			✓			
Own arena			✓			
Existence of visual detection of target						✓
Existence of visibility restricting phenomena						✓

Table 4.2
Major inputs of COLREGS 72 against an automatic system using all potential future technology

4.3.3 Expert systems with future technology (except AI)

To make Table 4.2 reflect this scenario, machine vision must be dropped. Without machine vision it is impossible meet the input requirements concerning visual detection and visibility restricting phenomena. This automatic system could not comply with the current regulations. It could not distinguish between the requirements of Sections II or III.

4.3.4 Expert systems, current technology and basic ACC

To make Table 4.2 reflect this scenario, machine vision and advanced radar must be dropped. Provision of target domain and arena by ACC must also be dropped. Only the most sophisticated version of ACC could provide target domain and arena through a protocol of sharing intentions and making agreements. The ACC in this scenario does provide target bearing and heading, and may also include target classification.

As with the previous scenario the inputs concerning visual detection and visibility restricting phenomena are not met. Target domain and arena are now not available. The ACAS cannot be sure of complying with Rules 16/17 in terms of achieving coordination. This must be judged bearing in mind that neither can the current manual system. If the ACC does not provide target classification, Rule 18 cannot be complied with.

4.3.5 Expert systems and currently operational technology only

This scenario results in several of the major inputs being omitted. Radar provides target bearing. Target heading may be obtained through the plotting of radar echoes as with ARPA, although this is historical data. Target classification is omitted and hence the requirements of Rule 18 cannot be met. As before the lack of visual detection etc. precludes the differentiation between Sections II and III.

4.4 COLREGS 72 RESPONSIBILITIES AND THE PROCESSOR

The COLREGS 72 and accompanying judiciary impose responsibilities on the mariner. It has already been noted (2.7.5.3) that the COLREGS 72 are worded such that the judicial system can always find the mariner at fault in the event of a collision. The "guilty" mariner may be demoted or removed from the watchkeeping population. The merit of this approach to responsibility for the human mariner is not of direct concern for this thesis. However when the human is removed and machine applied then responsibility becomes an issue.

4.4.1 Responsibility and the expert system

The expert system is finite in scope and does not develop in ability. The machine may be expected to follow its program in the same way throughout its life. A machine that will diligently follow its pre-programmed instructions may be tested prior to implementation. The substance of the computer program may be inspected, and the machine itself might be tested for at least the number of encounters which a human mariner would have during a life time at sea. Given success in the tests the machine will be deemed competent and issued with the appropriate certificate. The machine's competence will remain constant throughout its life-time.

Despite being tested to a level of undoubted satisfaction, the machine will not be able to account for all the circumstantial variables which are implied by the COLREGS. The machine's program may be massive but is finite. Action initiated by the machine is limited in useful application by the finite scope of the program.

It is apparent that the machine of limited program is not compatible with the nature of the COLREGS. To use a machine with a strictly limited rule-base in the face of the absolute rule system of the COLREGS would risk a collision which could not be defended in law. Knowingly operating with a machine which could not comply with the law in circumstances which may be encountered, would be to court criminal liability. For the automatic system to be properly used, the COLREGS and supporting judiciary would need to legitimise the machine's limitations. This would require the legal recognition of a discrete rule-base.

4.4.2 Responsibility and artificial intelligence

Whether or not true artificial intelligence created by man is possible, the concept of such can be considered. If a machine can be given the intelligence of man, then does not that machine have the same position as man? Man may create a machine which can learn, in the same way that he can create another human which can learn. The human creation learns and eventually the responsibility for the child's actions move from the creators(parents) to the individual. If the machine creation learns, then responsibility for its actions can move from its creators to the machine itself. The reasons for treating such a machine in the same way as a human, may span from ethical to pragmatic.

The intelligent machine behaves similarly to the human in that competence may be tested for, but the level of competence may subsequently change. The intelligent machine may develop in an unpredictable way, limiting the value of pre-implementation tests. It appears unfair to load the machine's creators with the full weight of responsibility given an inherent unpredictability in the learning process. This is an issue to be addressed for the application of any intelligent machine not only with respect to automatic collision avoidance.

4.5 SUMMARY AND CONCLUSION

It is noted that the current manual collision avoidance system can not obtain the data inputs of target domain and arena which are implied as requirements by the COLREGS 72.

An ACAS which is truly artificially intelligent and has machine vision could comply with the data requirements of the COLREGS 72. The use of an artificially intelligent processor invites debate over the appropriate delegation of responsibility.

The use of an expert system as the processor in an ACAS is not compatible with the COLREGS 72. The COLREGS 72 imply the need for the operator to be held responsible in all circumstances. The expert system type of processor will always be limited by its domain of knowledge. The use of such a machine requires the judicial recognition of the rule-base which makes up the machine's program.

Without machine vision an ACAS cannot provide the input data necessary to distinguish between the need to apply the rules of Section II or III. Only very sophisticated ACC can provide the inputs of target domain and arena as implied by Rules 16/17. An ACAS will only be able to comply with Rule 18 if ACC can provide target classification.

An ACAS implemented with presently available technology in support, would have radar and ARPA only. Such a system could not comply with the COLREGS 72 on several counts. These are on rules concerning: vision and visibility; and target classification. The fact that target heading as provided by ARPA is historical, may preclude the use of rules which use this data input. This would affect Rules 13, 14 and 15.

The relationship between operational technology and governing rules is indicated by the varying compatibility of the COLREGS 72 to the range of ACAS scenarios.

CHAPTER 5

THE DEVELOPMENT OF REGULATIONS FOR SIMULATOR TESTING

5.1 INTRODUCTION

It has been shown that an ACAS without true artificial intelligence cannot comply with the COLREGS 72. New rules would be necessary for the introduction of such a system. Investigation would be needed to determine whether such rules would be compatible with application by human watchkeeper. The human application of rules can be investigated using a navigation simulator. The first stage is to develop the rules which will apply in the simulator tests.

In this chapter a particular technological scenario will be assumed, and general and specific rule criteria will be noted. Previous collision regulation/avoidance work from which new rules might be drawn will be considered. Finally the experimental rule-base and undergirding justifications will be set out.

5.2 TECHNICAL SCENARIO

In Chapter 4 it was apparent that the operational technology and governing regulations needed to be compatible. Before a rule-base is devised the technological scenario must be considered. The technological scenario assumed for the experimental rule-base is as follows: manually and automatically operated vessels operate in the same theatre of operation; the automatic processor is of the knowledge based expert system type; primary radar is available as a sensor.

The reasons for choosing this level of technological fit are several. It is most likely that automatic collision avoidance will exist in the same theatre as manual operation. Even if automation were to become universally applied, the two modes of operation are bound to run concurrently during a transition phase. The present machine sensors are limited to radar. By avoiding the more futuristic technologies it is likely that the scenario will represent a common denominator between vessels. By limiting the technology to that in current use, the effect of the new regulations will not be confused with the effect of new technology, and the existing simulator facilities do not require adaptation for the experiments.

5.3 RULE-BASE CRITERIA

5.3.1 General criteria

There are two criteria which may be applied generally to collision regulations:

-the rules must aid collision avoidance by promoting complementary action;

-the rules must be able to be successfully applied by all vessels in the theatre of operation.

The criteria are derived from ideas concerned with the role of collision regulations and expressed in chapter 2. It is not supposed that the criteria represent some absolute truth or are all encompassing. They do form a presumption from which this argument will develop.

5.3.2 A discrete rule-base and the collision regulations

The discrete rule-base which makes up the machine processor's program must be recognised by the judiciary. This implies that the judiciary sanctions the quantification in the rule-base. Risk of collision, the point of manoeuvre, and sense and scale of manoeuvre would all have to be prescribed and therefore lawful and judicially accepted values for specific cases. If there were no manual collision avoidance, then the machine program and collision regulations could be one in the same. However, regulations for application by the human mariner would be too complex if they attempted to reflect judicial quantification for all circumstances. Regulations which reflect judicial quantification would have to start with the simplest case. This is a two vessel encounter in open water.

5.3.3 Judicial quantification embedded in collision regulations

Given that the COLREGS 72 are almost devoid of quantification it is worth outlining the reasons for including quantification in the regulations. Firstly, judicial quantification form the primary standards against which collision avoidance behaviour will be judged in the event of a collision. The mariner will be judged by the standards, and so it is only proper to indicate what the acceptable standards are, in the regulations, as far as is possible. Secondly, the expert systems will, by definition, operate using the judicial quantification. For simple coordination human behaviour needs to be compatible. Thirdly, the argument for rules to act to aid coordination in general, implies a need to establish a mutual perception of various quantifiable aspects of an encounter.

The argument for not having judicial quantification embedded in the rules is that it cannot account for all circumstances if the regulations are to be kept suitably simple for human application. Problems may occur when the human mariner has to decide when and how not to obey the simple quantification. When faced with a complex encounter, the simple rules may inappropriately influence the mariner's decision making.

5.3.4 Specific criteria

Given a particular scenario, specific criteria can be derived from the general criteria. The technological scenario is that described in chapter 3 and 4 as "expert systems and currently operational technology only". Analysis of this scenario with respect to the COLREGS 72 indicates some criteria.

-rules must not require inputs of specific visual detection

-rules must not require inputs of vessel classification

-rules may require inputs of target range and bearing

It is an arguable point whether judicial quantification is necessary in collision regulations. The consideration of expert system ACAS raises the question, and therefore judicial quantification will be included in these rules. This will allow a preliminary investigation into the practicality of such an approach. The quantification will be aimed at meeting the coordination requirements, and in the first instance aim to be suitable for a two vessel encounter in open water.

-rules should aid a mutual perception of risk of collision

-rules should aid a mutual perception of the strategy to be applied

-rules should aid a mutual perception of when manoeuvres are to be made

Specific criteria on quantification are now established.

-rules must indicate acceptable values for risk of collision

-rules must indicate acceptable manoeuvres

-rules must indicate the acceptable point at which manoeuvres should be made

The use of target heading (as is extensive in the COLREGS 72) is a grey area in this technological scenario, because of differences in the historical derivation of such by plotting and the instantaneous acquisition through vision. The use of target heading will be avoided at this stage.

5.4 PREVIOUS RESEARCH

Previous research and propositions may be drawn on to help make up new regulations. Previous work will be considered under three areas: whether to manoeuvre; when to manoeuvre, and sense and scale of manoeuvres.

5.4.1 Whether to manoeuvre (risk of collision)

If "risk of collision" describes the state when action to avoid collision is necessary, then quantification and a mutual perception of this state must be found.

The predicted distance of closest point of approach (cpa) may be considered as a measure of risk. Cpa is mutual between vessels and therefore, given suitably accurate prediction methods, mutual quantification is possible. Given an agreed risk value of cpa, a mutual perception of risk of collision can be obtained. An agreed cpa can be imagined as forming a circular domain around each vessel. Predicted infringement of the "risk" domain indicates a "risk of collision" situation.

5.4.1.1 Domain shape

Goodwin[1], Fujii[2] and Coldwell[3] used the concept of the ship domain to model and quantify mariner behaviour. Goodwin's domain is defined as "the area about own-ship that a navigator wished to keep free with respect to other ship's and stationary objects". Traffic observation produced a typical domain shown with three sectors (Fig 5.1).

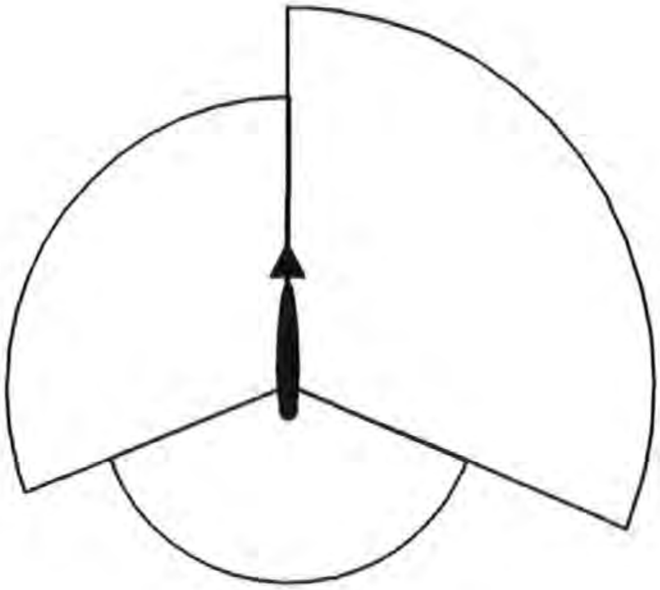

Fig.5.1
Goodwin domain
Source: Author based on Goodwin

Goodwin's domain was modified by Davis[4] for the purpose of computerised traffic modelling (Fig 5.2). The differing sector sizes of Goodwin's domain, and the consequent offset vessel in Davis' circular domain, may be attributed to the effect of the COLREGS on traffic behaviour.

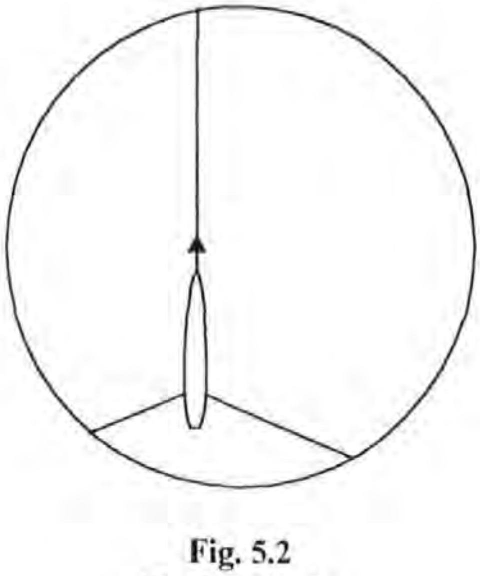

Fig. 5.2
Davis domain
Source: Author based on Davis

Using the asymmetric Davis domain for definition of risk of collision, a non-mutual perception of the encounter may be illustrated Fig.5.3. The relative velocity vectors indicate that one vessel has her domain infringed while the other does not. In this particular case, under the present rules the vessel which considers risk of collision to exist is required to stand-on. This phenomenon of the domain has caused the validity of Goodwin's method of domain construction to be questioned[5]. Goodwin's method of domain construction pretends that the domain area is dependent on relative bearing but not target aspect.

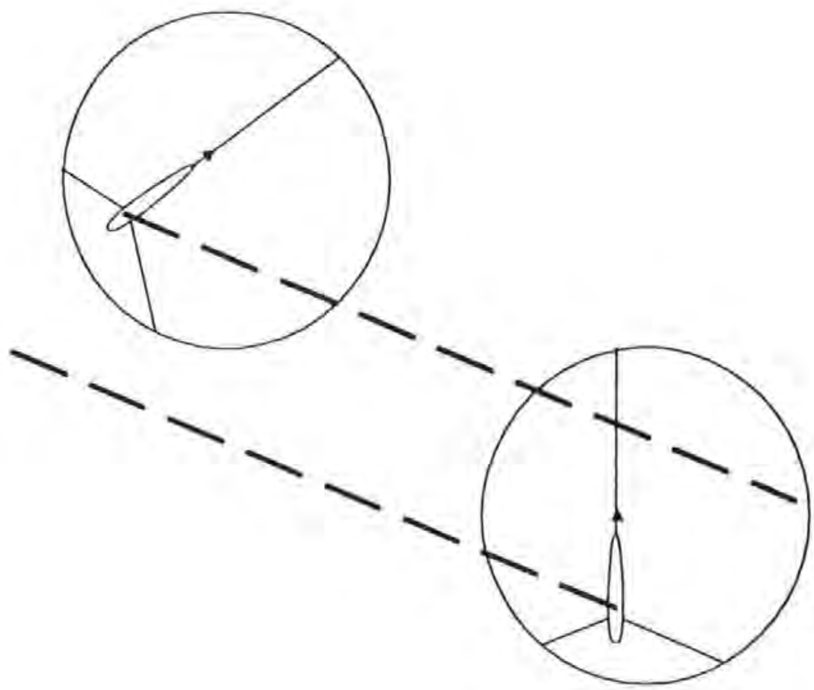

Fig. 5.3
Davis' asymmetric domains give non-mutual assessment of risk
Source: Author

The general use of any asymmetric domains for risk of collision definition is open to non-mutual perception (Fig. 5.4). The circular domain with the vessel at the centre is necessary to give mutual perception. The existence of an asymmetric domain is probably due to the psychological needs of the mariner who faces retribution in the event of a collision. The mariner "needs" to have a greater passing distance for green to green encounters than for red to red because the regulations encourage the latter. A greater passing distance is "needed" when passing ahead because the regulations encourage passing astern. Regulations which encompassed a quantified definition of risk of collision may go some way to meeting the psychological needs of the mariner.

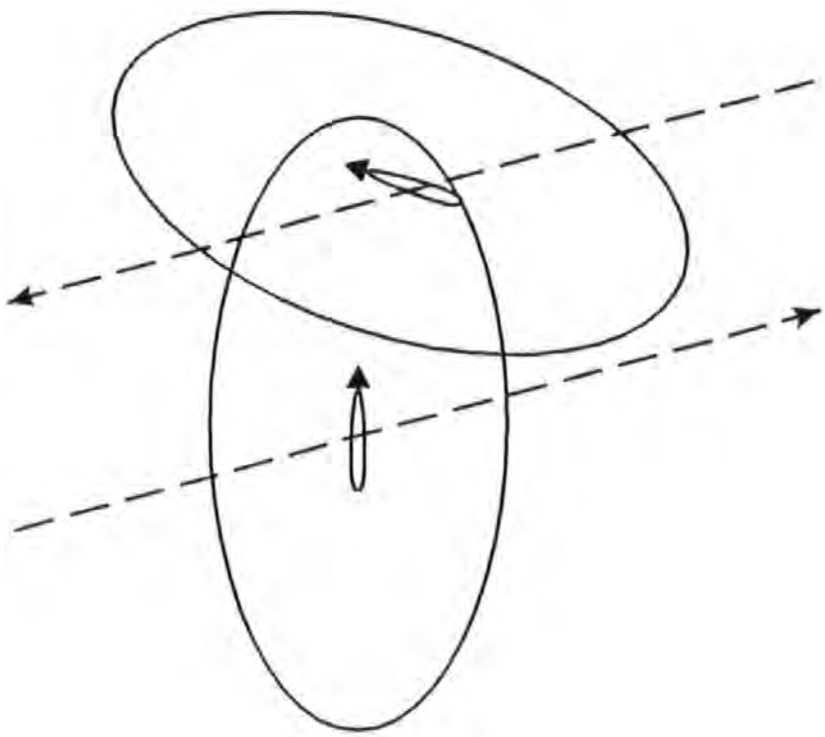

Fig. 5.4
Asymmetrical domains can imply a non-mutual perception of risk
Source: Author

5.4.1.2 Domain size

An agreed size for the symmetrical circular domain is necessary for mutual perception. Natural domain size will vary depending on many factors including the individual mariner, and vessel size. The rule-base domain size must create an acceptable norm from a range of natural behaviour. Safety must be considered against the needs of vessels to make progress on a track.

An acceptable size for the open water two vessel encounter is a matter for investigation. The size chosen for the experimental regulations is one nautical mile(mile). This speculative figure is justified thus. The domain size should be as small as possible so as to minimise disruptions to traffic flow. The minimum value is dependent on the three factors which effect prediction of collision: interaction, accuracy, and uncertainty.

Interaction might have a significant effect at a range of no more than a few hundred metres. Accuracy of prediction methods such as ARPA, are usually within one mile. Casual evidence exists that mariners perceive ARPA as having at least such an accuracy[6]. Uncertainty, while impossible to quantify, must be accounted for. Cahill[7] has suggested a "provisional" definition of close quarters as "...that area around a vessel where a collision with an approaching vessel could not be avoided by the action of the approached vessel alone if the approaching vessel made a major, sudden and unexpected course change". He goes on to consider particular scenarios where a vessel makes a sudden alteration across the head of the other, as if a steering gear failure had occurred. The analysis includes particular ship lengths, breadths, and tactical diameters; speed ratios and assumed speed loss in the turn. "Collision zones" are established which show the positions of the errant vessel at steering gear failure, from which the other cannot avoid collision. Of the examples given almost all the collision zones were within a mile radius of the vessel.

5.4.2 When to manoeuvre

A mutually perceived point at which manoeuvres are to be made might be measured by range and or time.

5.4.2.1 Range

Range of target is mutual between vessels and therefore, given sufficient measurement accuracy and agreed values, a mutual perception of when to manoeuvre can be had. The simplicity of range as a manoeuvre trigger is attractive, however a single value does not reflect differing relative velocities.

Relative velocity is a product of vessels' relative positions, individual speeds, and individual headings. A crude allowance for relative velocity can be made by varying the manoeuvre range with target bearing. In a simple case targets forward of the beam will require action at x, while targets abaft the beam will require action at y, where x>y. This would introduce the stand-on give-way concept, giving precedence to slower targets being overtaken. A more sophisticated example is Davis' arena concept which he created for use in traffic simulation[8]. The arena was circular with own vessel offset from the centre. The arena boundary was asymmetrical relative to own ship heading, which does not give a mutual perception of when to manoeuvre. For a mutual perception with an asymmetrical arena it is necessary to have knowledge of the target's arena. This would need new equipment to illustrate the target arena and is dependent on having accurate target heading. In any case the arena is a crude tool for determining manoeuvre point. The arena considers the relative positions/bearings of vessels but does not encompass vessel headings. Vessel speeds are allowed for only very roughly in that vessels approaching from abaft the beam will in general have a lesser relative speed than vessels approaching from forward of the beam. In order to allow for relative velocity it is necessary to use time as a measurement of when to manoeuvre.

5.4.2.2 Time

The time to go to an identifiable point in an encounter is mutual between vessels. Given suitable measurement accuracy a mutual perception of when to manoeuvre can be had.

A mutually identifiable point in an encounter is the cpa. The time to closest point of approach (tcpa) is a product of radar plotting and readily available to a good accuracy from ARPA. By specifying tcpa's, mutual expectation can be obtained and give-way stand-on responsibilities delimited. Under such a rule, with the cpa at zero, the range at which manoeuvres are made will be directly proportional to the relative speed. The variability of range with relative speed is likely to achieve more agreeable results than a fixed range rule. There are anomalies however at the extremes of relative speed.

With a very high relative speed, say 60 knots, at 12 minutes to collision the vessels will be 12 miles apart. If the vessels are detected and plotted by 12 miles, action in open water is possible. Action at 12 miles in more constricted waters is unlikely to be attractive. A special rule may be needed here.

The difficulty of a low relative speed was recognised by Colley in marine traffic computer simulation[9]. Using a manoeuvring time based on range/range rate, Colley found that when the relative speed(range rate) approached zero, vessels would approach too close before a manoeuvre was triggered. His solution was the range to domain/range rate (RDRR) concept. Measuring the time to a specified domain boundary ensures a minimum distance at which a manoeuvre is required or triggered.

5.4.2.3 RDRR quantification

The experimental rule-base uses the RDRR concept. It remains to quantify and find the most effective balance of range and time elements. Starting with the domain shape and range it should be noted that it is not fundamental for the risk domain to be the same as the manoeuvre domain. That said, logic argues that if vessels can pass just outside the risk domain it is likely to be acceptable for vessels to approach the same domain before a manoeuvre is triggered. The experimental rule-base uses a circular manoeuvre domain with the vessel at the centre (allowing mutual perception) of radius one mile. A small advantage obtained by making risk and manoeuvre domains the same is that the rule-base appears less complex to the mariner.

The time values used in the rule-base have been tested by inspection and give apparently sensible results in many encounters. Full validation would need extensive testing and consideration of the whole rule-base. Values of 18, 12 and 6 minutes have been used. These time markers delineate periods of responsibility. Multiples of 6 minutes are used at this stage for ease of arithmetic, and their typical use in radar plotting, manual and automatic.

5.4.3 Sense and scale of manoeuvre

This part of the rule-base will define the strategy which is to be implemented. For application to an open water scenario manoeuvres are restricted to course changes.

The strategies used in the COLREGS 72 were (i) and (iii) as described in chapter 2. In applying the strategies the COLREGS 72 used concepts of visual detection and vessel classification. As indicated in chapter 3 these concepts cannot be used with this technological scenario. The new rules must be suitable for vessels operating in any state of visibility and the limitations of vessels with restricted manoeuvrability must be catered for. In avoiding the need to know target heading, the rules are restricted to a fixed sight-line rotation sense, strategy (i) (anti-clockwise) being favourite.

There are many rule proposals published, which appear to offer some value[10,11,12,13,14,15,16]. The specific choice at this stage is not critical; the need is to find something to test. The point of considering earlier work is not to put forward some polished article but to avoid reinventing the wheel. All of the manoeuvre diagram-based rules are attractive especially if they contain quantification. The choice for the rule-base is the Royal Institute of Navigation (RIN) working party's manoeuvre diagram[17].

5.4.3.1 RIN manoeuvring diagram

Work by Calvert[18] in 1960 initiated debate over a more mathematically based approach to collision avoidance. A RIN working party which formed in 1970, discussed the practical application of work by Calvert and subsequent authors. A manoeuvring diagram with majority consent was a result (Calvert was a dissenter). The diagram quantifies action according to target relative bearing. Positive action (anti-clockwise rotation) is promoted, i.e. strategy (i). Give-way action is required for targets forward of a line from 112½° through to 292½°. Abaft the line escape action is recommended. The diagram came with accompanying notes which were concerned with resumption of course, escape action and changes of speed. The diagram was broadly compatible with the "not in sight" rules, which emerged later, in the COLREGS 72.

5.5 THE EXPERIMENTAL RULE-BASE

Two sets of rules have been compiled. Appendix A contains RULE-SET A and RULE-SET B, in full, as presented to experiment subjects. The workings of the rules are most easily understood by direct study and will not therefore be described in full here. It is noted that each rule-set is contained on only four pages of A4 including explanatory diagrams. Such conciseness has clear value for operational use, and compares favourably against the current regulations.

5.5.1 Difference between sets A and B

The RULE-SETS are different with respect to the escape action of the vessel standing on for a target abaft the fore/aft boundary line. Both sets require the vessel to stand-on between 18 and 12 minutes before the risk domain is infringed. At 12 minutes the requirements differ.

Rule set A specifies escape action for the stand-on vessel. A choice of standing on or manoeuvring as per the diagram is given between 12 and 6 minutes. At less than 6 minutes action as per the diagram is compulsory.

Rule set B does not specify escape action, although wise words are offered on what should be taken into account when choosing a manoeuvre. The stand-on vessel may manoeuvre or continue to stand-on, as is deemed appropriate by the mariner.

5.5.2 Theoretical effectiveness

5.5.2.1 Manoeuvre diagram

Action taken by both vessels which is compliant with the manoeuvre diagram will, with one exception, result in complementary action. The exception is action for targets bearing from 210° to 292½°. Comparison of the manoeuvring diagram with the Calvert/Hollingdale analysis (Fig.2.1 and Fig. 2.2) indicates that the recommended action will not contribute to positive rotation. However this action will only be necessary when the other vessel has failed in her responsibility to give-way at an earlier stage. In any case the required action will tend to reduce relative speed and presents a minimum aspect to the target. The merit of a specific manoeuvre for escape action is subject to the experimental investigation in this thesis.

5.5.2.2 Vessels restricted in ability to manoeuvre

For most meeting and crossing encounters both vessels have a responsibility to manoeuvre. In theory the rules allow some, if not all, of the burden to be removed from a vessel restricted in her ability to manoeuvre. Vessels which are being overtaken are generally given stand-on precedence. A vessel restricted in her ability to manoeuvre, finding herself overtaking, may often have speed reduction as an option.

5.6 SUMMARY AND CONCLUSION

This chapter has discussed and described the development of collision avoidance rules which were tested in a navigation simulator for human applicability.

A particular technological fit of expert system type processing and primary radar, has been assumed for an ACAS. Justification for having judicial quantification embedded in collision regulations has been given. Specific criteria have been derived for the new rule-base.

Previous research which may be of use in constructing new rules has been considered. Domain theory has been examined with respect to defining a mutual perception of whether to manoeuvre. Achieving a mutual perception of when to manoeuvre involved discussion of range and time as criteria. The superiority of RDRR theory over arenas is noted.

The sense and scale of manoeuvre causes consideration of strategy. Given the technological fit (NB knowledge of target heading is not assumed), only a fixed sight-line sense is acceptable. Much previous work has implied such an approach, and the choice made here is the RIN manoeuvre diagram.

The experimental rules exists as two sets. The differences between the sets concern escape action for stand-on vessels.

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18. ibid 11.

CHAPTER 6

EXPERIMENTAL TESTING OF THE COLLISION AVOIDANCE RULE SETS

6.1 INTRODUCTION

Chapter 5 described the formation of RULE-SETS for experimental testing. This chapter describes the experimental procedure. The elements in the experiment are the navigation simulator; the participating mariners; the individual exercises, and the questionnaire procedure.

6.2 NAVIGATION SIMULATOR

6.2.1 Simulation as a research tool

The operational analysis of marine navigational watchkeeping is hindered by the nature of the subject. Evaluation of real life events requires researchers and or recording equipment to travel with a vessel which in the course of its usual duties may move between ports possibly all around the globe. The time between watchkeeping events (i.e. an encounter with another vessel) may be large. The time between events which are of specific use to the analyst (an encounter with a particular set of circumstances) will be even larger, possibly spanning years. While modern information technologies and communication systems make event recording a more feasible means of data collection, they do not solve all the analyst's problems.

Simulation allows resources to be concentrated solely on significant events. Variables can be controlled allowing event factors to be isolated. The repetition of events is easy, and measurements can be made to a high accuracy.

A particular advantage of simulation over real life is that high risk circumstances may be deliberately examined. Operations may be tested to simulated destruction which would have a prohibitive cost in real life. New operational techniques may be tried and tested. In real life the new operation may be illegal and or as an untested procedure, prove to have disaster potential.

6.2.2 Validity of simulation

Simulation is widely used as a training and research tool in marine industries. The validity of radar simulators for research was considered by Curtis and Barratt[1]. Comparing vessel separations for actual behaviour in the Dover strait with simulator exercises, they found that "mariners can be expected to respond in the same way as the subjects in the tests, given unrestricted sea room". While the study could not indicate that all aspects of mariner response would be the same at sea as in the simulator, it was clear that simulator action does have a relationship with actual behaviour.

In order to create the feeling of attendance on the ship's bridge it has been considered necessary for the simulator to[2]:

"1. display the view from the bridge

2. model realistically the dynamic behaviour of the ship

3. provide a simulated radar and instrumentation package."

6.2.3 University of Plymouth navigation simulator

The simulator used for experiments in this research is the Racal MRNS 9000 as installed at the University of Plymouth. The simulation is in real time, with night time visuals, realistic ship models, and simulated radar, instruments and controls.

6.2.3.1 Ship models

The validity of the mathematical ship models used in the simulation has been considered by Tapp[3]. The specification of the vessels simulated in the exercises are detailed in Appendix B. The vessels are a tanker, container vessel, ferry and jet foil. The jet foil was used in order to achieve a 30 knot speed. The mariners were told that the vessel was a container ship.

6.2.3.2 Bridge instruments

The simulator is equipped with radar and ARPA. A VDU display indicates heading; rudder angle; rate of turn; water log speed; and autopilot demands. Steering by autopilot is through push button control. Hand steering by wheel is also available. Speed control was not available to mariners in the experiments, however it could have been provided by push button or telegraph.

6.2.3.3 ARPA

The ARPA is the Racal Decca 65411. This machine had typical radar and ARPA features. The set had a choice of head up or North up display. Electronic bearing line and variable range marker were available. Automatic plotting could be switched between true or relative mode, and vector length was adjustable to half minute intervals. Cpa and tcpa, target speed and heading were all displayed. A trial manoeuvre facility was available.

For the experiments an overlay indicating the new rule-base "convention" manoeuvres was put around the radar screen. This was valid with respect to target bearing when the radar was operated in head up mode.

6.2.3.4 Visual scene

The visual scene is restricted to night time simulation. Target vessels show lights as prescribed by the COLREGS 72. The arc of visual scene is restricted to 135°. This is from right ahead to 22½° forward of the port and starboard beams.

6.2.3.5 Geographical database

The simulator has a geographical data base against which it positions the vessels. The database includes information which will allow the radar images of land and navigational marks to be generated. This will be compatible with an actual geographical area.

In order to create an open sea simulation the vessels were positioned beyond the edge of data for radar generated land and navigational aids. In the tests no land or targets other than the single target vessel was shown on the radar.

6.3 HUMAN SAMPLE

Sixteen mariners took part in the experiments. Seven were recruited from University staff and students, nine were externally recruited by selected mail shot and word of mouth. One was Canadian, the others British. All were male. To preserve anonymity each was given a code letter.

All subjects held Class 1 certification or equivalent. Twelve had served as master, the remaining four as chief officer. The total sea time of the 16 was 349 years, equating to a mean of almost 22 years per person.

All bar one of the mariners had ARPA experience. The mean ARPA experience for the 15 mariners was just over eight years per person. Experience by ship type was varied. Some individuals had only tanker, or only small general cargo experience. The majority had a wide range of ship type experience. Ship size ranged from 300 grt to 200 000 dwt. Types included container vessels; tankers, oil and gas; bulk carriers; general cargo; reefers; ferries, passenger and RO-RO; frigates; mine-layers and mine-sweepers; tugs; customs cutters; launches, and drill ships.

The time span over which experience was gained is illustrated in Table 6.1. All had operated at sea since the implementation of the last major COLREGS revision (1977). Three had begun their careers before the 1948 conference regulations came into force (1954). All bar two had been at sea within the last five years; 11 of the 16 were employed at sea at the time of the experiments.

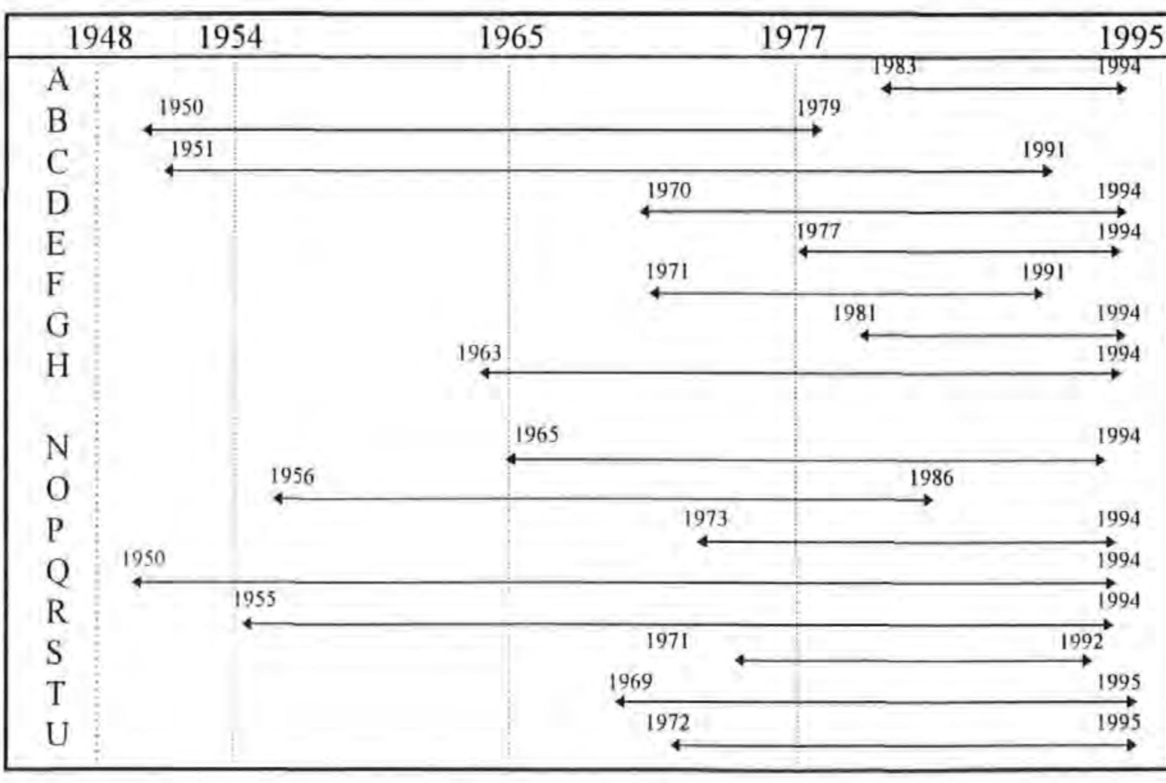

Table 6.1
Sea experience time span of human sample

The experiments in which mariners partook are illustrated in Table 6.2. In some instances it can be seen that two groups exist, each executing different exercises. The groups, where they exist, are mariners ABCDEFGH (A-H) and NOPQRSTU (N-U). Experience by group is as follows.

A-H: Four served as master; four as chief officer. Mean sea time 16.25 years

N-U: All served as master. Mean sea time 27.375 years.

The disparity of experience across the groups was unintentional. It will be borne in mind during analysis when appropriate.

Exercise	Mariners	
1	ABCDEFGH	RSTU
2	ABCDEFGH	-
2X	F	NOPQRSTU
3	ABCDEFGH	RSTU
3R	F	NOPQRSTU
4A	ABCDEFGH	-
4B	-	NOPQRSTU
4R	-	NOPQRSTU
5A	ABCDEFGH	-
5B	-	NOPQRSTU
5R	-	NOPQRSTU
6	ABCDEFGH	NOPQT
7	ABCDEFGH	NOPQT
7R	-	NOPQRSTU

Table 6.2
Mariners participating in exercises

6.4 DESCRIPTION OF EXERCISES

Fourteen different exercises were run. Eight were completely different, there being several with role reversal or different RULE-SET applications. The start conditions for each exercise are tabulated in Appendix C. All exercises are open water, two vessel encounters. The exercises are described below along with the requirements of the rules. The exercises are also described in diagrams showing vessel position and speeds; own domain; relative track of target; and relevant manoeuvre points. All ranges are in nautical miles (M).

6.4.1 Exercise 1

Own ship is a tanker at 10 knots. The target, initially on a bearing of Green 7°, has a similar speed and reciprocal course. The initial closing speed is about 20 knots. The target can be observed visually a few minutes into the exercise.

If no action is taken: the vessels will pass green to green with a cpa of 0.9M.

Rule set requirements: risk of collision exists;
at range <6.4 but >4.5 stand-on or convention manoeuvres only;
by range 4.5 convention manoeuvre is mandatory;
convention manoeuvre is an alteration to starboard of 60° to 90°.

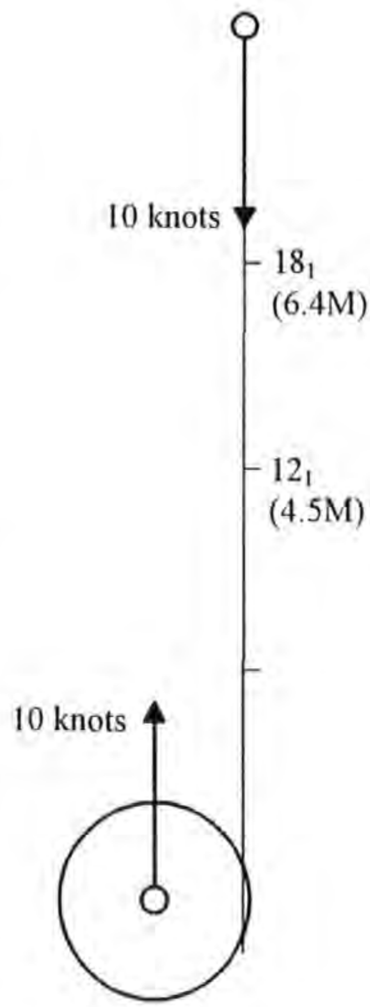

Figure 6.1
Exercise 1
Source: Author

6.4.2 Exercise 2

Own ship is a tanker at 10 knots. The target, initially on a bearing of Green 11°, has a similar speed and reciprocal course. The initial closing speed is about 20 knots. The target can be observed visually a few minutes into the exercise.

If no action is taken: the vessels will pass green to green with a cpa of 1.4M.

Rule set requirements: risk of close quarters exists;

at range <6.6 stand-on or convention manoeuvres only;

convention manoeuvre is an alteration to starboard of 60° to 90°.

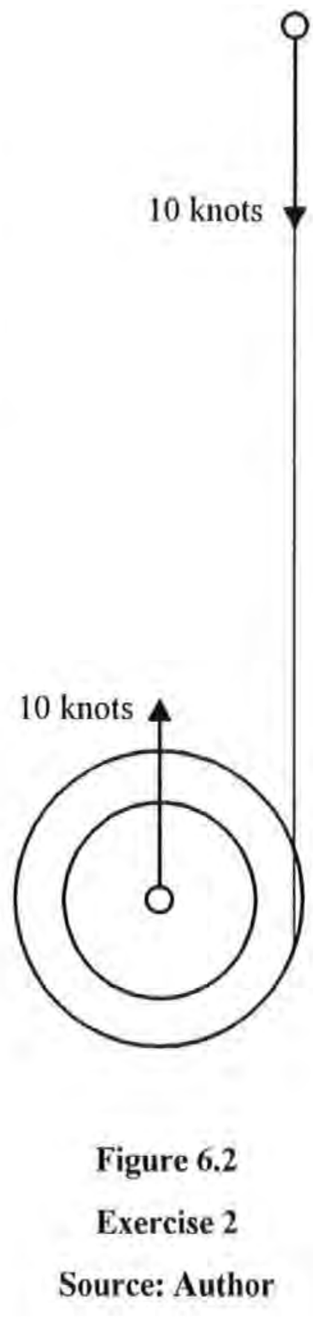

Figure 6.2

Exercise 2

Source: Author

6.4.3 Exercise 2X

Own ship is a container vessel at 21 knots. The target, initially on a bearing of Green 6°, has a speed of 15 knots and reciprocal course. The initial closing speed is about 36 knots. The target can be observed visually a few minutes into the exercise.

If no action is taken: the vessels will pass green to green with a cpa of 1.4M.

Rule set requirements: risk of close quarters exists;

at range <11.4 stand-on or convention manoeuvres only;

convention manoeuvre is an alteration to starboard of 60° to 90°.

Figure 6.3

Exercise 2X

Source: Author

6.4.4 Exercise 3

Own ship is a tanker at 15 knots. The target, initially on a bearing of Green 4°, has a speed of 21 knots and a reciprocal course. The initial closing speed is 36 knots. The target can be observed visually a few minutes into the exercise.

If no action is taken: the vessels will pass green to green with a cpa of 0.9M

Rule set requirements: risk of collision exists;

at range <11.3 but >7.8 stand-on or convention manoeuvres only;

by range 7.8 convention manoeuvre is mandatory;

convention manoeuvre is an alteration to starboard of 60° to 90°.

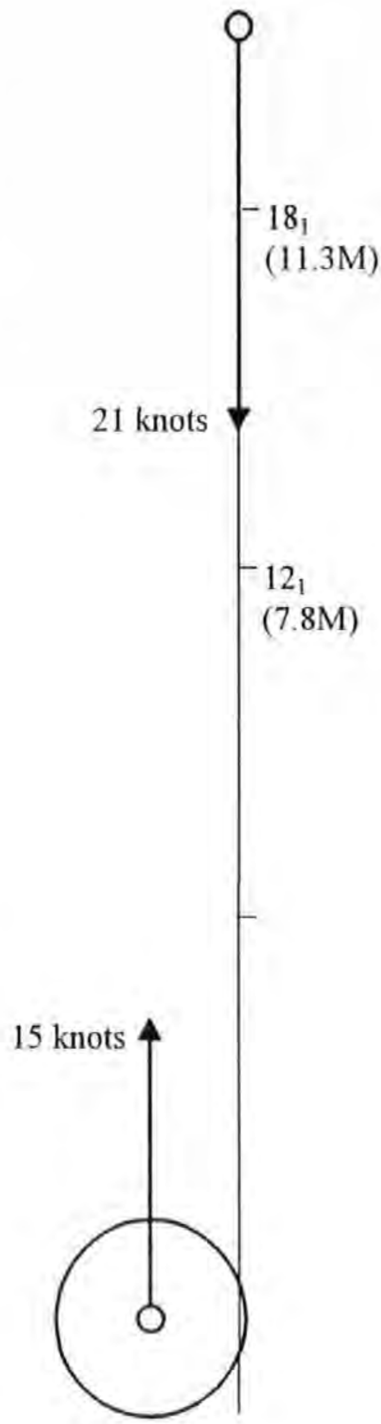

Figure 6.4

Exercise 3

Source: Author

6.4.5 Exercise 3R

Exercise 3R is exercise 3 with roles reversed.

Own ship is a container vessel at 21 knots. The target, initially on a bearing of Green 4°, has a speed of 15 knots and reciprocal course. The initial closing speed is about 36 knots. The target can be observed visually a few minutes into the exercise.

If no action is taken: the vessels will pass green to green with a cpa of 0.9M

Rule set requirements: risk of collision exists;

at range <11.3 but >7.8 stand-on or convention manoeuvres only;

by range 7.8 convention manoeuvre is mandatory;

convention manoeuvre is an alteration to starboard of 60° to 90°.

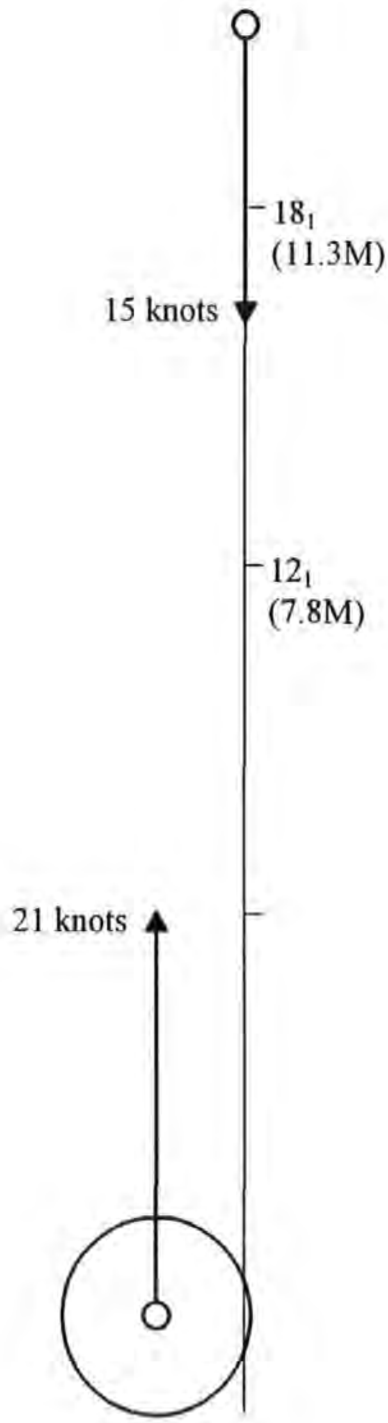

Figure 6.5

Exercise 3R

Source: Author

6.4.6 Exercise 4 (A&B)

Own ship is a tanker at 10 knots. The target, initially on a bearing of Red 127°, has a speed of 30 knots, and a course 42° to the starboard of own course. The initial closing speed is about 23 knots. The target cannot be observed visually.

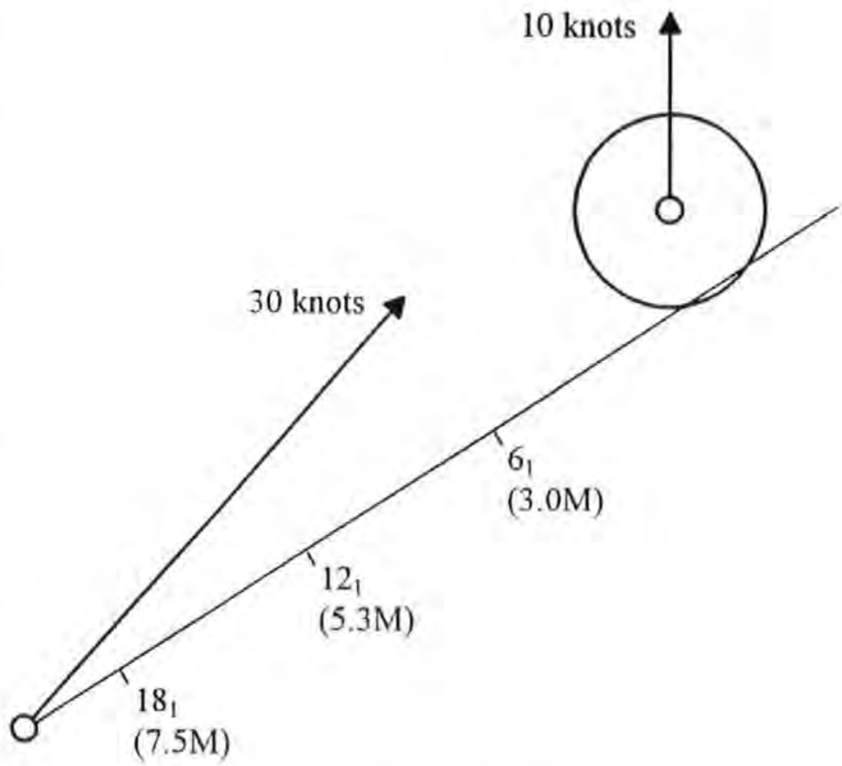

Figure 6.6
Exercise 4 A & B
Source: Author

If no action is taken: the target will pass astern of own, with a cpa of 0.9M occurring on own ship's starboard quarter.

Rule set requirements: risk of collision exists;
at range <7.5 but >5.3 stand-on only;

6.4.6.1 Exercise 4 Rule set (A)

at range <5.3 but >3.0 stand-on or convention manoeuvres only
by range 3.0 convention manoeuvre is mandatory;
convention manoeuvre is an alteration to starboard until the target is astern.

6.4.6.2 Exercise 4 Rule set (B)

at range <5.3 stand-on or convention;
convention manoeuvres are turns to port or starboard at the mariner's discretion.

6.4.7 Exercise 4R

Exercise 4R is exercise 4 with roles reversed. The mariner is told that own ship is a container vessel at 30 knots (in fact the simulator ship model is a jet foil). The target, initially on a bearing of Green 11° has a speed of 10 knots and a course of 42° to the port of own course. The initial closing speed is about 23 knots. The target may be observed visually when the range has decreased to about 3M.

If no action is taken: own ship will pass astern of the target, with a cpa of 0.9M occurring on the target's starboard quarter.

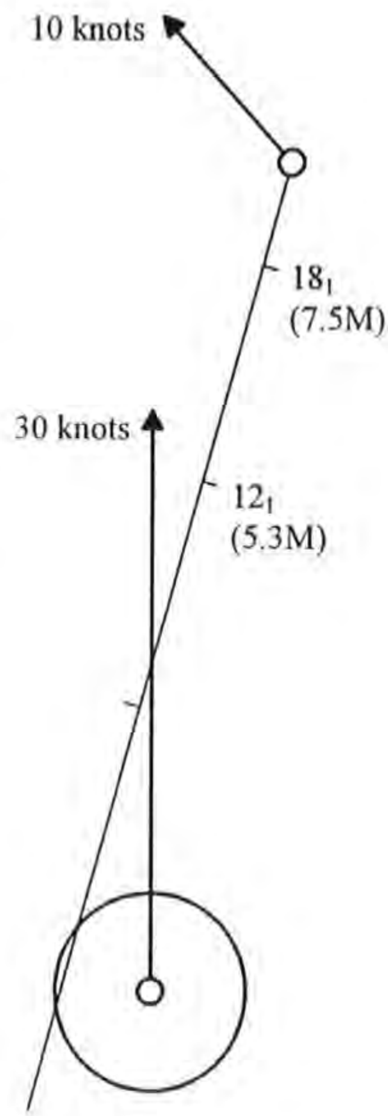

Figure 6.7
Exercise 4R
Source: Author

Rule set requirements: risk of collision exists;

at range <7.5 but >5.3 stand-on or convention manoeuvres only;

by range 5.3 convention manoeuvre is mandatory;

convention manoeuvre is an alteration starboard of 60° to 90°.

6.4.8 Exercise 5 (A&B)

Own ship is a tanker at 10 knots. The target, initially on a bearing of Red 177°, has a speed of 30 knots and a course 7° to the port of own course. The initial closing speed is about 20 knots. The target cannot be observed visually.

If no action is taken: the target will pass on own ship's port side, with a cpa of 0.9M occurring on own ship's port beam.

Rule set requirements: risk of collision exists;

at range <6.7 but >4.7 stand-on only;

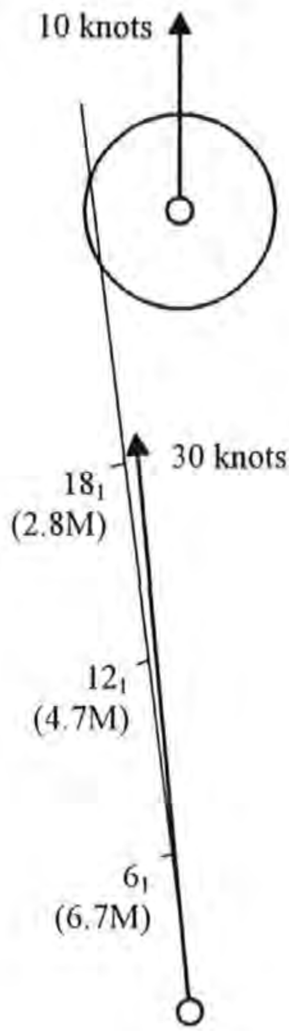

Figure 6.8

Exercise 5 A & B

Source: Author

6.4.8.1 Rule set (A)

at range <4.7 but >2.8 stand-on or convention manoeuvres only

by range 2.8 convention manoeuvre is mandatory;

convention manoeuvre is an alteration to port between 20° and 40°.

6.4.8.2 Rule set (B)

at range <4.7 stand-on or convention;

convention manoeuvres are to port or starboard at the mariner's discretion.

6.4.9 Exercise 5R

Exercise 5R is exercise 5 with roles reversed.

The mariner is told that own ship is a container vessel at 30 knots (in fact the simulator ship model is a jet foil). The target, initially on a bearing of Green 4°, has a speed of 10 knots and a course of 7° to the starboard of own course. The initial closing speed is about 20 knots. The target may be observed visually when the range has decreased to about 3M.

If no action is taken: own ship will pass on the target's port side, with a cpa of 0.9M occurring on the target's port beam.

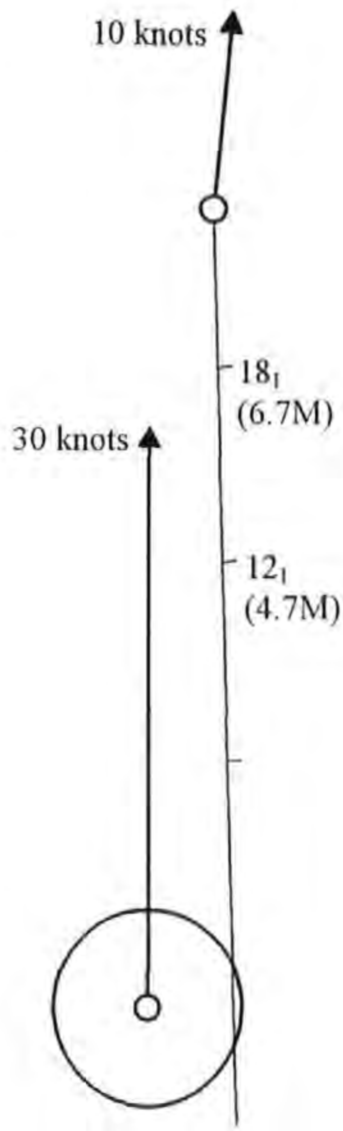

Figure 6.9

Exercise 5R

Source: Author

Rule set requirements: risk of collision exists;

at range <6.7 but >4.7 stand-on or convention manoeuvres only;

by range 4.7 convention manoeuvre is mandatory;

convention manoeuvre is an alteration starboard of 60° to 90°.

6.4.10 Exercise 6

Own ship is a tanker at 10 knots. The target initially on a bearing of Red 58°, has a speed of 20 knots and a course of 91° to the starboard of own course. The initial closing speed is about 22½ knots. The target cannot be observed visually unless an alteration to port is made by own ship.

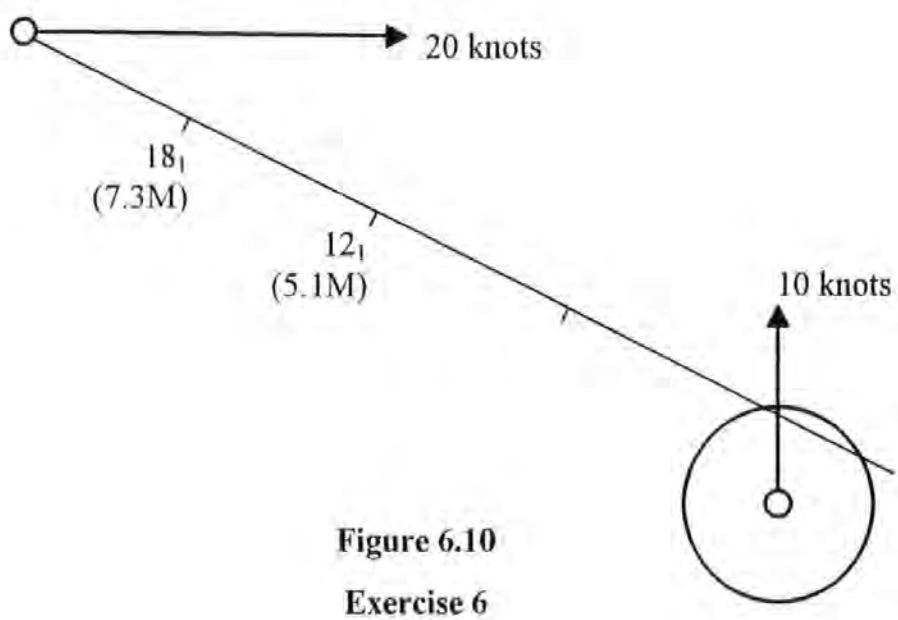

Figure 6.10

Exercise 6

Source: Author

If no action is taken: the target will pass ahead of own at a distance of just less than 1M, with a cpa of 0.8M occurring on own ship's starboard bow.

Rule set requirements: risk of collision exists;

at range <7.3 but >5.1 stand-on or convention manoeuvres only;

by range 5.1 convention manoeuvre is mandatory;

convention manoeuvre is an alteration to starboard until the target is on the port beam.

The convention manoeuvre does not eliminate risk of collision in this case. The subsequent RULE-SET requirements initially make own a stand-on vessel. At 12 minutes to domain penetration, own may stand-on or use convention manoeuvres.

Rule set (A) makes convention manoeuvre mandatory at 6 minutes to domain infringement. The convention manoeuvre is to turn to starboard until the vessel is astern.

Rule set (B) does not make convention manoeuvres mandatory over standing on. The convention manoeuvres are turns to port or starboard at the mariner's discretion.

6.4.11 Exercise 7

Own ship is a container vessel at 20 knots. The target, initially on a bearing of Red 40°, has a speed of 18 knots, and a course 84° to the starboard of own course. The initial closing speed is about 25 knots. The target can be observed visually soon after the exercise begins. After an alteration to starboard visual contact may be lost.

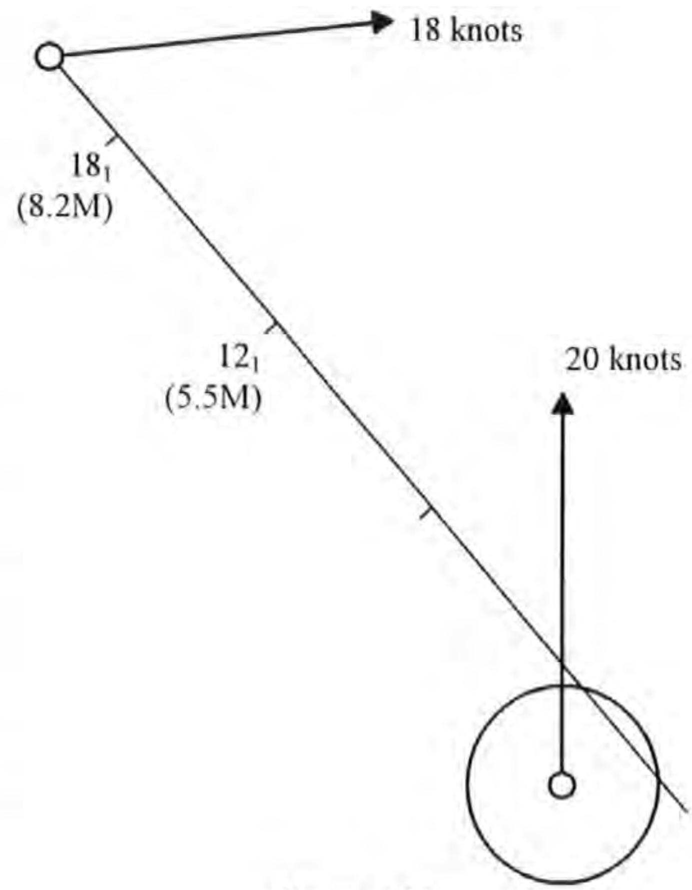

Figure 6.11

Exercise 7

Source: Author

If no action is taken: the target will pass ahead of own at a distance of about 1.2M, with a cpa of 0.8M occurring on own ship's starboard bow.

Rule set requirements: risk of collision exists;

at range <8.2 but >5.5 stand-on or manoeuvre convention only;

by range 5.5 manoeuvre convention mandatory;

convention manoeuvre is an alteration to starboard until target is on the port beam.

6.4.12 Exercise 7R

Exercise 7R is exercise 7 with roles reversed.

Own ship is a ferry at 18 knots. The target, initially on a bearing of Green 56°, has a speed of 20 knots, and a course 84° to the port of own course. The initial closing speed is about 25 knots. Initially the target cannot be observed visually. Visual observation is available after an alteration to starboard.

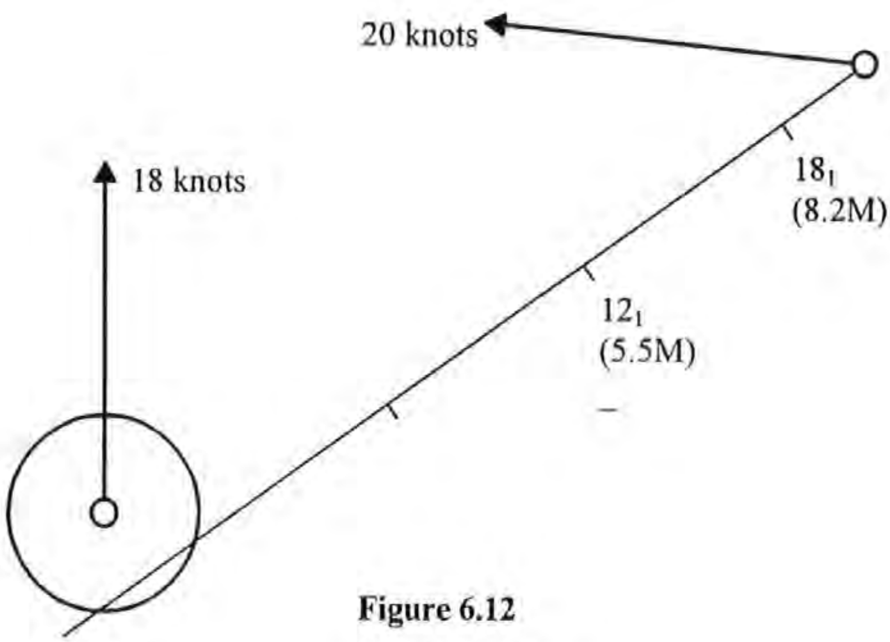

Figure 6.12

Exercise 7 R

Source: Author

If no action is taken: own ship will pass ahead of the target at a distance of about 1.2M, with a cpa of 0.8M occurring on the target's starboard bow.

Rule set requirements: risk of collision exists;

at range <8.2 but >5.5 stand-on or manoeuvre convention only;

by range 5.5 manoeuvre convention mandatory;

convention manoeuvre is an alteration to starboard until target is at least 30° on the port bow.

6.5 QUESTIONNAIRE PROCEDURE

Immediately after each exercise the subjects were given a verbal questionnaire. The questionnaire attempted to determine the mariners' usual action at sea in the exercise circumstances, and whether they were comfortable following the action prescribed by in the RULE-SET. If the mariner was not comfortable following the RULE-SET, he was asked what aspect he did not like, and what action he would find agreeable.

6.5.1 Data collection

The simulator exercises and questionnaire procedure yield three sets of manoeuvre data for each mariner-exercise. The sets are named "usual", "simulator", and "new". "Usual" is intended to reflect the mariner's usual action at sea in the circumstances presented to him. "Simulator", is the action actually taken during the simulated encounter. "New", is the action that the mariner would be agreeable to in the hypothetical case of acting under the new rules, considering his experience in the simulator.

The "usual" and "new" data were obtained by the post-exercise questionnaire. The answers given can be related to the actual action taken in the simulator. For example, if a mariner considers the range at which he manoeuvred in the simulator as commensurate with his usual action at sea, then this range is available without the mariner having to quantify it. If his usual range for manoeuvre was greater or less than that which he made in the simulator, then his answer can be made in relative and comparative terms, rather than absolute terms. The extent to which data is collected by comparison will depend on the mariner's action in the simulator and style of answering.

By using a post-exercise questionnaire, the circumstances are presented to the mariner practically, and an answer reference is created. By minimising the purely cerebral processes that are associated with a "cold calling" questionnaire, and maximising the norms of collision avoidance practice during the question and answer process, a greater level of validity should be achieved. This is particularly important for the "new" action data set.

6.5.2 A learning experience

The simulator exercise gives the mariner practical experience of applying the new rules. It was intended that the period in the simulator be a learning opportunity regarding the rules and their application. Each mariner was given a copy of the rules a few days before the experiments. He also had explanatory notes and self test questions. Before the first exercise began the mariner was questioned as to his understanding of the rules and any misperceptions were corrected.

The mariner's attitude to the rules' application was addressed. Attention was drawn to rules 1 and 2. It was made clear that the mariner was responsible for keeping his ship safe and that following the rules as if an automaton was not required. It was stated that "If the rules do not appear to offer a solution for avoiding risk of collision, you are at liberty to take action outside the rules". It was also implied that action outside the rules would need to be justified after the exercise. The mariner's attitude to the rules has bearing on the action taken in the simulator and the answers given.

6.5.3 Questions 1 to 7

The answers are tabulated in appendix D. A key to the tables is shown below (Figure 6.13) with an example data cell. Questions one to seven and their use are detailed below.

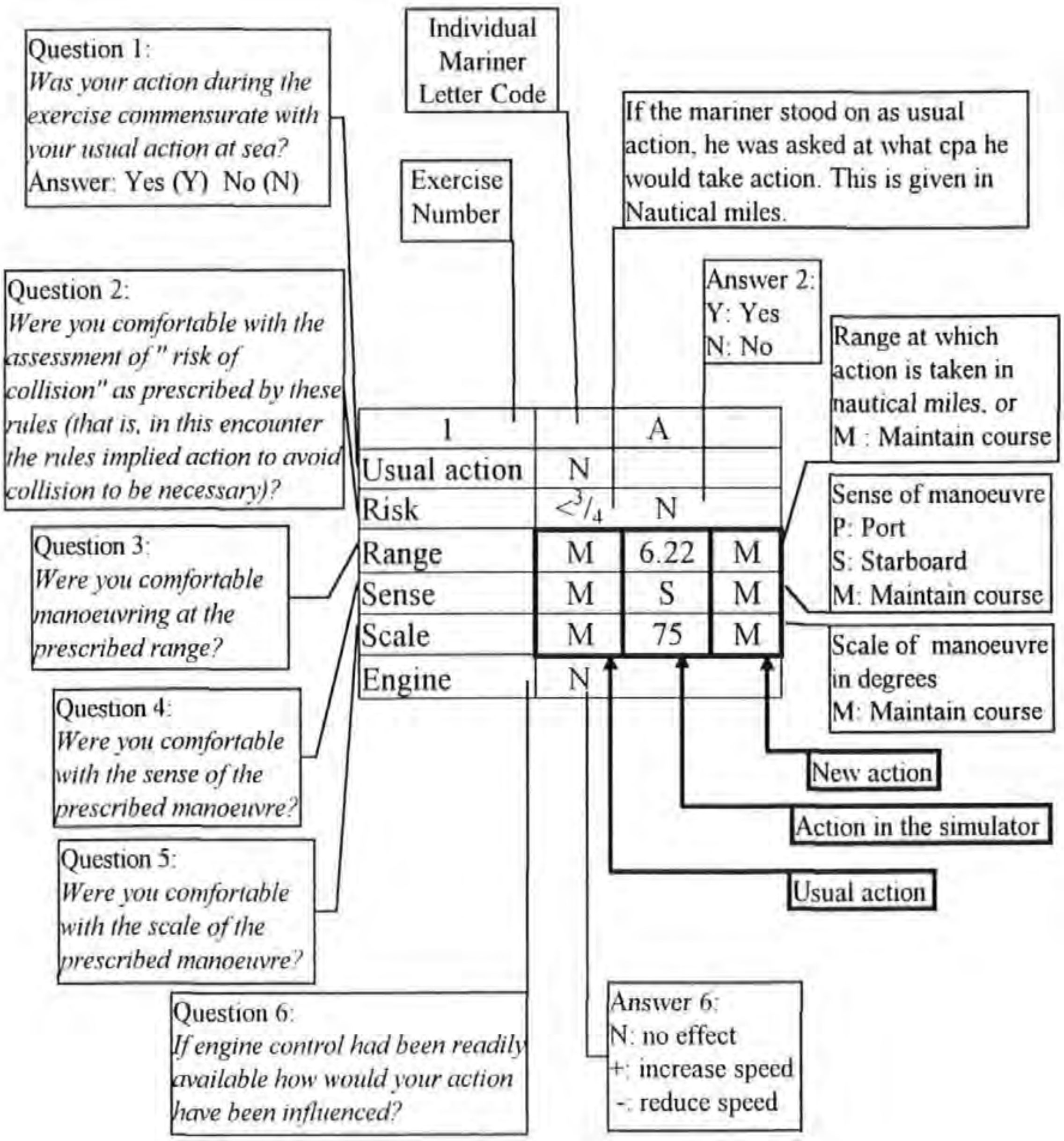

Figure 6.13

Key to exercise result sheets

Source: Author

Question 1

"Was your action during the exercise commensurate with your usual action at sea?"

If the answer to this question was Yes, the values for range, sense and scale of the manoeuvre which were recorded for the exercise, were taken to represent usual behaviour at sea.

If the answer was No, further questions were put to ascertain what was "usual" action.

Question 2

"Were you comfortable with the assessment of " risk of collision" as prescribed by these rules (that is, in this encounter the rules implied action to avoid collision to be necessary)?"

If the answer to this question was No, the mariner was asked what was the maximum cpa at which he would usually make a manoeuvre.

Question 3

"Were you comfortable manoeuvring at the prescribed range?"

If the mariner had manoeuvred within the prescribed range and the answer to this question was Yes, the range at which the mariner had manoeuvred in the exercise was recorded as new action.

If the answer was No, the mariner was asked to give an agreeable range of manoeuvre, which was recorded as new action.

Question 4

"Were you comfortable with the sense of the prescribed manoeuvre?"

If the mariner had manoeuvred with the prescribed sense and answered Yes, then that sense was entered as new action.

If the answer was No, the mariner was asked to give an agreeable sense of manoeuvre, which was then recorded as new action.

Question 5

"Were you comfortable with the scale of the prescribed manoeuvre?"

If the mariner was comfortable with the prescribed sense of manoeuvre (Q.4), manoeuvred to the prescribed scale and answered Yes, his action in the simulator was recorded as new action.

If the mariner had not been comfortable with the prescribed sense of manoeuvre (Q.4), he was asked to give a scale to complement the agreeable manoeuvre sense.

Question 6.

"If engine control had been readily available how would your action have been influenced?"

Answers could be none, slow down, or slow down combined with a particular action.

6.6 SUMMARY AND CONCLUSION

The use and limitations of simulation of navigational watchkeeping have been considered. The navigation simulator used in this research has been described.

The group of mariners participating in the experiments has been detailed by experience and qualification. The experiment exercises have been described. The requirements for vessels acting under the rules are noted. The post exercise questionnaire procedure is explained. Three sets of manoeuvre data are ascertained for each exercise: usual action at sea; action in the simulator; agreeable action in light of simulator/rule experience.

6.7 REFERENCES

1. CURTIS, R.G. and BARRATT, M.J. On the validation of radar simulator results, *Journal of the Institute of Navigation*, 1981, V.34, p.187-201.

2. McCALLUM, I.R. Needs first - kit after, the influence of operational considerations on ship simulator design, *International Conference on Simulators*, 1983, p.41.

3. TAPP, N.J. A non dimensional mathematical model for use in marine simulators, *M.Phil. thesis*, (CNAA), University of Plymouth, 1988.

CHAPTER 7

EXPERIMENTAL RESULTS AND ANALYSIS

7.1 INTRODUCTION

This chapter presents and describes the results obtained from the experimental work, and will show the subsequent analysis and discussion. First consideration will be given to the validity of the results, before conducting an analysis.

Mariners' "usual" action will be compared with similar work in qualitative and quantitative terms, to give some indication of validity. The influences on the validity of mariners' "new" action will be discussed.

The analysis will consider the effect of the rules as a whole, and then continue with a detailed inspection of the results by individual encounter. The analysis will break mariner responses into four parts as may be identified in the rules: Risk; Range (point of manoeuvre); Sense (of manoeuvre), and Scale (of manoeuvre).

7.2 RESULTS

The results are tabulated in Appendix D, and in more digestible diagram format in Appendix E. An example of the result diagram format is given below (Figure 7.1). This shows mariners' sense and scale of action, and the point of manoeuvre in relation to time to risk domain infringement. In appendix E, "usual" action and "new" action results are shown on the same page for comparison.

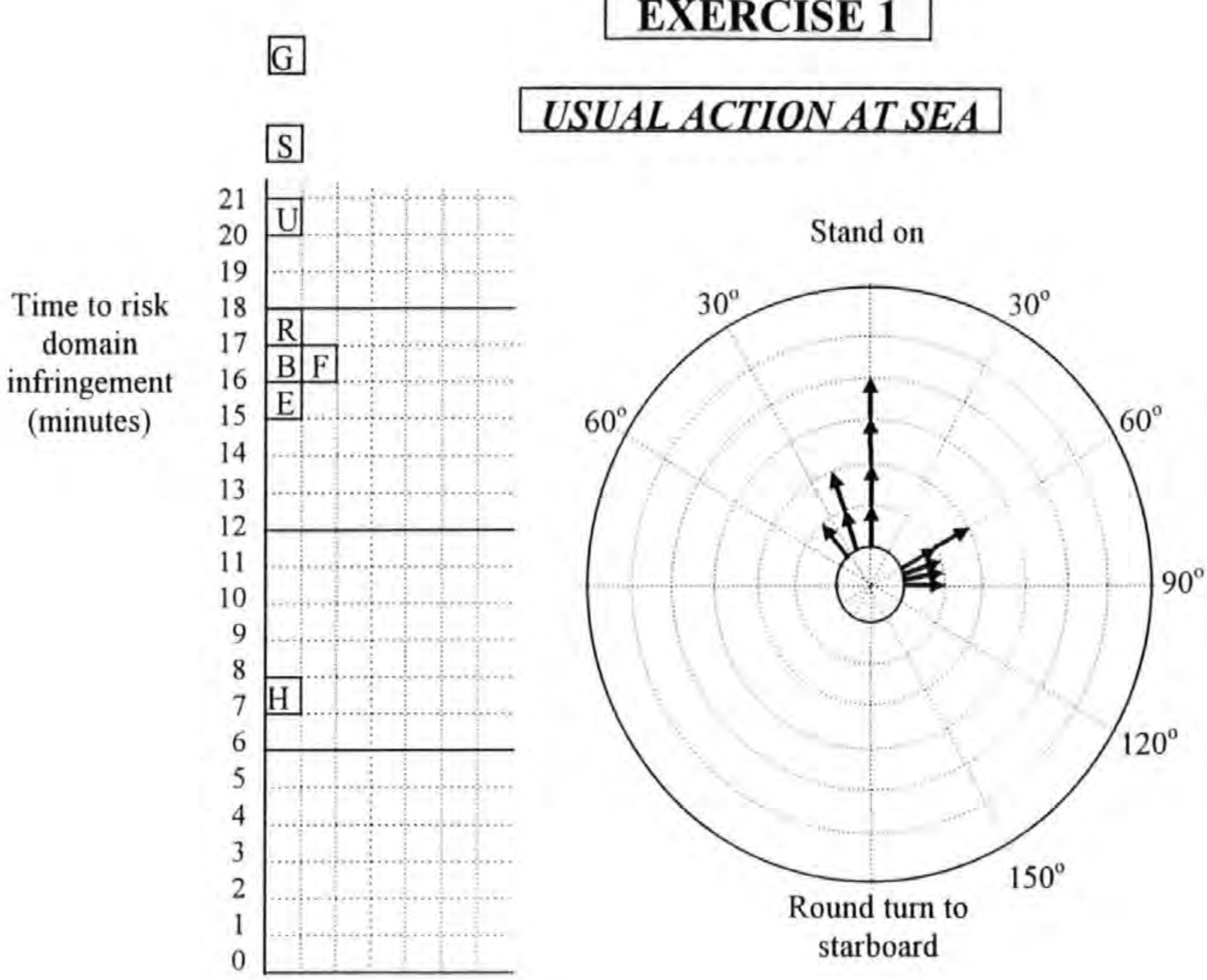

Figure 7.1

Example result diagram (exercise 1 usual action)

Source: Author

7.3 VALIDITY OF "USUAL" ACTION AT SEA

The data for usual action at sea can be validated by comparison with data from similar experiments. The comparison data is derived from work by Kemp[1], Wang[2], Corbet[3] and Redfern[4]. The detail and results of this work are described in Appendix F.

Reciprocal course encounters

7.3.1 Exercise 1 and 2

The sense of manoeuvre results for exercise 1 and 2 are displayed in Table 7.1. The encounters had green to green separations of 0.9 and 1.4M. For simplicity of comparison this has been rounded to 1.0 and 1.5M respectively. Actual data collected is indicated by capital letters. It will be noted that as well as at 1.0 and 1.5M separation, actual data exists for 0.75M. Mariners who stood-on at 1.0M would be asked at what separation would they make a manoeuvre and what manoeuvre would that be. No mariner stood-on with a separation of less than 0.7M. Lower case letters indicate interpolated data. The interpolation is dependent on two assumptions. First, all mariners will alter to starboard when the separation is zero. Second, having maintained course for a particular separation, mariners will maintain course for a greater separation. Data that defies interpolation despite the two assumptions is entered with both possibilities. Data from Kemp, Wang and Corbet is shown for comparison.

7.3.1.1 Significant differences between comparison data and actual data

The comparison data is obtained from encounters with exactly the same geometry as encounters 1 and 2. The vessels' speeds are the same or similar. However, there are several significant differences that must be considered when making a comparison.

All three comparison data sets were derived from encounters in restricted visibility. Exercises 1 and 2 were conducted in conditions with night time visual detection. It may be expected that in conditions with visual detection, a smaller passing distance will be acceptable to mariners.

		Green to green Off set (Miles)					
		0.0	0.5	0.75	1.0	1.5	2.0
	A	s	s	S	M	M	m
	B	s	s	s	S	M	m
M	C	s	s	S	M	M	m
a	D	s	s	s	M	M	m
r	E	s	sp	sp	P	M	m
i	F	s	s	s	S	M	m
n	G	s	s	s	S	M	m
e	H	s	sp	sp	P	M	m
r	R	s	s	s	S	sm	sm
s	S	s	s	s	S	sm	sm
	T	s	s	S	M	M	m
	U	s	sp	sp	P	pm	pm
	Total	12s	9s:3sp	-	5S:4M:3P	2sm:9M:1pm	2sm:9m:1pm
	Kemp	6S	5S:1P	-	4S:2P	2M:4P	5M:1P
	Wang	9S	7S:2P	-	5S:4P	2S:2M:5P	2S:6M:1P
	Corbet(%)	98S	78S:3M:12P	-	34S:16M:25P	-	1S:66M:15P

Table 7.1
Exercise 1 and 2, usual manoeuvre sense results compared with data from Kemp, Wang and Corbet

Key:	**S** alteration to starboard **M** course maintained **P** alteration to port Upper case: actual data Lower case: interpolated data

The Kemp and Corbet data sets were derived from conditions with manual radar plotting. Exercises 1 and 2 used ARPA. It may be expected that the superior accuracy associated with automatic plotting would tend to encourage smaller passing distances. It is not known what plotting method was available in the Wang experiments.

The Corbet data was obtained by a questionnaire. There may be a tendency for responses to a questionnaire to lean towards the strict compliance with rules, rather than reflect actual behaviour at sea.

The vessel size used by Kemp and Corbet was 10 000 and 15 000 tons respectively. Experiments 1 and 2 used a 98 000 ton tanker. The effect of using a much larger vessel is not clear. Goodwin's work suggested that while an increase in vessel size was accompanied by a general trend of increased domain size, the largest of vessels tend to accept smaller passing distances. It is not known what vessel size was used in the Wang experiments.

Vessel speed in the Corbet experiments was 12 knots. The slightly faster speed may encourage an alteration to starboard across the head of the target, instead of stand-on and port alterations.

The sample of mariners is different regarding time, race and experience. The Kemp experiments were carried out in the early 1970's, Corbet's questionnaire during the period 1980-81, and Wang, by 1987. Corbet has compared data collected for his questionnaire with a similar study over 1968-69 (See Appendix F). The results differ significantly. The earlier data for green to green reciprocal encounters, show a greater tendency to alter to port and greater reluctance to alter to starboard. The 1 mile passing distance was accepted more than twice as readily in the 68/69 study. The change in behaviour may be due to the introduction of the 1972 conference rules in 1977, and commensurate change in training. Whatever the reason, the change must be considered when making the comparison.

The nationality of the subjects participating in the experiments in this thesis was British and one Canadian. It is assumed that the subjects in the Kemp and Corbet exercises were at least in the main British. The subjects for Wang's experiments carried out at Dalian Maritime University, were probably Chinese. There may be differences in culture and training regime that will influence the data. It is not known whether there is any effect or what this would be.

The mariners who participated in the experiments for this thesis were of high experience. All had Class 1 certificates, ¾ had command experience, and the mean sea time accrued was almost 22 years. The subjects used by Kemp and Corbet appear, as groups, to be a little less experienced in terms of certification and sea time. The effect of this difference if any is not known. The experience of the Wang subjects is not known.

7.3.1.2 The comparison

Despite the differences mentioned above it may be expected that a similar qualitative pattern of the distribution of manoeuvre sense will be in evidence if the results are valid. The quantitative element of the distribution will be affected by the difference factors.

The distributions of starboard, stand-on and port alteration for all four sets of data have been presented graphically (Figures 7.2/3/4). For ease of comparison the data has been converted to percentages. It should be remembered that the actual number of mariners represented are 6 (Kemp), 9 (Wang), 108 (Corbet) and 12 (Perkins). There was no data at 1.5M for Corbet. The Perkins data only has points at 1.0M and 1.5M. The other points are made up by using the interpolation method indicated for Table 7.1. Where the data point could not be interpolated, for the sake of the graphical presentation, each possibility was awarded ½ a mariner each.

7.3.1.3 Distribution of starboard alteration

It may be expected that with a cpa of zero, all mariners will alter to starboard. As the separation increases, the number altering to starboard will decrease until all accept the passing distance or alter to port. The Perkins data follows this pattern as does the comparison data. In quantitative terms the Perkins data fits within the bounds of the comparison data. This analysis gives no reason to suspect the validity of the data.

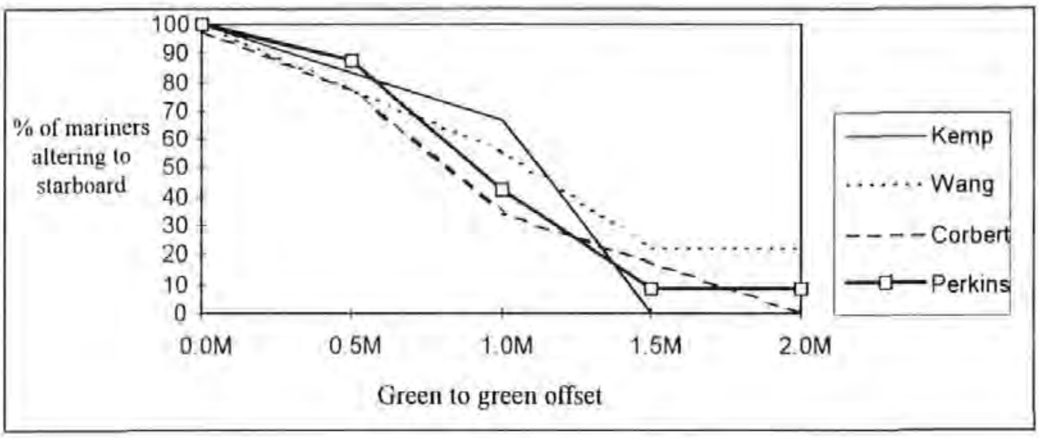

Figure 7.2
Exercise 1 and 2
Distribution of Starboard alteration

Source: Author

7.3.1.4 Distribution of stand-on manoeuvre

It may be expected that with a cpa of zero, no mariners will stand-on. As the cpa increases so will the number of mariners, until all accept the passing distance and stand-on. The Perkins data follows this pattern as does the comparison data. In quantitative terms it can be seen that the Perkins mariners will more readily stand-on at lesser cpas than the comparison data mariners. The acceptance of smaller passing distances may be explained by the differences described above: visual detection and use of ARPA. The validity of the data is supported by this analysis.

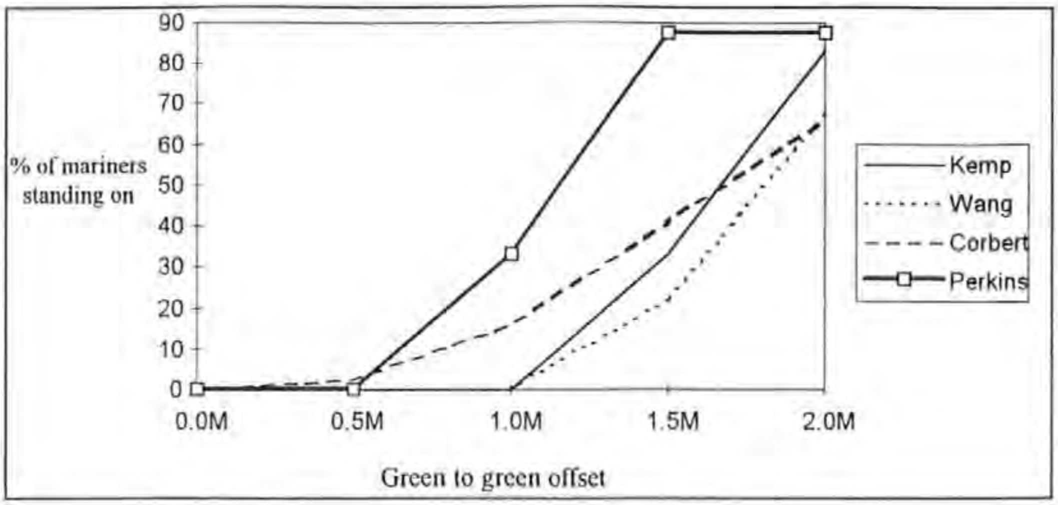

Figure 7.3
Exercise 1 and 2
Distribution of Stand-on manoeuvre

Source: Author

7.3.1.5 Distribution of port alteration

It may be expected that with a cpa of zero, the number of mariners altering to port will tend to zero. As the cpa increases, in a green to green reciprocal encounter, the number of mariners altering to port will initially increase, and then decrease to zero. The Perkins data follows this pattern as does the comparison data. In quantitative terms the Perkins data partially coincides with the Corbet data, however, there is a considerable disparity with that of Kemp and Wang. The comparison over time carried out by Corbet (as considered above) suggests that the Kemp data collected in the early 1970's will indicate a higher proportion of alterations to port than data collected at a later date. This argument cannot be applied to the Wang data that is reported much later. That the Perkins data shows a partial correlation with the Corbet data arouses suspicions about the effect of questionnaires. It may be that answers given in the questionnaires, both Perkins and Corbet, lean towards strict compliance with the COLREGS rather than normal behaviour at sea. Mariners may not be prepared to admit that they alter to port in such circumstances. This analysis indicates that the data is broadly in tune with expectations, however it must be considered that the data may not truly reflect the extent of port alterations. There may be a commensurate over reporting of the alternative actions: alteration to starboard and stand-on.

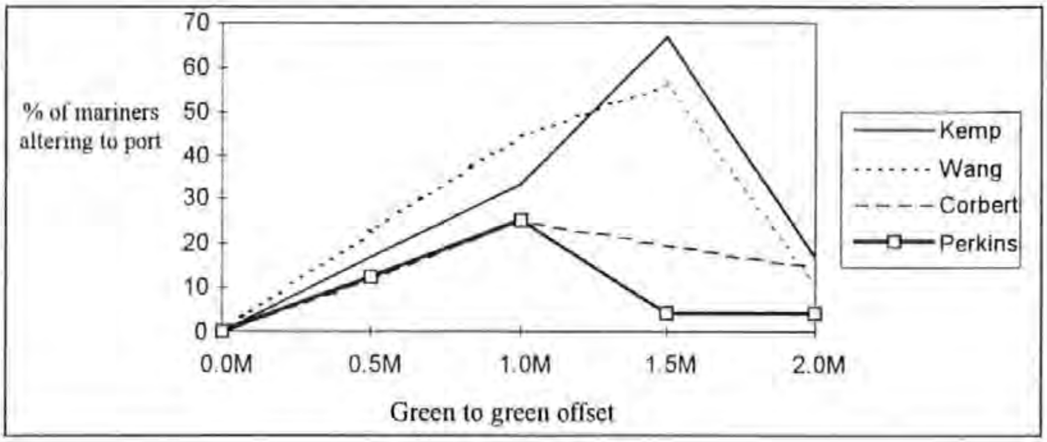

Figure 7.4
Exercise 1 and 2
Distribution of Port alteration

Source: Author

7.3.2 Exercise 3

The sense of manoeuvre results for exercise 3 are displayed in Table 7.2. Actual data collected is for green to green separations of 0.9M and occasionally 0.75M and 0.5M. Other data points are filled by interpolation using the method previously described for Table 7.1. Data from Redfern is shown for comparison. The only difference between the Redfern exercise EDTP24 and exercise 3 is that the former had a cpa of 0.4M and the later 0.9M. Other aspects of encounter geometry were the same. Other factors, ship speeds and type; the simulator and bridge equipment, and the general level of experience of the human sample, were similar.

		Green to green Offset (Miles)				
		0	0.4	0.5	0.75	0.9
	A	s	s		S	M
	B	s	s			S
M	C	s	s		S	M
a	D	s	s			S
r	E	s	s/p			P
i	F	s	s			S
n	G	s	s			S
e	H	s	s	S		P
r	R	s	s			S
s	S	s	s			S
	T	s	s		S	M
	U	s	s			S
	Total	12s	11s:1s/p			7S:3M:2P
	Redfern		8S:0M:1P			

Table 7.2
Exercise 3, usual manoeuvre sense results, compared with data from Redfern

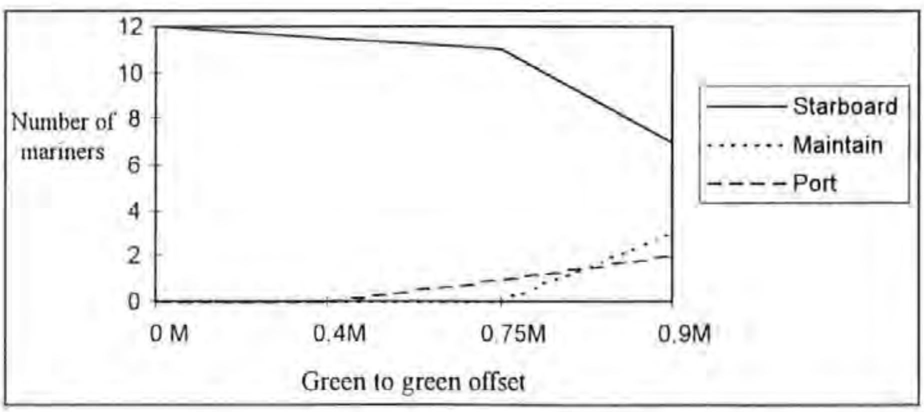

Figure 7.5
Exercise 3, manoeuvre sense results

Source: Author

Figure 7.5 illustrates the distribution of the manoeuvre sense as plotted from the tabulated data at points 0; 0.4; 0.75, and 0.9M. The data and interpolation are in keeping with the expected pattern. A quantitative examination shows that at 0.4M, 11 of 12 mariners will definitely alter to starboard, leaving one whose sense of alteration cannot be determined. No mariner will stand-on. Redfern's results show a good correlation. Eight of nine alter to starboard, and one to port. No mariner stood-on. There is nothing in this analysis to cast doubt on the validity of the results.

7.3.3 Exercise 2X and 3R

Table 7.3 indicates the results of exercise 2X and 3R. Actual data was collected for points 0.9M and 1.4M and occasionally 0.75M. Other data is derived from the interpolation method described earlier. Data from Redfern is shown for comparison.

		Green to green Offset (Miles)				
		0	0.4	0.75	0.9	1.4
Mariners	F	s	s		S	S
	N	s	s		S	M
	O	s	s		S	M
	P	s	s		S	M
	Q	s	s		S	S
	R	s	s		S	S
	S	s	s		S	M
	T	s	s	S	M	M
	U	s	s/p		P	M
	Total	9s	8s:1s/p		7S:1M:1P	3S:6M:0P
	Redfern		7S:0M:2P			

Table 7.3
Exercise 2X and 3R, usual manoeuvre sense results compared with data from Redfern

The only difference between the Redfern exercise EDTP24 and exercise 2X and 3R is that the initial cpas are 0.4M, 0.9M and 1.4M respectively. All other aspects of the simulated encounter are the same. Figure 7.6 illustrates the distribution of the manoeuvre sense as plotted from the tabulated data at points 0; 0.4; 0.9, and 1.4M. The data and interpolation are in keeping with the expected pattern. A quantitative examination shows that at 0.4M, 8 of the 9 mariners will definitely alter to starboard, leaving one who's sense of alteration cannot be determined. No mariner will stand-on. Redfern's results show reasonable correlation. Seven will alter to starboard and two to port. Again, none stood-on. There is nothing in this analysis to cast doubt on the validity of the results.

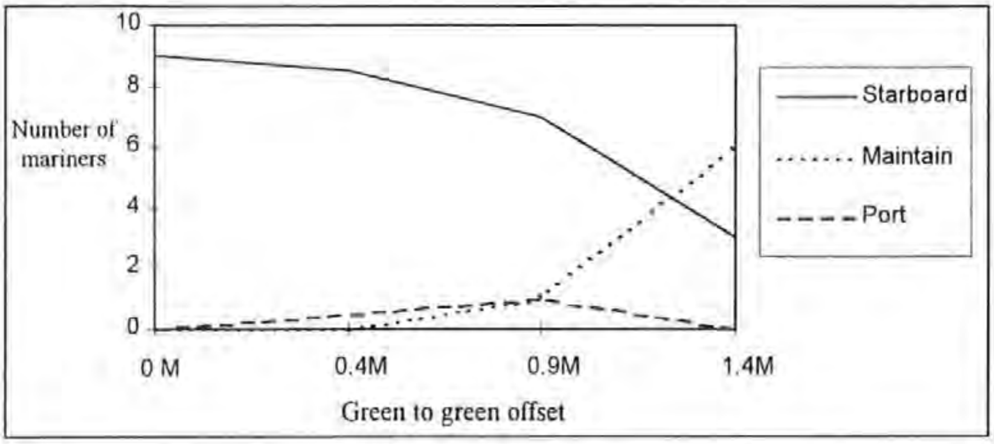

Figure 7.6
Exercise 2X and 3R, manoeuvre sense results

Source: Author

<u>Right angled crossing</u>

<u>7.3.4 Exercise 7</u>

The sense of manoeuvre results for exercise 7 are displayed in Table 7.4. Results from Redfern's EDTP01 are shown for comparison. Differences between exercise 7 and EDTP01 were that the initial cpas were 0.8M and 0.3M respectively, and that other vessels were present in the Redfern exercise. The greater passing distance will increase any tendency for standing on. The other vessels in EDTP01 were largely incidental. However, the presence of a target being overtaken on own vessel's port side may have had a dissuading influence on alterations to port.

	Perkins		Redfern	
Action	No.	%	No.	%
A/c starboard	5	38	6	40
Round turn starboard	6	46	7	46
A/c port	1	8	1	7
No action	1	8	1	7
Total	13	100	15	100

Table 7.4
Exercise 7, usual manoeuvre sense results compared with data from Redfern

The distribution of sense of manoeuvre can be seen to be almost identical between the Perkins and Redfern data. This includes the distinction between round turns to starboard and other starboard alterations. It is noted that the port alteration in the Redfern data set was unintentional.

The range at which manoeuvres were made are plotted in Figure 7.7. Apart from one exceptionally early manoeuvre the Perkins data broadly matches that of Redfern. Three miles is the clear mode in the Perkins data. It is suggested that while

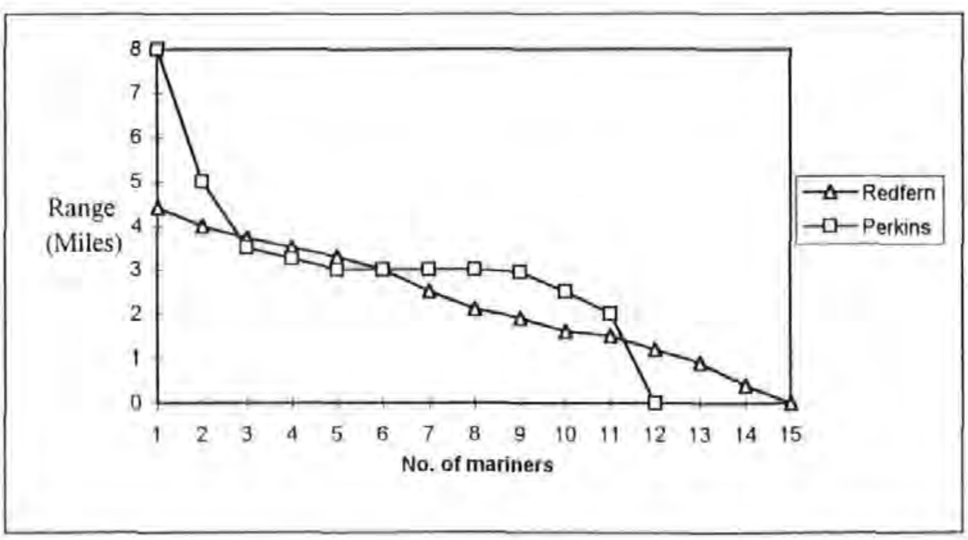

Figure 7.7
Exercise 7, point of manoeuvre results compared with data from Redfern
Source: Author

three miles appears as a mode for the questionnaire a more true reflection of action at sea is that indicated by the Redfern data, with action being taken over a less defined array of ranges. The Redfern data also suggests that some individuals will take action at less than two miles. This is not indicated by the Perkins data.

NB. The Perkins' port alteration was made at 8.5M but is not plotted for range in Figure 7.7. The Redfern port alteration could not be distinguished from the starboard alterations and has been plotted.

7.3.5 Exercise 7R

Exercise 7R can be compared with Redfern's EDTP02. Differences between exercise 7R and EDTP02 were that the initial cpas were 0.8M and 0.3M respectively, and that other vessels were present in the Redfern exercise. The greater passing distance will increase any tendency for standing on. The other vessels in EDTP02 were largely incidental. However, "the situation was complicated by the presence of a second vessel, T3, crossing from starboard which posed no immediate threat, having an earlier and negative cpa of two miles, but could influence the time at which action was taken." In fact only two Redfern mariners waited to pass ahead of the second target before taking action to avoid the main threat.

The manoeuvre sense results of exercise 7R are shown in Table 7.5 with EDTP02 results for comparison. No mariner stood-on in either of the experiments. All the Perkins mariners altered to starboard, with 13 of 15 Redfern mariners doing likewise. It must be suspected that a proportion of mariners will alter to port in these circumstances as suggested by the Redfern data. The mariners making up the Perkins sample are N to U who are, as a group, of especially high experience.

	Perkins	Redfern
A/c staroard	8	13
A/c Port	0	2
No action	0	0
Total	8	15

Table 7.5
Exercise 7R, usual manoeuvre sense results compared with data from Redfern

The scale of starboard manoeuvre ranged from 60° to 95°, with an average of 77½°, for the Perkins data set. The Redfern mariners made "substantial alterations of course to starboard, the average value being 76°". Both data sets indicate a clear similarity in this case.

7.3.6 Summary of usual action validity

7.3.6.1 Limitations

Before summarising the findings of the validity comparisons, it is first proper to consider the limitations of the method. Perhaps most important is the limited amount of experimental and comparison data. Only the Corbet data (108 mariners) could begin to stand any serious scrutiny from a statistician. Given that the data sets are of a small size, what can be inferred will only show where the results are invalid, or suspected, rather than a positive validation of the data.

Another limitation is that of the similarity of comparison encounters. None of the encounters had exactly matching circumstances, which results in a need to consider the likely effect of the difference. Clearly different mariners on different days may be included as differing circumstances, but here, only a large sample will counteract the diversity. Not all the experiment exercises had "usual" action data available for comparison. Reciprocal and crossing encounters were covered, but overtaking and overtaken were not.

7.3.6.2 Results validity

Overall the results appeared to show a high level of correlation with the comparison data. Four issues can be identified which indicate the likelihood of invalidity.

The results for exercise 1 and 2 indicate a suspected under reporting of port alteration. If this is so, there will be a commensurate over reporting of starboard or stand-on action.

Exercise 7 produced a too common range of manoeuvre answer for give-way action. The usual action is more likely to be over a more even spread around the value of the reported range.

The range at which give-way action was taken for exercise 7, may be artificially early for some mariners, who would usually act at less than 2M in practice.

In exercise 7R no mariner altered to port. The size of the sample may not be large enough to indicate this action and or under reporting may be extant. The comparison data indicates that a proportion of the mariners will make a port alteration.

7.4 VALIDITY OF ACTION UNDER THE NEW RULE-SETS

The results for new rules can give some indication of the ease with which such rules might be implemented at sea in reality. The results do not directly represent what will happen at sea if the new rules are implemented. The various reasons for the difference between the simulation results and actual operation are discussed below.

7.4.1 Attitude to rules

The force of law that supports the current COLREGS has an affect on the mariner's attitude towards rules and their application. That deviants can face punishments will influence attitude. There was no real force of law acting on mariners during the simulator exercises and post exercise questionnaire. While a mariner may have been uncomfortable with action prescribed by the new rules, they may have obeyed if the force of law had been extant. Conversely, the mariner may act within the scope of the rules while under training or observation, but go on to develop non-compliant behaviour when at sea. Time and experience will influence the application of rules. The human constantly updates his problem solving method.

7.4.2 Experience of and with rules

The mariners' experience of the new rules is minimal. The period spent learning the new rules was a matter of a few hours; experience of applying the rules was limited to the exercises in the simulator. This must be contrasted against the lifetime of experience and training that the mariner has received for the existing rules. The introduction of any major revision of the COLREGS, would today be accompanied by a package of education and training, preferably using simulators. Novice mariners would be 'indoctrinated' with the new rules at the beginning of their career.

7.5 ANALYSIS

Questions that the experiments may be used to answer include

What is the effect of the rules?

What is the chance of implementing the rule-base?

What is the chance of implementing individual rules?

To evaluate the effect of the rules it is necessary to consider two features of the results. First, how many mariners would be compliant with the rule-base by their usual action at sea, and second, how many mariners may be persuaded to change their behaviour to comply with the rule-base. This analysis will be done, considering the results as a cumulative whole.

7.5.1 The effect of the rules

Table 7.6 indicates the number and proportion of mariners who are not compliant with the rules as their usual action, and their new action. It also shows the change in behaviour effected by the rules. The analysis breaks down mariner action into Risk; Range; Sense and Scale of manoeuvre.

NB. Mariners have been judged as being compliant with the point of manoeuvre rule if they manoeuvre within one minute of the proper time period.

7.5.1.1 Risk

On 19 out of 117 occasions (16%), mariners did not "usually" consider risk to exist. On only 6 out of 117 occasions (5%) did mariners feel uncomfortable complying with the new rules. The effect of the new rules was to change mariner behaviour on 13 out of 19 occasions (68%).

		1	2	2X	3	3R	4A	4B	4R	5A	5B	5R	6	7	7R	TOT	%
Risk	Usual	4/12	0/9	0/9	3/12	1/9	5/8		1/8	2/8		0/8	2/13	1/13	0/8	19/117	16%
	New	2/12	0/9	0/9	1/12	1/9	2/8		0/8	0/8		0/8	0/13	0/13	0/8	6/117	5%
	Change	**2/4**	**0/0**	**0/0**	**2/3**	**0/1**	**3/5**		**1/1**	**2/2**		**0/0**	**2/2**	**1/1**	**0/0**	**13/19**	**68%**
Range	Usual	1/8			3/9	1/8	1/3	1/7	3/7	2/6	0/6	2/8	8/11	10/12	0/8	32/93	34%
	New	1/10			2/11	0/8	2/6	1/7	3/8	6/8	0/6	2/8	5/13	6/13	1/8	29/106	27%
	Change	**0/1**			**1/3**	**1/1**	**0/1**	**0/1**	**0/3**	**0/2**	**0/0**	**0/2**	**4/8**	**5/10**	**0/0**	**11/32**	**34%**
Sense	Usual	3/8		0/3	2/9	1/8	1/3		1/7	5/6		3/8	1/11	1/12	0/8	18/83	22%
	New	2/10		0/4	2/11	1/8	4/6		1/8	7/8		3/8	1/13	0/13	0/8	21/97	22%
	Change	**1/3**		**0/0**	**0/2**	**0/1**	**0/1**		**1/1**	**0/5**		**0/3**	**0/1**	**1/1**	**0/0**	**3/18**	**17%**
Scale	Usual	0/5		1/3	2/7	4/7	1/2		6/6	1/1		4/5	9/10	9/11	4/8	41/66	63%
	New	0/8		1/4	0/9	2/7	1/2		7/7	1/1		4/5	6/12	1/13	2/8	25/76	33%
	Change	**0/0**		**0/1**	**2/2**	**2/4**	**0/1**		**0/6**	**0/1**		**0/4**	**3/9**	**8/9**	**2/4**	**17/41**	**41%**

Table 7.6

Proportion of new rule non-compliance for usual and new action, and the effect of new rules on mariner behaviour

Note: Consider entry for Exercise 1, Risk.

"Usual 4/12" indicates that four out of 12 mariners would not usually(under present rules) take action(w.r.t Risk) that complied with the new rules.

"New 2/12" indicates that two out of 12 mariners were not agreeable to the prescribed action under the new rules.

"Change 2/4" indicates that the effect of the new rules was to change mariners' usual behaviour to rule compliant behaviour on two out of four occasions.

Mariners who did not accept risk criteria are not considered for compliance w,r,t Range or Sense or Scale of manoeuvre.

Mariners who did not accept Sense of manoeuvre are not considered for compliance w.r.t Scale of manoeuvre.

The risk criterion used in the rule-base appears to be generally acceptable to the mariners in the circumstances presented to them. It is suggested that the one mile radius risk domain would maintain its acceptability regardless of the geometry of encounters presented. The slowest vessel in the experiments was at 10 knots. Slower vessels will have increasing difficulty with this rule. Encounters with a cpa >1½M were not presented and therefore the validity of the size of the "close-quarters' domain" cannot be stated. This issue is considered below, in further detail when discussing the individual exercises. At first sight it appears that the risk rule would have a good chance of being successfully implemented for open water, two vessel encounters. Further consideration would have to be given to "slow" vessels.

7.5.1.2 Range

On 32 out of 93 occasions (34%), mariners would "usually" alter course at a range that was outside the rule-base. On 29 out of 106 occasions (27%), mariners felt uncomfortable altering at the range specified in the new rules. The effect of the new rules was to change mariner behaviour on 11 out of 32 occasions (34%).

The requirement to alter at particular points required a significant change in mariner behaviour. On only a $^{1}/_{3}$ of occasions, were mariners prepared to make the change. At first sight there is some doubt whether this rule could be implemented successfully as it stands. A more detailed examination below, will reveal that mariners' difficulty with this rule is mainly concentrated around encounters with a vessel crossing from the port side, and that the sense of manoeuvre prescribed for one encounter (Ex.5A) affected the mariners' answer regarding the acceptable point of manoeuvre. If these individual cases can be addressed, the acceptance of the point of manoeuvre rule will be greater.

Specific manoeuvring points in rules are a novel idea for the mariners who partook in the experiments. One mariner (who represents five occasions of being uncomfortable with this aspect of the rules), admitted finding the use of vector lengths to determine the point of manoeuvre, an "alien experience," and to not really understanding the reasoning behind the rules. The use of education to emphasise the coordination benefits of such a rule, is likely to have a significantly beneficial effect.

7.5.1.3 Sense

On 18 out of 83 occasions (22%), mariners would "usually" alter course in a sense, contrary to the requirements of the new rules. On 21 out of 97 occasions (22%), mariners felt uncomfortable altering in the sense specified in the new rules. The effect of the new rules was to change mariner behaviour on 3 out of 18 occasions (17%).

In two exercises, 4A and 5A, the new rules required the mariners to take action that clearly put their vessel at risk. If these exercises are discounted, then the mariners operating outside the rule-base reduce to 16% for usual action and 12% for new action.

While the number of disaffected mariners may be small, the impact that the rule has on them is also small. A more detailed examination of individual exercises below will indicate that most non-compliance with the sense of manoeuvre part of the rules, is perpetrated by mariners who may be judged to be non-compliant with the current regulations. This may suggest that the natural action of mariners is dominant over rule following. Extraordinary efforts may be needed to make the disaffected mariners comply in these cases.

7.5.1.4 Scale

On 41 out of the 66 occasions (63%) when mariners would "usually" alter course in the sense required by the new rules, they would not alter to the scale required. On 25 out of 76 (33%) occasions, mariners who alter in the correct sense by the new rules, felt uncomfortable altering to the scale specified in the new rules. The effect of the new rules was to change mariner behaviour on 17 out of 41 occasions (41%).

The effect of individual exercises is masked by considering the scale of manoeuvre results as a whole. Clearly specific circumstances affect the results. In exercise 4R the rules failed to make any impact on mariners' action on seven occasions. In exercise 7, eight out of nine mariners were prepared to change the scale of their manoeuvre.

The source for the manoeuvre scale, the RIN manoeuvring diagram, was originally intended for use when the target was not in sight. In more general use in this rule-base, sometimes with visual contact and ARPA information available, it is not unexpected that the extent of the manoeuvres is deemed to be excessive in some circumstances. It is unlikely that this part of the rule-base could be implemented successfully.

7.6 ANALYSIS IN DETAIL BY ENCOUNTER TYPES

To examine the remaining non-compliant behaviour it is appropriate to look at the exercises individually. In doing so, further insight on the influence of and human interaction with rules may be gained. In particular the following questions may be answered:

How can the rule-base or individual rules be modified to enfranchise the non-compliant mariners?

How may the non-compliant mariners be encouraged to comply?

Is it likely that the non-compliant mariners can be persuaded to comply?

To what extent does the non-compliant action undermine the coordination efforts to the rule-base?

7.6.1 The reciprocal course encounter

Exercises 1, 2, 2X, 3, and 3R were all green to green reciprocal course encounters. A rule-base that adopts anti-clockwise sight-line rotation as a convention, risks non-complementary action in the green to green reciprocal encounter.

If the mariner considers the initial passing distance in a reciprocal encounter to be too small, he must, according to the rules, alter to starboard to effect a red to red passing of appropriate distance. However, when the initial sight-line rotation is clockwise, the starboard alteration is unattractive because of the need to pass across the target vessel's head, and the distance to be covered before original course can be regained. The positive action must overcome the existing negative rotation before any red to red passing distance is produced. It is tempting for the mariner to alter to port. A port alteration is more in keeping with the natural principles suggested by Kemp (2.3.3.1). It is only when the issue of coordination is considered, that a port alteration is faulted.

The strategy implied by the current regulations requires an alteration to starboard to effect a red to red passing. It should be noted that an alteration to starboard, in this case, must be made early enough to cross ahead of the target with a suitable margin. Case law supports this common sense observation.[5] Standing on is accepted and presumes acceptance of the passing distance. An alteration to port is anti-strategy, although if taken at an early stage, when risk of collision could be deemed not to exist, it may not be considered as illegal. However, alteration to port is generally censured in texts interpreting the regulations.[6] An alteration to port to increase the passing distance infers that risk of collision exists and therefore the sense of alteration should be to starboard. In any case a port alteration contradicts what coordination attempts are made by the current rules and as such may be described as anti-regulation.

The graphs of data from other researchers (Figures 7.2/3/4), illustrate mariner action in green to green reciprocal encounters. There appears to be an opportunity for non-coordinated action in encounters with passing distances from 0.5 to 2.0M. The potential for non-coordination appears to maximise between 1.0 and 1.5M. The exercises 1, 2, 2X, 3, and 3R specifically test in this area.

All 16 mariners took part in at least two of the green to green reciprocal encounters. Of those 16, three (E,H,U) altered to port when the cpa was 0.9M as their usual action at sea. With a cpa of 1.4 E, H, and U would stand-on in the circumstances presented to them.

The new rules attempt to avoid non-complementary action by making alteration to starboard compulsory when the cpa is ≤1.0M. Port alterations are banned when the cpa is ≤1.5M. It is hoped that when the initial cpa is >1.5M the passing distance is accepted.

7.6.1.1 Exercise 1, 3, & 3R

Where appropriate, the results from exercises 1, 3, and 3R are discussed as a group.

Usual action:	6P	8M	19S
New action:	5P	4M	24S

Table 7.7
Exercise 1, 3, & 3R, usual and new manoeuvre sense results

7.6.1.1.1 Risk

Of the 33 exercise runs (16 persons), 8 (4 persons) usually stand-on at sea. In the light of new rules, on 4 occasions (3 persons) the risk criterion was accepted, an alteration to starboard being made. On the other 4 runs (2 persons) the need to stand-on was maintained. In this case the rule has had the effect of changing mariner behaviour concerning risk, on 4 out of 8 occasions.

7.6.1.1.2 Range

Of 25 exercise runs (16 persons), five (4 persons) usually manoeuvre after the twelve minute limit. New action saw late manoeuvres reduced to three (2 persons). Of these one mariner made two port alterations with only 7 minutes to domain infringement. Starboard alterations must be made earlier to effect a reasonable passing distance.

7.6.1.1.3 Sense of manoeuvre

The usual alteration was to port on a disturbing six (3 persons) out of 25 occasions (13 persons). Of the 6 exercise runs where usual action was an alteration to port, the new rules had the effect of changing action in one instance.

The 20 to 25% of usual port alterations suggested by these results, indicates that the current regulations in practice, are not providing a coordination solution. That the explicit instructions of the new rule-base did little to influence mariner behaviour suggests that the problem is deep rooted. A proportion of mariners clearly find the natural principle of increasing existing cpa more compelling than either set of rules.

7.6.1.1.4 Scale of manoeuvre

Exercise 1

Five out of five mariners who altered to starboard as usual action, would alter by 60-90°.

Eight out of eight mariners who made a starboard alteration as new action, would alter by 60-90°.

Exercise 3

Five out of seven mariners who altered to starboard as usual action would alter by 60-90°.

Nine out of nine mariners who made a starboard alteration as new action, would alter by 60-90°.

Exercise 3R

Three out of seven mariners who altered to starboard as usual action, would alter by 60-90°.

Five out of seven mariners who made a starboard alteration as new action, would alter by 60-90°.

Own vessel in exercises 1, 3, and 3R is a tanker at 10 knots, a tanker at 15 knots, and a container vessel at 21 knots respectively. It appears that as the vessels increase in collision avoidance ability (greater speed and manoeuvrability) the usual and new alteration is decreasing in scale.

7.6.1.2 Exercise 2 and 2X

	Exercise 2	Exercise 2X
Usual action	0P:9M:0S	0P:6M:3S
New action	0P:9M:0S	0P:5M:4S

Table 7.8
Exercise 2 and 2X, usual and new manoeuvre sense results

Under the new rules the mariners were allowed to alter to starboard or stand-on. The usual and new action was in keeping with the rules. In this case the rules did not need to alter mariner behaviour.

As before (1,3,3R Scale) the results suggest that vessel collision avoidance ability affects mariners' choice of manoeuvre. Both exercises had an initial cpa of 1.4M. In exercise 2, where own ship was a tanker at 10 knots, 9/9 mariners stood on as usual and new behaviour. In exercise 2X, where own ship was a container vessel at 21 knots, 3/9 would usually alter to starboard, and 4/9 altered to starboard as new action.

With some mariners altering when the cpa was 1.4M, the data collected does not indicate what action can be expected with a greater cpa. A greater initial cpa will generally result in more standing on. The results show this. They do not show whether those mariners who manoeuvre at cpa 1.4M will stand-on at a cpa of 1.6M (just outside the rule domain). Also, they do not show whether the mariners altering to starboard with a cpa of 1.4M, will be tempted to alter to port with a cpa outside the rule domain.

7.6.2 The crossing encounter

Three exercises tested the right angled crossing case. Exercise 6 and 7 had a target crossing from port that would pass ahead creating a cpa of 0.8M. In exercise 6 own ship was a tanker at 10 knots with the target at twice the speed. In exercise 7 own ship was a container vessel at 20 knots with the target at 18 knots. Exercise 7R was a reversal of exercise 7; own ship was a ferry at 18 knots.

7.6.2.1 Exercise 7R

Under the current regulations own ship is required to "give-way" to the target (Rule 15). If possible action should "avoid crossing ahead". For avoidance by course alteration this implies a turn to starboard.

7.6.2.1.1 Risk

Eight out of eight mariners made manoeuvres as usual and new action.

7.6.2.1.2 Range

Eight out of eight would usually act before the 12 minute limit.

Seven out of eight were agreeable to new action within the 12 minute limit.

One out of eight held that a manoeuvre in the 10th minute was agreeable given that a manoeuvre of 80-100° was required. His usual action was an alteration of 60°, 3 minutes earlier at 13 minutes.

7.6.2.1.3 Sense

Eight out of eight mariners turned to starboard as their usual and new action. It is noted that when validating the usual action results (7.3.5), a proportion of mariners would be expected to alter to port in these circumstances. The group of mariners participating in this exercise were of particularly high experience.

7.6.2.1.4 Scale

Four out of eight made a usual alteration of a scale that was in keeping with the rules (80-90°).

Six out of eight were agreeable to a new action alteration of 80-100°.

The remaining two maintained their usual action (60° and 70°).

This rule for the circumstances presented was largely uncontroversial. Four of the mariners would not usually alter so far to starboard. Two of the four were not agreeable to altering to the extent required. The responsibilities placed on own ship by this rule, in these circumstances, appear to be compatible with those accepted by the mariners under the existing COLREGS.

7.6.2.2 Exercise 6 and 7

7.6.2.2.1 Current regulations

Under the current regulations, if the vessels are in sight of one another, own ship is required to stand-on (Rule 15). The stand-on vessel may take action once it is apparent that the give-way vessel is not obeying the rules. This action must avoid if possible, an alteration to port (Rule 17(a)(i)). Rule 17(b) requires that the stand-on vessel takes avoiding action if she "...finds herself so close that collision cannot be avoided by her action alone..." The give-way vessel may be expected to take "...early and substantial action to keep well clear."(Rule 16).

7.6.2.2.2 New rules

The new rules require at or before 12 minutes, an alteration to starboard until the target is on the port beam. In exercise 6, this action decreases the cpa and the target will continue to cross ahead of own. The tcpa is increased and own-ship must stand-on until the new 12 minute point. After the new 12 minute point own-ship may continue the turn to starboard until the target is astern.

In exercise 7 altering to starboard until the target is on the port beam creates a cpa of 2 to 3M, with own crossing ahead.

	Ex. 6 and 7
Usual	2P:3M:21S
New	1P:0M:25S

Table 7.9
Exercise 6 & 7, usual and new manoeuvre sense results

7.6.2.2.3 Risk

Of the 26 exercise runs (13 persons), on 3 occasions (3 persons) the usual action was to stand-on. In the light of the new rules three out of three accepted the risk criteria and altered to starboard.

7.6.2.2.4 Range

The point at which action is taken shows a similar pattern across both exercises.

Port alterations

Both usual port alterations were made at 19-17 minutes, 9-7M.

Starboard alterations

The point at which usual starboard alterations were made range from 17 to 4 minutes, 8 to 2M. The mean usual point for alteration is 7.3 minutes, about 3½M. Excluding two particularly early actions by one mariner (G), the mean reduces to 6.3 minutes, about 3M. Three miles was also the mode.

On two out of 21 occasions (1 person) altered before the 12 minute point as usual action.

On 11 out of 25 occasions (10 persons) altered before the 12 minute point as new action.

This rule required considerable change in mariner behaviour. The rules had the effect of changing behaviour on 50% of occasions (see Table 7.6). The principle of standing on for a target on the port bow appears to have a strong effect, even in the face of contrary new rules.

7.6.2.2.5 Sense of manoeuvre

Of the two occasions (2 persons) when action would usually be an alteration to port, the rules had the effect of altering mariner behaviour once.

7.6.2.2.6 Scale of manoeuvre

The scale of an alteration to starboard is divided into four:

i) turns to put the target abeam

ii) turns up to a parallel course

iii) turns to put the target astern

iv) round turn (180° through to 360°)

The four types of turn are illustrated and quantified in Figure 7.8

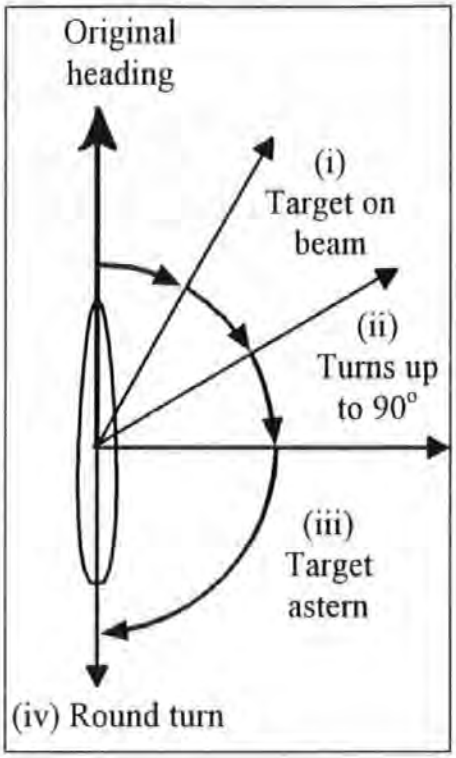

Figure 7.8
Exercises 6 and 7, divisions of the scale of manoeuvre
Source: Author

Exercise 6

The scale of starboard alteration in the circumstances of exercise 6 may be made in two stages, (1) and (2).

	Starboard alterations			
	Target on beam	Turns up to 90°	Target astern	Round turn
Usual (1)	1	4	0	5
Usual (2)	0	3	1	6
New (1)	6	3	0	3
New (2)	0	3	3	6

Table 7.10
Exercise 6, usual and new scale of starboard turn results

The usual scale of starboard alteration in these circumstances was to parallel the target's course (turns up to 90°) or take a round turn. Only one mariner would put the target on the port beam as usual action. About half the mariners were agreeable to the new action and would put the target on the port beam. Most of the converts were from those who would usually make a round turn. Of the four who usually altered to parallel the target's course only one was comfortable with the new rules.

In exercise 6 the target maintained her course making a secondary action necessary for the six mariners who had put the target on the port beam. Subsequent application of the manoeuvre diagram required a turn to starboard until the target was astern. Three would do this as new action, the remaining three making a round turn.

Those mariners paralleling the target's course make a solution to the encounter, with the target vessel standing on, with one manoeuvre. Three of the six mariners who would be happy to put the target on the port beam, saw this manoeuvre as an intermediate step to their usual round turn

Exercise 7

	Starboard alterations			
	Target on beam	Turns up to 90°	Target astern	Round turn
Usual	3	1	1	6
New	12	0	0	1

Table 7.11
Exercise 7, usual and new scale of starboard turn results

Three of the 11 mariners who usually altered to starboard would put the target on the port beam as usual action. A round turn to starboard would usually be taken by six of the twelve mariners. Ten out of 11 mariners who usually altered to starboard were agreeable to put the target on the port beam as new action. Twelve of 13 mariners who were agreeable to a starboard alteration as new action were also agreeable to put the target on the port beam.

7.6.2.2.7 Comparing exercises 6 and 7

Clearly mariners were more comfortable with the new rules in the circumstances of exercise 7 rather than exercise 6 as far as manoeuvre scale is concerned. In exercise 7 the new rules offered a proactive means to deal with the target on the port beam. While the rules were the same for exercise 6, the mariners were less comfortable with their use when in the more passive role.

7.6.3 Overtaking

Exercise 4R and 5R present own ship in an overtaking situation. In both cases own ship is a container vessel at 30 knots, and has a target on the starboard bow, at a speed of 10 knots. The cpa is 0.9M in both. In exercise 4R the initial sight-line rotation is anti-clockwise; in 5R the rotation is clockwise. The current rules require own-ship to keep clear of the target and, even under Rule 19(d), an alteration of course to port may be acceptable, especially in Ex.5R, but not normally in Ex.4R. The new rules require an alteration to starboard of 60-90° by the 12 minute point. The only significant difference in mariner behaviour between exercises 4R and 5R was that concerned with sense of manoeuvre (see below).

	4R			5R		
Usual action	1P	1M	6S	3P	0M	5S
New action	1P	0M	7S	3P	0M	5S

Table 7.12
Exercise 4R & 5R, usual and new manoeuvre sense results

7.6.3.1 Risk

On 15 of 16 occasions mariners manoeuvred as usual action. All 16 mariners manoeuvred as new action. In both exercises the requirements of the new rules concerning risk, were commensurate with nearly all the mariners' usual behaviour.

7.6.3.2 Range

The usual and new action ranged from 20-6 minutes, 8-3M. The mean new point of manoeuvre was 13.75 minutes, almost 6M. Ten out of 15 mariners would usually take action before the 12 minute point. The rules had no significant effect on the behaviour of the non-compliant mariners.

7.6.3.3 Sense

In exercise 4R, on the one occasion that a mariner altered to port as usual action, the rules had the effect of making new action a starboard alteration. Strangely one mariner who would usually alter to starboard, altered to port as new action. In exercise 5R five out of eight mariners altered to starboard as usual and new action. The rules had little significant effect on the sense of manoeuvre in either exercise. Although there are too few results from which to draw real conclusions, it appears that the initial negative sight-line rotation in exercise 5R has a strong influence on the choice of manoeuvre sense.

7.6.3.4 Scale

Only one of the 11 usual starboard alterations fell within the 60-90° scale. No mariner was persuaded by the new rules to make a starboard alteration of such an extent. In exercise 4R new action ranged from 10-40°. In exercise 5R new starboard alterations ranged from 20-65°. Nearly all mariners found the scale of starboard manoeuvre to be excessive.

7.6.4 Overtaken

In exercises 4A, 4B, 5A and 5B, own vessel is being overtaken. The initial scenarios are the reverse of exercises 4R and 5R respectively. The exercises 4 and 5 are each run with two RULE-SET versions A and B.

7.6.4.1Exercise 4A

7.6.4.1.1 Risk

Three out of eight mariners manoeuvred as usual action. Six out of the eight manoeuvred as new action.

7.6.4.1.2 Range

Of the three mariners who usually took action, two would wait until after the 12 minute limit. Five out of six mariners would wait until after the 12 minute limit as new action.

7.6.4.1.3 Sense

Two out of three mariners altered to starboard as usual action. Two of six mariners altered to starboard as new action. The rules made no impact of mariner behaviour here. An alteration to starboard in these circumstances could put own vessel into greater danger. In exercise 4B the mariner was left to decide an appropriate sense of manoeuvre. It is telling that all altered to port.

7.6.4.1.4 Scale

Of the two mariners who altered to starboard only one was within the scale prescribed by the rules, for both usual and new action.

7.6.4.2 Exercise 4B

7.6.4.2.1 Risk

Seven out of eight mariners manoeuvred as usual and new action.

7.6.4.2.2 Range

Six out of seven mariners altered after the 12 minute point as usual and new action.

7.6.4.2.3 Sense and Scale

There was no rule instruction as to the sense or scale of the manoeuvre. All seven mariners altered to port between 20° and 50°, as usual and new action.

7.6.4.3 Exercise 5A

7.6.4.3.1 Risk

Six out of eight mariners would usually take action. All eight manoeuvred as new action.

7.6.4.3.2 Range

Four out of six mariners would manoeuvre after the 12 minute point as usual action. Only two out of eight would wait until after the 12 minute point as new action.

7.6.4.3.3 Sense

Only one out of six mariners would usually alter to port. The same one out of eight would make a port alteration as new action. This action would be taken at the 16th minute (about six miles). A port alteration after the 12 minute point would put own vessel into danger.

7.6.4.3.4 Scale

The scale of port alteration required was between 20° to 40°. The single mariner altering to port as usual and new action would alter by 60° in each case.

7.6.4.4 Exercise 5B

7.6.4.4.1 Risk

Six out of eight mariners would usually make a manoeuvre. Seven of the eight manoeuvred as new action.

7.6.4.4.2 Range

Seven out of seven mariners would wait until after the 12 minute point for both usual and new action.

7.6.4.4.3 Scale and Sense

There was no rule instruction as to the sense or scale of the manoeuvre. Six out of six altered to starboard between 10° and 40° as usual action. Seven out of seven altered to starboard between 10° and 60° as new action.

7.6.4.5 Comparing exercise 5A and 5B

A significant difference between the results of 5A and 5B was that in 5B all mariners were prepared to wait until after the 12 minute point for their manoeuvres. In 5A only two out of eight would wait. It is suspected that the requirement of the RULE-SET A to make a specific manoeuvre has influenced the point at which the mariners would make their manoeuvre.

It is noted that different groups of mariners partook in the A and B exercises. The group that executed exercise 5B were mariners N to U, who were noted earlier as having a higher mean level of experience than the other group, A to H. However it is thought that this is unlikely to be significant in this case.

7.6.4.6 Comparing RULE-SETS A and B

Rule set B is clearly more acceptable to mariners in the given circumstances. Inspection indicates that rules specifying a particular sense of manoeuvre and a fixed risk criterion, cannot be safely applied to the general case for vessels of "slow" speed. This phenomenon may be especially noticeable when one is being overtaken. The mariners left to make up their mind what sense of manoeuvre to make, waited until after the 12 minute point, hence attempting to maintain the coordination efforts of the rules. This suggests that the approach of RULE-SET B, with regard to escape action, is the correct one.

7.6.4.7 Objective rules adversely affecting mariner behaviour

Rule set A (apart from the caveat of Rule 2) applied to the overtaking exercises (4 and 5) would put own vessel further into danger. The issue of objective rules inappropriately influencing mariner behaviour may be examined here. That only once out of 16 occasions (E in exercise 4A) were the rules followed as wrote, indicates that the mariners were able to recognise circumstances in which the rules could not be safely applied. However the prescriptive sense of manoeuvre required in 5A inappropriately affected the range at which action was taken.

7.7 CONCLUSION AND SUMMARY

7.7.1 Validity

The "usual" action data collected in the experiments appears to show a reasonable amount of validity when compared to the work of other researchers. However, the sample is small.

The validity of "new" action data cannot be ascertained without full scale real life implementation of the new rules. Factors that will create a difference between the results and actual mariner behaviour if there is full scale real life implementation include:

the mariners making up the human sample were not fully indoctrinated into the new rule system;

the simulation of encounters is a pseudo representation of real life events which will to a certain extent make the mariners act differently;

human behaviour is influenced over time by experience; action today may not be representative of action in 10 years time;

the force of law and commensurate threat of retribution is not acting on mariners during the simulation exercises or questionnaire.

Despite the difference factors it is held that the data does suggest what may be acceptable practice, and what rule elements have a chance of implementation.

7.7.2 What is the effect of the rules?

The new rules affected mariner behaviour. The effect varied depending on the particular exercises. Given the particular experiments carried out, the risk rule had a large effect and the sense rule a small one. The mariners maintained a critical view of the rules. It is comforting that mariners are prepared to break the rules in order to avoid dangerous situations. It is equally disturbing when, despite objective rules, some mariners persist with behaviour which is ripe for a non-complementary response from a target.

7.7.3 What is the chance of implementing the rule-base?

The chance of implementing the RULE-SET A as a whole as it stands would be almost none. Rule set B with its less prescriptive approach to escape action would have a better chance but would suffer many rule infringements.

7.7.4 What is the chance of implementing individual rules?

Given the particular exercises that were run, the least contentious part of the rules was that concerning risk. The one mile circular domain as a criterion for risk appears to have a good chance of being implemented. Further work concentrating on acceptance by slower vessels is necessary. The acceptance and effectiveness of the 1½M close quarters' domain has not been properly ascertained.

The successful implementation of the point of manoeuvre rule is not certain. Other parts of the rule-base influenced the acceptance of this rule. For this rule to be successfully implemented a programme of education emphasising the importance and reasons for the rule would be needed.

Rule set A required sense of manoeuvre action that put own vessel further into danger. If the exercises specifically concerned with RULE-SET A are ignored, there are only 10 out of 83 occasions (12%) when mariners were not comfortable with the rules. While this is not a great proportion the anti-rule behaviour is likely to be deeply rooted and would be difficult to change. The new rules had almost no effect on this aspect of mariner behaviour.

The scale of manoeuvre required by the rules was the part least accepted by the mariners. The manoeuvre diagram was originally intended as advice when vessels were not in sight of each other. The rule-base had basic data requirements of target range and bearing. In practice however mariners had ARPA data and visual input. The mariners appear not to accept the general approach of a manoeuvre diagram which assumes no knowledge of target heading. It is also clear that knowledge of own speed influences acceptable scale of manoeuvre: a faster speed encourages a lesser manoeuvre. The rules had a significant effect on mariners behaviour but ended with one third remaining non-compliant. It is unlikely that this rule would be rigorously adhered to. In most cases the exact scale of manoeuvre is not critical which may explain why the rules had a significant effect.

7.7.5 How can the rule-base or individual rules be modified to enfranchise the non-compliant mariners?

As already mentioned the RULE-SET B would have a much better chance of implementation than set A. The less prescriptive approach for escape action is more acceptable to mariners and appears to better maintain coordination by encouraging mariners to stand-on until action is absolutely necessary.

The prescription of scale of manoeuvres appears to be not only inefficient but unacceptable to mariners in the general case. Removing the general requirement to manoeuvre to a particular extent would not harm the coordination efforts of the rules. An alternative quantitative requirement could be to make manoeuvres that create a prospective cpa of a prescribed distance. Mariners successfully make judgements to this effect at present.

A special case of prescribed manoeuvre scale is for targets bearing red 30° to 67½°. The requirement to "turn to starboard until the target is abeam to port" makes the maximum contribution possible to anti-clockwise sight-line rotation. There is some value in retaining this scale of manoeuvre. However the whole idea of altering for a vessel crossing from port had a mixed reception in the experiments. When it was possible to cross ahead of the target, the action was almost unanimously accepted. When unilateral action did not allow own-ship to pass ahead, and a secondary manoeuvre was needed, acceptance was mixed.

It would be less controversial if with a target crossing from port own-ship was allowed to stand-on as is the case in the COLREGS 72. Knowledge of target heading would be required in order to apply the rule. It was a criterion derived from the technological scenario that target heading data was not available. Alternatively, standing on could be an option if target heading was known and indicated a crossing vessel. In any case it is thought that the mariners discomfort with this rule is largely due to unfamiliarity. The simulator experiences were worst case scenarios and were not designed to indicate the general benefits of being able to proactively contribute to a coordinated solution.

7.7.6 How may, and is it likely that, the non-compliant mariners can be persuaded to comply?

The use of education would greatly enhance the success of any rule implementation. The education and experience associated with the current regulations are what have made the current regulations almost sacrosanct for many mariners. The role of education and especially experience through simulators would be to introduce and indicate the benefits of a new rule system. Such education would need to overcome the prejudice embedded through past practice and experience. While it may be difficult to reverse wholly the pattern of behaviour in experienced mariners, new recruits will be more susceptible to indoctrination of fresh practices.

Education may have limits. The exercises of this thesis and the work of others indicates that a proportion of mariners persist in action that overtly disregards rules whether they be the COLREGS 72 or proposed new rules. Anti-regulation action is typically altering to port in reciprocal course or crossing encounters. The COLREGS 72 and various commentaries make it clear that altering to port is ridden with danger and not generally acceptable. The new rules are explicit in their requirements and yet the anti-rule behaviour of the COLREGS 72 is maintained. Such behaviour has withstood all influences of education.

New technology may offer a solution in the policing ability of automatic data recording and transmission as considered in chapter 3 (3.6.2). In using a quantified rule-base it is simple to define anti-rule behaviour, at least for two vessel open water encounters. Rule infringements can now be prosecuted which may in turn have a regulating effect on mariner behaviour.

7.7.7 To what extent does the non-compliant action undermine the coordination efforts of the rule-base?

The most significant non-coordination comes from mariners who alter course with the incorrect sense. In general with a target forward of the fore aft line an alteration to starboard is required. If the target has own vessel in its forward sector then only starboard alterations will do. Mariners who alter to port in these circumstances are likely to undermine the coordination effort of the rule-base.

Vessels being overtaken need to stand-on until the 12 minute point. Although the rules command the overtaking vessel to alter to starboard, it appears that this requirement is not generally acceptable. In practice the overtaken vessel must expect to have the target alter to pass her on either side. Conversely the overtaking vessel should act before the 12 minute point to avoid pre-empting the stand-on vessel's manoeuvre. The experiments showed that in general the overtaken vessels, when allowed to make their own appropriate manoeuvre, would stand-on until at least 12 minutes. However a proportion of the <u>overtaking</u> vessels left manoeuvres too late, which could result in non-complementary action.

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"Doctoratitis. The assumption that a man's worth is to be measured by mere diligence. A man spends three years minutely documenting documents if you understand my meaning, anyway investigating issues that have escaped more discerning scholars, and emerges from the ordeal with a doctorate which is supposed to be proof of his intelligence. Than which I can think of nothing more stupid. But there you are, that's the modern fashion. It comes, I suppose, from a literal acceptance of the ridiculous dictum that genius is an infinite capacity for taking pains. These fellows seem to think that if you can demonstrate an appetite for indigestible and trivial details for three years you must be a genius. In my opinion genius is the capacity to jump the whole process of taking infinite pains, but then as I say, nobody listens to me. I mean there must be millions of people taking whatever these infinite pains are without a spark of intelligence let alone genius between them. And then you have a silly fellow like Einstein who can't even count... It depresses me, it really does, but it's the fashion." The Dean of Porterhouse College

in TOM SHARPE *Porterhouse Blue*, Secker and Warburg, 1974, p.148.

CHAPTER 8

CONCLUSION

8.1 DESCRIBING THE PROBLEM

In chapter 2 various fundamental elements of the collision avoidance problem have been derived and described. The term "risk of collision" is used to define the state when action to avoid collision is necessary (2.3.3). It is noted that risk of collision cannot be eliminated in practice. An acceptable level of risk must exist for any marine venture (2.2.4). Statistically, risk increases with proximity to land and commensurate increase in traffic density. In practice, acceptable risk rises, and passing distances decrease. The human mariner's perception of acceptable risk is known to vary with circumstances.

8.1.1 Complementary action

The establishing and maintenance of sight-line rotation of approaching vessels has previously been cited as an essential collision avoidance principle (2.3.1). It is deduced therefore that the action of two vessels should aim to be complementary, and not cancel each other's contribution to sight-line rotation. Three complementary action strategies that achieve this have been defined (2.3.3). To avoid cancelling action, vessels must each adopt the same strategy in a particular case.

Natural principles as defined by Kemp, do not provide a means for vessels to ensure that each applies the same strategy (2.3.3.1). A vessel can wait until the other manoeuvres, thus indicating her perception of what is the required strategy. However it is not always possible to observe the action of the other vessel, and in any case, it is not satisfactory for each vessel to be indefinitely waiting for the other to manoeuvre. For the complementary strategies to be mutually adopted, a form of coordination must be imposed.

8.1.2 Rogue vessels

An examination of the three strategies, indicates that when the target appears to be a rogue, anti-strategy action may be necessary (2.4.3).

8.1.3 Coordination requirements

An examination of possible reasons for a target appearing as a rogue (2.4.4), indicates that to minimise rogue behaviour, vessels must have a mutual perception of risk, and when to manoeuvre, as well as the strategy to be applied (2.4.5). The three items of mutual perception are coordination requirements. It has been noted that rules can form a tacit agreement between parties and hence aid coordination (2.4.6.3).

8.1.4 Rules

It has been said that rules should require action which is as close to mariners' natural behaviour in order that they are most likely to be followed. Conversely the role of a rule is to bring a spectrum of natural behaviour to a narrow set of normal behaviour. There is a compromise to be had between achieving normal behaviour and creating a rule which will be followed (2.5.2.1).

8.1.5 Rule limitations

Rules which try to cater for all variables will become infinitely complex. Rules for operational use by humans must be relatively simple. This means that whether following a set of rules produces a useful result depends on the circumstances of the case (2.6.3).

8.1.6 Current Regulations

The current regulations use a variety of concepts and procedures (2.7). The data inputs implied by the current collision regulations have been noted (Table 2.1). The current rules do not meet the coordination requirements of providing mutual perception of risk and when to manoeuvre (2.7.4). Mutual perception of strategy is not always provided by the current rules. The current rules imply that the mariner is responsible for avoiding collision regardless of circumstances (2.7.5). The mariner must know when, and when not, to apply the rules.

8.2 TECHNOLOGY

Chapter 3 examines the current and developing technology which may be applied to the collision avoidance problem. A collision avoidance system may be considered as having sensor and processor elements. A sensor acts as a transducer, obtaining data from the environment which is passed to the processor. Human sensors include the eye and ear.

8.2.1 Machine sensors

Machine sensors are marine radar and other radio communications (3.4). Use of primary radar is wide spread on merchant vessels. Vhf radio-telephone is common on all classes of vessel. The use of mobile satellite communications continues to grow. Digital selective calling for terrestrial and space segment communication allows large amounts of data to be transferred efficiently.

8.2.2 Automatic cooperative communications

The concept of automatic cooperative communications (ACC) covers technology that allows vessels to share information automatically with other parties (3.4.4). The base technology for a sophisticated exchange of information between vessels is already being demonstrated. The specifics of any system depend as much on political-economic as technological issues. The most sophisticated ACC system could revolutionise collision avoidance practice.

8.2.3 Machine processors

Processors take data from the sensors and use it to produce useful information for solving the collision avoidance problem (3.5). ARPA and advisory expert systems are sub-processors that pass on information to primary processors such as the human brain or automatic expert systems. ARPA is common on large merchant vessels. Technological advance will make ARPA available to all vessels that currently carry radar. The information derived through ARPA gives a quantitative description of the geometrical and dynamic relationship between own and target vessels. Expert systems are finite in their field of application. Machines that are truly intelligent do not yet exist.

8.2.4 General technology

A high accuracy Global Navigation Satellite System (GNSS) for vessel positioning is likely to evolve from the technology of GPS and GLONASS. Moves are being made to administer such a system on an international civilian basis. The transmission of own GNSS position through an ACC system will be influential on collision avoidance practice (3.6.1).

The combination of ACC and "black box" technology would allow the automatic recording and reporting of collisions and near misses. This potential development brings the opportunity to detect automatically action that is proscribed by quantitative regulations. This may affect mariner behaviour and the acceptance of rules (3.62 and 7.7.6).

8.2.5 Automatic collision avoidance system

By definition an automatic collision avoidance system has no human input. A range of technological scenarios for an ACAS have been considered (3.7). The most advanced, with truly artificially intelligent processing and commensurate sensors, may be able to mimic all human functions. Simpler systems with expert system type processing can be imagined with a range of supporting technology.

8.3 TECHNOLOGY AND RULES

Chapter 4 describes the relationship between the collision avoidance system and the collision regulations. The data and information that are implied by the rules must be compatible with that which the CAS can produce.

The current manual collision avoidance system cannot meet data input requirements that are implied by the COLREGS 1972.

An ACAS that is truly artificially intelligent and has machine vision, will probably also have use of sophisticated ACC. Such a system could comply with the data requirements of the COLREGS 72. The use of true artificial intelligence opens questions of responsibility in all fields not just that of collision avoidance.

The use of an expert system type processor is not compatible with the COLREGS 72. The use of such a machine requires the judicial recognition of the discrete rule-base that makes up the machine's program.

The availability of certain sensors determines the ability to comply with several COLREGS 72 rules. Without machine vision an ACAS does not have the data inputs necessary to distinguish between the need to apply the rules of section II or III. The sophistication of ACC determines whether Rules 16 and 17, and Rule 18 can be complied with.

8.4 RULES FOR AN ACAS

The development of rules for an ACAS is described in chapter 5. This thesis tests the human application of a rule-base that is suitable for a certain ACAS technological scenario. The scenario is one with an expert system processor, and sensors limited to radar. This leads to a rule-base that has target range and bearing as the only inputs, and quantification as a reflection of the ACAS program. In using quantification it has been possible to meet the three coordination requirements of providing means to achieve a mutual perception of risk, point of manoeuvre and the strategy to be applied. Mutual perception of risk requires the use of a circular domain centred on own vessel. Mutual perception of when to manoeuvre uses

RDRR theory with defined points at which responsibility changes. An element of dual responsibility has been adopted by use of a manoeuvring diagram which implies anti-clockwise sight-line rotation. Single responsibility "protects" vessels being overtaken. The rule-base as presented to mariners was contained on four sides of A4 paper including explanatory diagrams (Appendix A).

8.5 SIMULATION EXPERIMENTS

Chapter six describes the simulation experiments. Mariners were asked to apply the new rules to encounters presented in a navigation simulator. Immediately after the exercise a verbal questionnaire was used to ascertain the mariner's usual action at sea and what action he was agreeable to take in the light of the new rules.

8.6 EXPERIMENTAL RESULTS

The experimental results are described in chapter 7. The number of runs of particular exercises was too small to offer value in a statistical analysis. The data for mariner's usual action at sea appears to make a reasonable match with that of previous researchers. Specific areas where it must be suspected that there is a difference between actual behaviour and behaviour reported by the results have been highlighted. The differences are marginal and do not invalidate the whole of the data (7.3.6.2).

The data for mariner's action in the light of new rules (new action) cannot be taken as a direct representation of actual mariner behaviour in the event of the new rules being implemented (7.4). The new action data does have value by indicating the important issues linked with applying a quantitative rule-base. The issues that are raised would warrant further investigation before action is taken.

The majority of action required by the new rules was in keeping with mariners' usual practice. The new rules had a significant effect on the occasions that they demanded a change in behaviour. However a critical view of the rules was maintained by the mariners. They would not follow rules that put their vessel into danger and the influence of prior experience was evident.

There would be no real success in implementing either version of the rule-base as a whole. The less prescriptive approach to escape action, in set B, had better results, and is the more appropriate way. The requirement to alter at an early stage with a target crossing from port was unfamiliar. It would be less controversial to allow standing on as an option, although this implies knowledge of target heading in order to distinguish between crossing and overtaking situations.

8.6.1 Implementing individual rules

The experimental results indicate little that condemn the concept or size of the circular risk domain. This aspect of the rules shows the most promise for ease of application. Further work will need to consider vessels of slow speed and their difficulty in unilaterally overcoming existing sight-line rotation (7.5.1.1).

The experimental results indicate little that condemn the concept or size of the circular risk of close quarters domain. However the results were too few and isolated to be of any significant value.

Quantitatively regulating the point of manoeuvre may be the most important aspect of rules. The experimental results were mixed. Other aspects of the rules had an influence on the acceptance of this rule. Future work needs to test this rule type in isolation (7.5.1.2).

The sense of manoeuvre required by the new rules was often commensurate with usual behaviour. On the relatively few occasions that sense of manoeuvre needed to be changed the rules had little effect. The limited number of results suggests that rules will often have difficulty in changing the sense of manoeuvre that a mariner would otherwise make (7.5.1.3).

The scale of manoeuvre required by the new rules was often excessive. Knowledge of target heading caused mariners to minimise the size of their alterations. A more appropriate quantification of the scale of manoeuvre may be to require a new cpa of prescribed distance (7.7.5).

8.6.2 Own speed

Own speed appears to affect agreeable manoeuvres in two ways. First with greater speed comes a greater willingness to manoeuvre to increase a passing distance (7.6.1.2). Second with greater speed there is a tendency towards decreasing the initial scale of the collision avoidance manoeuvre (7.6.1.1.4).

8.6.3 Education

The use of education will be essential to accompany any major change in collision regulations. Acceptance of the rules is increased with individuals' understanding of the accompanying reasons and benefits. Education may have limits. Some usual action that is clearly anti-COLREGS 72 persisted and became new action, despite the unequivocal instructions of the new rules (7.7.6).

8.7 RECOMMENDATIONS - FURTHER WORK

The case for judicial recognition of a discrete rule-base for the sake of an ACAS has been made in this thesis. Such a rule-base would have legally sanctioned quantification throughout. This leads to the prospect of quantified collision regulations for application by human mariners. However ACAS are not the only grounds from which quantified collision regulations may evolve.

The coordination requirements of mutual perceptions have been discussed (2.4.5). ARPA technology is growing in availability and can provide quantified data to a reasonable accuracy. This data coupled with quantified rules means that mutual perception can now be achieved. ACC offer the prospect of quantified data to an accuracy and availability greater than ever before (3.4.4).

Interactive PC based software is being used for collision avoidance training and it is being proposed for testing for qualifications. Such interactive systems have quantification built in. The training and qualifying exercises imply acceptable quantification (3.6.3).

Any move towards large scale MTC would undoubtedly make use of computer run algorithms in order to help control traffic. Again this implies quantification of collision avoidance parameters. An expert system onboard ship, even in the guise of an advisory system, must have embedded quantification when applied to collision avoidance. On-line decision support from a piloting expert system suggests embedded quantification which may be linked to collision avoidance (3.5.2.1).

The argument for having quantification in collision regulations clearly can encompass more than ACAS. The testing of the human application of such rules has merit. The preliminary experimental study carried out as part of this thesis has indicated a number of issues which may be worthy of further investigation.

1. The experimental testing, in isolation, of the risk element of the rule-base. Particular effort should be given to the problems of slow speed vessels and the effectiveness of the close quarters domain concept.

2. The experimental testing, in isolation, of the point of manoeuvre element of the rule-base. By using this idea to quantify the responsibilities of the give-way and stand-on vessel under the current rules a better test can be made. The full value of such a rule will be seen while extraneous effects from other new rules will be avoided. Particular attention may be given to general rules applied to extremes of vessel speed and relative speed.

3. The experimental testing and theoretical analysis of a limited dual responsibility rule for a target crossing from the port side. The action of putting the target on the port beam is theoretically, and at least sometimes practically, attractive.

4. The experimental testing and theoretical analysis of objective rules in multi-ship encounters and encounters in confined waters. Simple rules, especially quantitative rules can be made to crack in complex situations (2.6). Matters of importance are:

How may be rules and quantitative limits be best squeezed in order to maintain the coordination integrity of the rule-base?

What risk is there of the mariner being inappropriately influenced by the rules, when in a complex situation which he would have otherwise dealt with satisfactorily?

8.8 KEY POINTS

1. Domain dependent processors require their limitations to have judicial recognition. This implies the statutory prescription and consequential judicial recognition of a discrete and quantified rule-base.

2. Domain dependent processors are not compatible with the COLREGS 72.

3. The COLREGS 72 imply various data inputs. Whether a collision avoidance system can meet the requirements will depend on the specific technology being employed.

4. The COLREGS 72 do not adequately provide the means truly to coordinate action between vessels.

5. Particular objective criteria are required if rules are to be used to help ensure coordination of vessels' actions.

6. The human application of a discrete and objective rule-base raises many issues, some of which are highlighted in this thesis.

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Appendix

Table of Contents

RULE-SET A

1. Responsibility

The mariner is responsible for making suitable decisions and taking appropriate actions to avoid collision under these rules.

2. Departure from these rules

Departure from these rules will only be tolerated if action under the rules does not allow risk of collision to be avoided. When making a departure from these rules, the rule obligations on target vessels must be taken into consideration.

3. Definitions

i)"own risk domain" is an area bounded by a circle of radius 1 mile centred on own vessel.

ii)"own close quarters domain" is an area bounded by own risk domain circumference, and a circle of radius 1.5 miles centred on own vessel.

iii)"fore/aft boundary line" runs through own vessel from 112.5° to 292.5°. This delineates between targets "forward" or "aft" for the purpose of these rules.

iv)"Risk of collision" exists if "own risk domain" is infringed by the relative velocity vector of the target vessel. i.e. CPA in range 0.0 to 1.0 inclusive.

v)"Risk of close quarters" exists if own "close quarters domain" is infringed by the relative velocity vector of the target vessel. i.e. CPA in range 1.1 to 1.5 inclusive

4. Manoeuvre requirements

a) Freedom - vessels operating under manoeuvre class "freedom" are free to manoeuvre(or stand-on) in any sense which does not result in a subsequent "risk of collision" or "risk of close quarters" situation.

b) Convention - vessels operating under manoeuvre class "convention" must use those manoeuvres prescribed on the manoeuvring diagram.

c) Stand-on - vessels operating under manoeuvre class "stand-on" must hold their course and speed.

5. Manoeuvre class application

a) Risk of collision

i) For targets forward of the fore/aft line:

When own risk domain is infringed by relative velocity vector of:

>18 minutes, manoeuvre freedom applies;
18 to 12 minutes, manoeuvre convention or stand-on applies;
<12 minutes, manoeuvre convention applies.

ii) For targets aft of the fore/aft line:

When own risk domain is infringed by relative velocity vector of:

>18 minutes, manoeuvre freedom applies;
18 to 12 minutes, stand-on applies;
12 to 6 minutes, manoeuvre convention or stand-on applies;
<6 minutes, manoeuvre convention applies.

b) <u>Risk of close quarters</u>

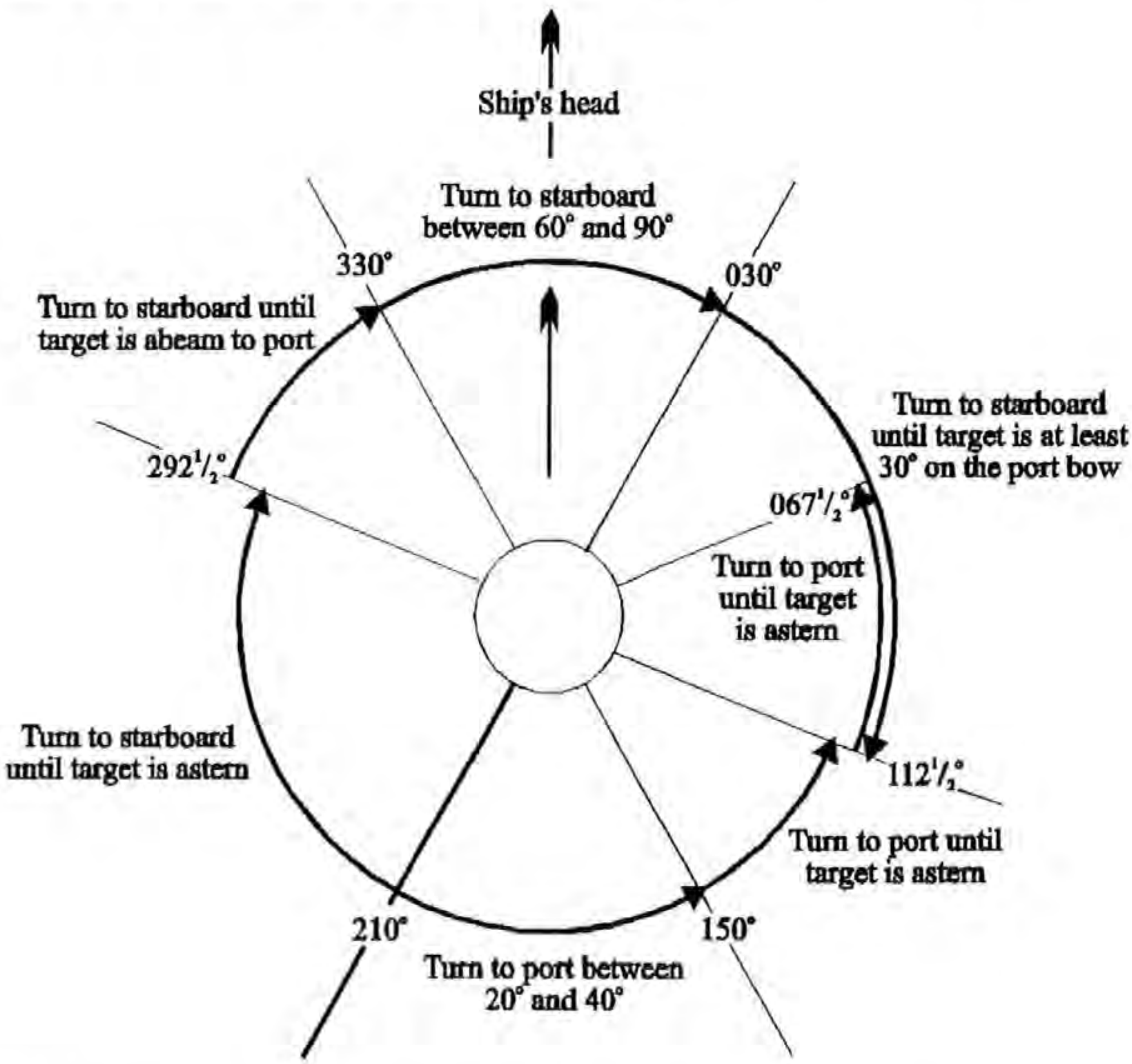
For all targets:

When own close quarters domain is infringed by relative velocity vector of <18 minutes, manoeuvre convention or stand-on applies.

6. Manoeuvre convention diagram

Convention manoeuvres depend on target relative bearing and are prescribed by the manoeuvre diagram.

If the convention manoeuvre given is not considered sufficient, a subsequent application of the manoeuvre diagram may be made by using the target's new relative bearing.

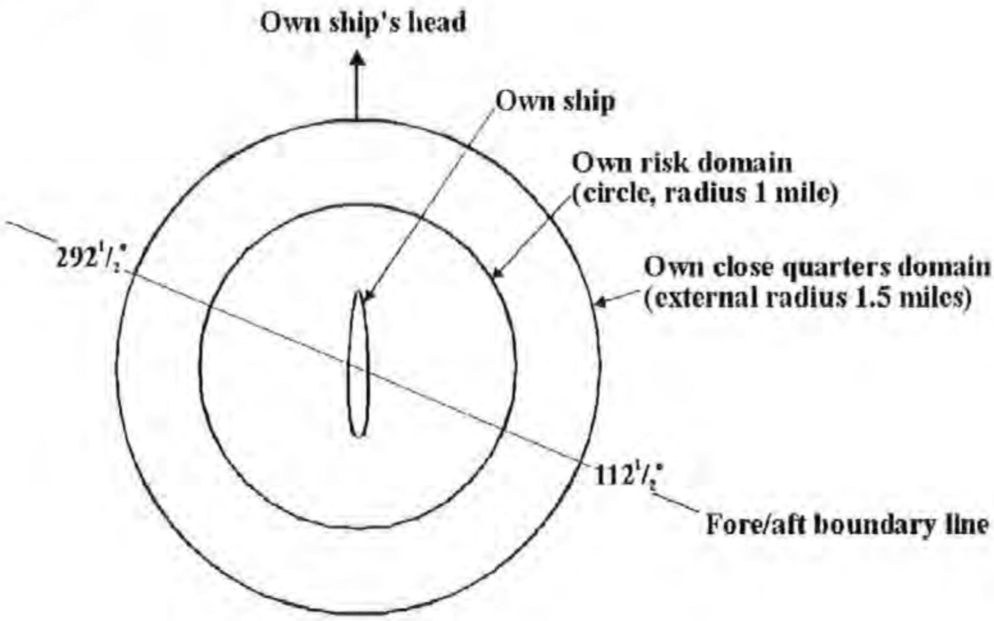


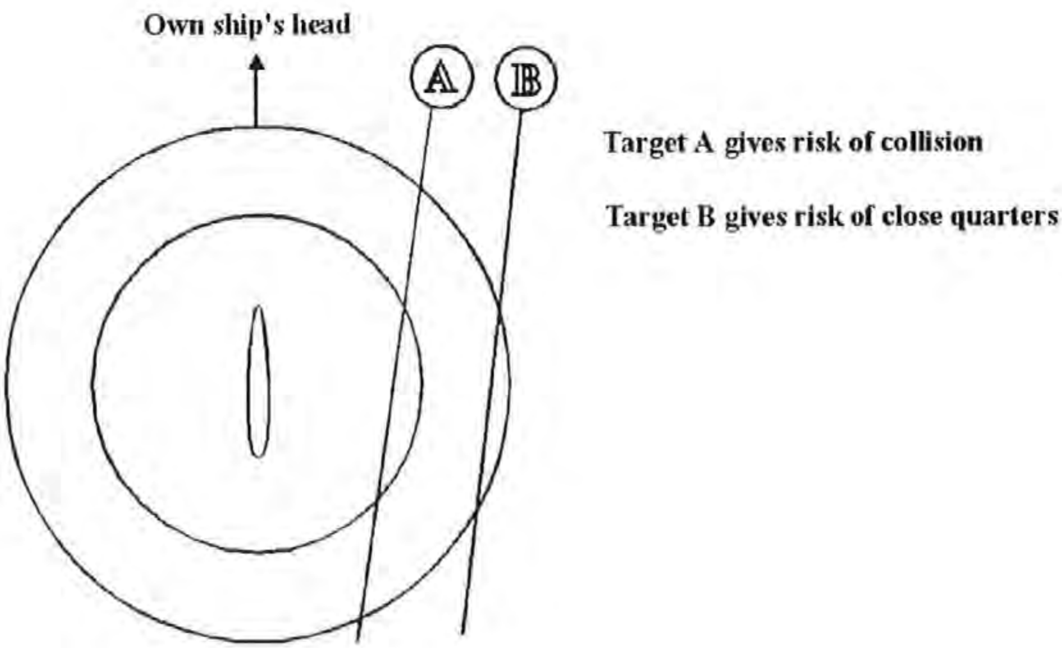
7. Return to course

Having manoeuvred to avoid collision, a return to original course may only be made when that course will give a CPA of at least 1.5 miles.

<u>RULE-SET A</u> continued

<u>Definition diagrams</u>
Own risk domain
Own close quarters domain
Ford/aft boundary line
Risk of collision
Risk of close quarters

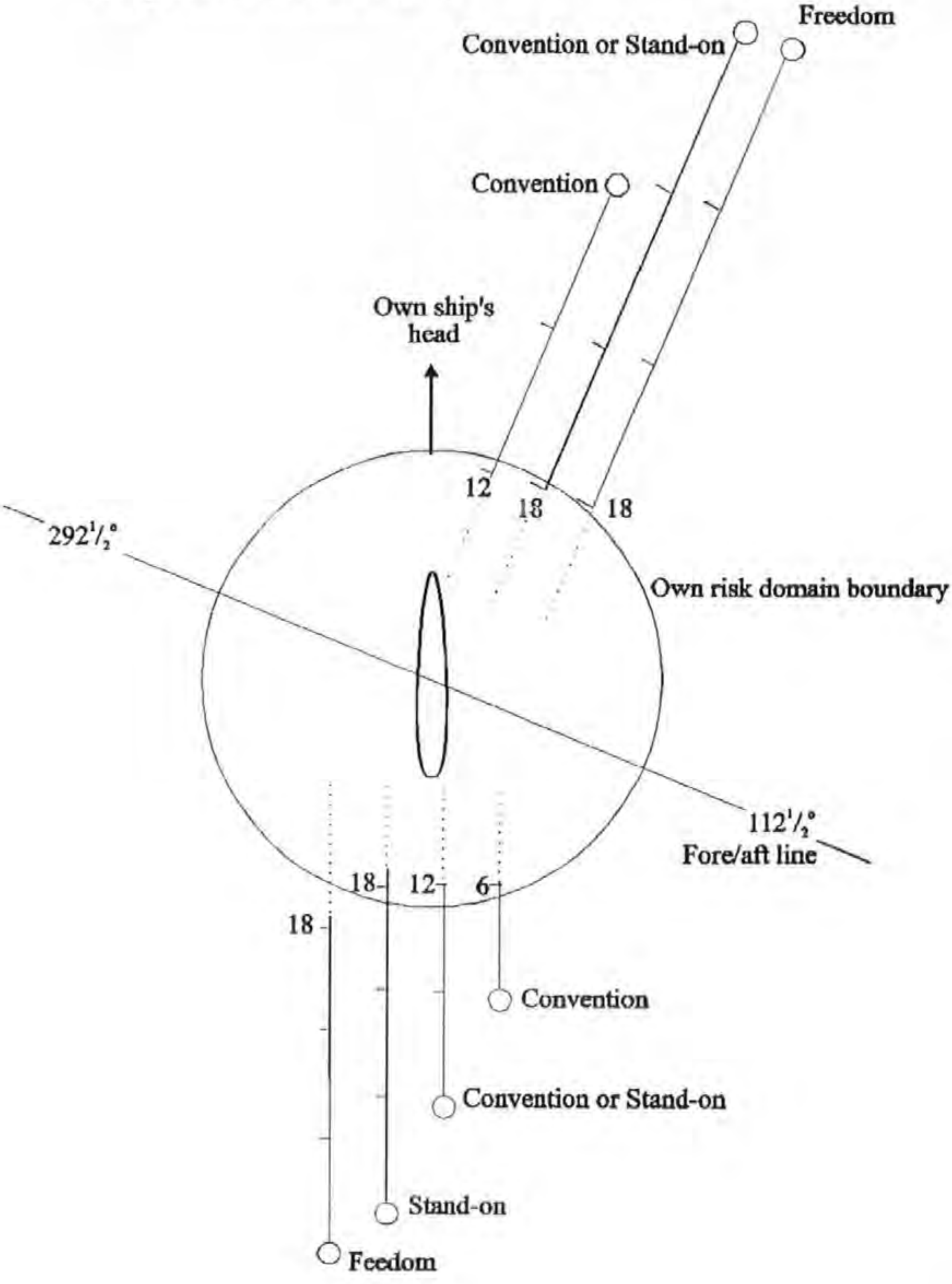




RULE-SET A continued

Manoeuvre Class Application Diagram

This diagram shows the applicable manoeuvre class with respect to:
- infringement of own risk domain,
- by relative velocity vector of varying length,
- for targets forward and abaft the beam.



RULE-SET B

1. Responsibility

The mariner is responsible for making suitable decisions and taking appropriate actions to avoid collision under these rules.

2. Departure from these rules

Departure from these rules will only be tolerated if action under the rules does not allow risk of collision to be avoided. When making a departure from these rules, the rule obligations on target vessels must be taken into consideration.

3. Definitions

i)"own risk domain" is an area bounded by a circle of radius 1 mile centred on own vessel.

ii)"own close quarters domain" is an area bounded by own risk domain circumference, and a circle of radius 1.5 miles centred on own vessel.

iii)"fore/aft boundary line" runs through own vessel from 112.5° to 292.5°. This delineates between targets "forward" or "aft" for the purpose of these rules.

iv)"Risk of collision" exists if "own risk domain" is infringed by the relative velocity vector of the target vessel. i.e. CPA in range 0.0 to 1.0 inclusive.

v)"Risk of close quarters" exists if own "close quarters domain" is infringed by the relative velocity vector of the target vessel. i.e. CPA in range 1.1 to 1.5 inclusive

4. Manoeuvre requirements

a) Freedom - vessels operating under manoeuvre class "freedom" are free to manoeuvre(or stand-on) in any sense which does not result in a subsequent "risk of collision" or "risk of close quarters" situation.

b) Convention - vessels operating under manoeuvre class "convention" must use those manoeuvres prescribed on the manoeuvring diagram.

c) Stand-on - vessels operating under manoeuvre class "stand-on" must hold their course and speed.

5. Manoeuvre class application

a) Risk of collision

i) For targets forward of the fore/aft line:

When own risk domain is infringed by relative velocity vector of:

>18 minutes, manoeuvre freedom applies;

18 to 12 minutes, manoeuvre convention or stand-on applies;

<12 minutes, manoeuvre convention applies.

ii) For targets aft of the fore/aft line:

When own risk domain is infringed by relative velocity vector of:

>18 minutes, manoeuvre freedom applies;

18 to 12 minutes, stand-on applies;

<12 manoeuvre convention or stand-on applies.

RULE-SET B continued

b) Risk of close quarters

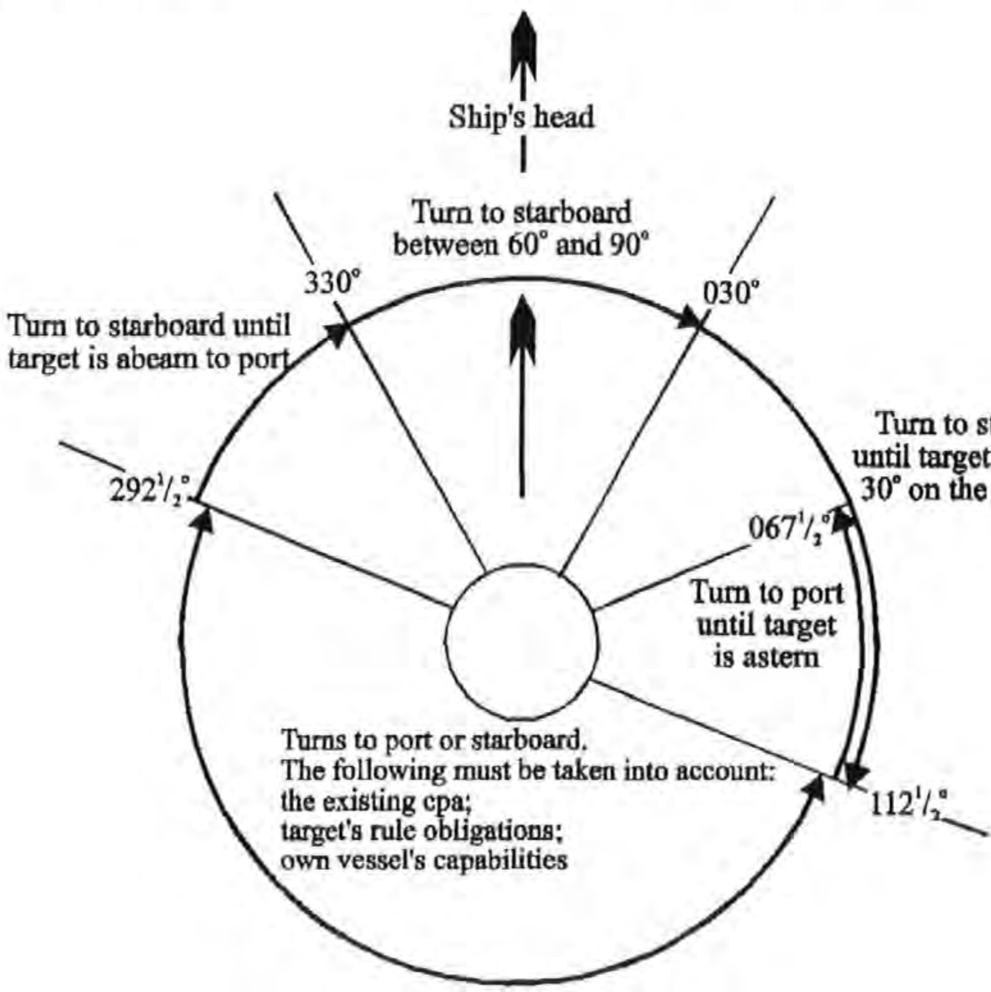
For all targets:

When own close quarters domain is infringed by relative velocity vector of <18 minutes, manoeuvre convention or stand-on applies.

6. Manoeuvre convention diagram

Convention manoeuvres depend on target relative bearing and are prescribed by the manoeuvre diagram.

If the convention manoeuvre given is not considered sufficient, a subsequent application of the manoeuvre diagram may be made by using the target's new relative bearing.

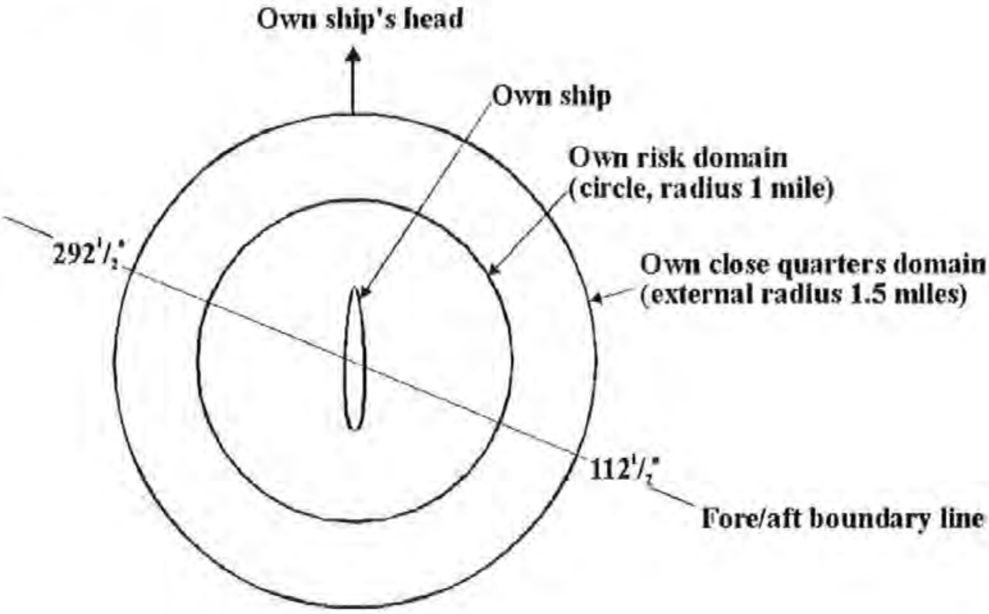


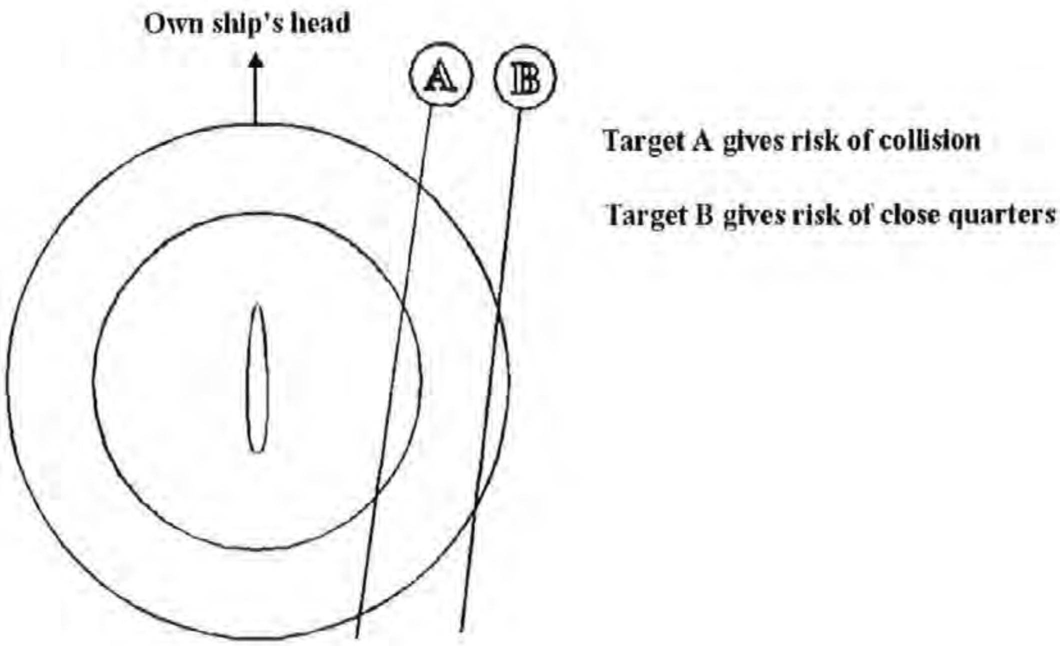
7. Return to course

Having manoeuvred to avoid collision, a return to original course may only be made when that course will give a CPA of at least 1.5 miles.

<u>RULE-SET B</u> continued

<u>Definition diagrams</u>
Own risk domain
Own close quarters domain
Fore/aft boundary line
Risk of collision
Risk of close quarters



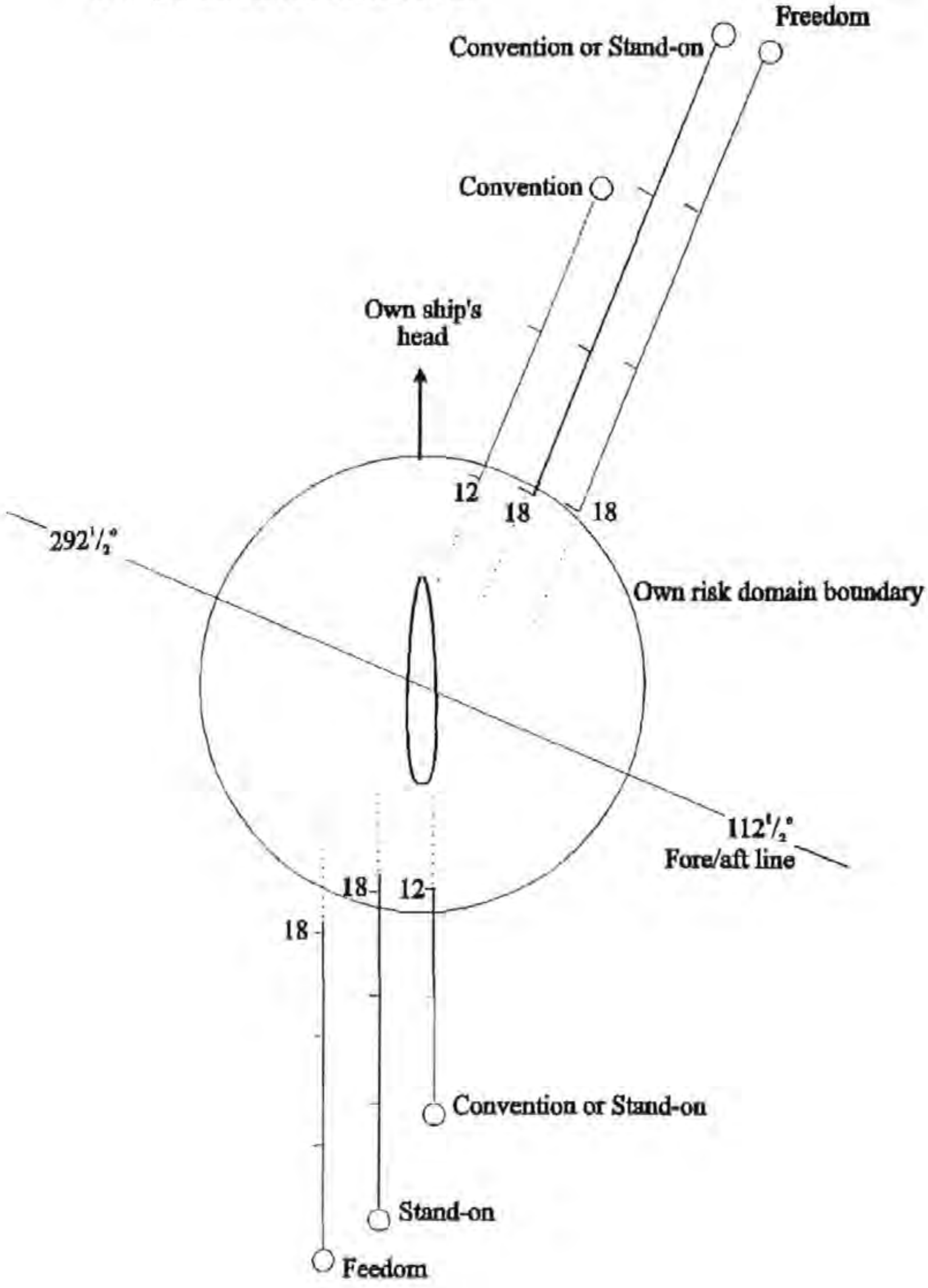


RULE-SET B continued

Manoeuvre Class Application Diagram

This diagram shows the applicable manoeuvre class with respect to:

infringement of own risk domain,
by relative velocity vector of varying length,
for targets forward and abaft the beam.



SHIP TYPE 3 Container

Specification

Displacement:	50100	Tonnes
Length B P:	212	
Block Coefficient:	0.6	
Type of Engines:	SSD	
Number of Shafts:	1	
Shaft Separation:	-	M
Direction of Rotation:	Clockwise	
Maximum Shaft Speed:	120	RPM
Type of Propellers:	1 Fixed	
Propellers Depth:	11	M
Area of Each Rudder:	44	Sq M
Maximum Rudder Angle:	35	Deg
Rudder Time Mid/Max:	13	S
Maximum Speed Full Away:	23	Kts
Maximum Speed Full Ahead:	17.2	Kts
Half ahead to Full Ahead Time:	860	S
Draught Forward:	12.2	M
Draught Aft:	12.2	M
Moulded Depth:	26	M
Bridge Height From Deck:	20	M
Bridge Distance From COG:	-71	M
Antenna Height From Sea:	37	M
Antenna Offset From COG:	-71	M
Radar Blind Arc:	178-183	DEG.REL

Characteristics (35 Deg Port Rudder)

Time to Steady State		
Speed and Rate of Turn:	631	S
Maximum Rate of Turn:	60.6	DEG/MIN
Percentage Loss of Speed:	50.9	
Steady State Speed:	8.4	Kts
Steady State Rate of Turn:	40.3	DEG/MIN
Steady State Drift Angle:	23.4	Deg
Time to Turn 360 Degrees:	491	S

Telegraph Settings

Ahead:	*RPM*	*Speed*	*Pitch-%*
Full	90	17.2 Kts	100
Half	70	13.4 Kts	100
Slow	50	9.6 Kts	100
Dead Slow	35	6.7 Kts	100
Stop	0	0 Kts	100
Astern:			
Dead Slow	35	5.4 Kts	100
Slow	45	6.9 Kts	100
Half	60	9.2 Kts	100
Full	80	12.2 Kts	100

SHIP TYPE 8 Tanker

Specification

Displacement:	98000	Tonnes
Length B P:	238	
Block Coefficient:	0.81	
Type of Engines:	SSD	
Number of Shafts:	1	
Shaft Separation:	-	M
Direction of Rotation:	Clockwise	
Maximum Shaft Speed:	90	RPM
Type of Propellers:	1 Fixed	
Propellers Depth:	11	M
Area of Each Rudder:	65	Sq M
Maximum Rudder Angle:	35	Deg
Rudder Time Mid/Max:	13	S
Maximum Speed Full Away:	16.5	Kts
Maximum Speed Full Ahead:	12.4	Kts
Half ahead to Full Ahead Time:	1663	S
Draught Forward:	12.6	M
Draught Aft:	12.6	M
Moulded Depth:	16	M
Bridge Height From Deck:	16	M
Bridge Distance From COG:	-79	M
Antenna Height From Sea:	23	M
Antenna Offset From COG:	-79	M
Radar Blind Arc:	178-183	DEG.REL

Characteristics (35 Deg Port Rudder)

Time to Steady State Speed and Rate of Turn:	810	S
Maximum Rate of Turn:	51.3	DEG/MIN
Percentage Loss of Speed:	72.4	
Steady State Speed:	3.4	Kts
Steady State Rate of Turn:	22.1	DEG/MIN
Steady State Drift Angle:	34.1	Deg
Time to Turn 360 Degrees:	807	S

Telegraph Settings

Ahead:	*RPM*	*Speed*	*Pitch-%*
Full	80	12.4 Kts	100
Half	55	8.5 Kts	100
Slow	35	5.4 Kts	100
Dead Slow	20	3.1 Kts	100
Stop	0	0 Kts	100
Astern:			
Dead Slow	20	2.5 Kts	100
Slow	30	3.7 Kts	100
Half	45	5.6 Kts	100
Full	60	7.4 Kts	100

SHIP TYPE 4 Ferry

Specification

Displacement:	5000	Tonnes
Length B P:	105	
Block Coefficient:	0.64	
Type of Engines:	MSD	
Number of Shafts:	2	
Shaft Separation:	10	M
Direction of Rotation:	Outwards	
Maximum Shaft Speed:	120	RPM
Type of Propellers:	2 CP	
Propellers Depth:	3	M
Area of Each Rudder:	8.5	Sq M
Maximum Rudder Angle:	35	Deg
Rudder Time Mid/Max:	12	S
Maximum Speed Full Away:	20	Kts
Maximum Speed Full Ahead:	15	Kts
Half ahead to Full Ahead Time:	320	S
Draught Forward:	4.2	M
Draught Aft:	4.2	M
Moulded Depth:	17	M
Bridge Height From Deck:	7	M
Bridge Distance From COG:	35	M
Antenna Height From Sea:	22	M
Antenna Offset From COG:	35	M
Radar Blind Arc:	178-183	DEG REL

Characteristics (35 Deg Port Rudder)

Time to Steady State		
Speed and Rate of Turn:	364	S
Maximum Rate of Turn:	101.3	DEG/MIN
Percentage Loss of Speed:	53.8	
Steady State Speed:	6.9	Kts
Steady State Rate of Turn:	55.3	DEG/MIN
Steady State Drift Angle:	34	Deg
Time to Turn 360 Degrees:	364	S

Telegraph Settings

Ahead:	*RPM*	*Speed*	*Pitch-%*
Full	100	15 Kts	100
Half	85	12.75 Kts	100
Slow	85	7.65 Kts	60
Dead Slow	85	3.2 Kts	25
Stop	85	0 Kts	0
Astern:			
Dead Slow	85	2.0 Kts	25
Slow	85	4.8 Kts	60
Half	85	8.0 Kts	100
Full	100	9.4 Kts	100

SHIP TYPE 11 Jetfoil

Specification

Displacement:	115	Tonnes
Length B P:	50	
Block Coefficient:	0	
Type of Engines:	GT	
Number of Shafts:	1	
Shaft Separation:	-	M
Direction of Rotation:	Clockwise	
Maximum Shaft Speed:	2150	RPM
Type of Propellers:	1 Fixed	
Propellers Depth:	0	M
Area of Each Rudder:	0	Sq M
Maximum Rudder Angle:	0	Deg
Rudder Time Mid/Max:	0	S
Maximum Speed Full Away:	45	Kts
Maximum Speed Full Ahead:	45	Kts
Half ahead to Full Ahead Time:	282	S
Draught Forward:	0	M
Draught Aft:	0	M
Moulded Depth:	0	M
Bridge Height From Deck:	0	M
Bridge Distance From COG:	0	M
Antenna Height From Sea:	11	M
Antenna Offset From COG:	0	M
Radar Blind Arc:	0	DEG.REL

Characteristics (35 Deg Port Rudder)

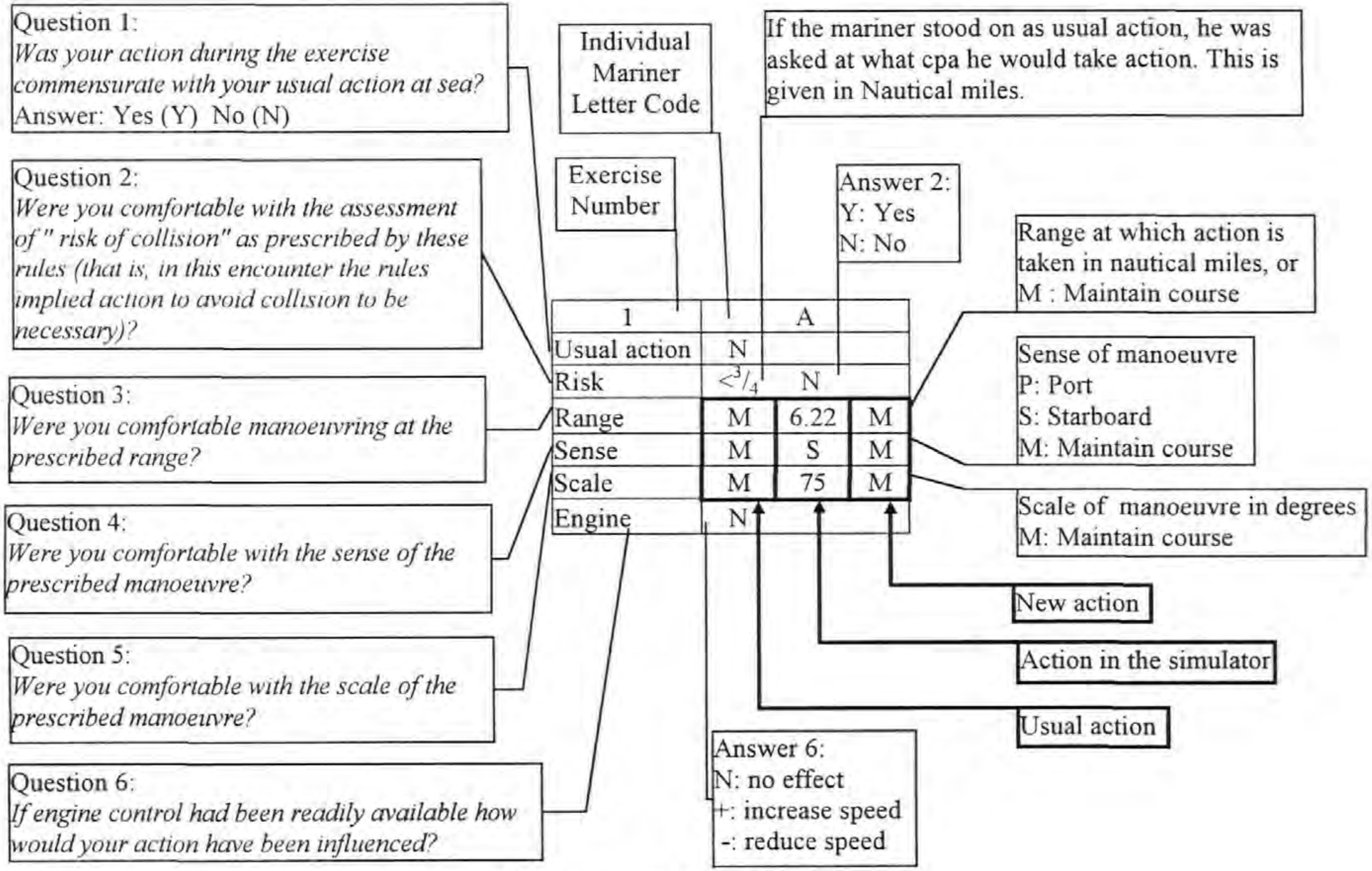
Time to Steady State		
Speed and Rate of Turn:	10	S
Maximum Rate of Turn:	187	DEG/MIN
Percentage Loss of Speed:	0	
Steady State Speed:	45	Kts
Steady State Rate of Turn:	140.5	DEG/MIN
Steady State Drift Angle:	0	Deg
Time to Turn 360 Degrees:	154	S

Telegraph Settings

Ahead:	*RPM*	*Speed*	*Pitch-%*
Full	2150	45 Kts	100
Half	2000	41.9 Kts	100
Slow	1900	39.8 Kts	100
Dead Slow	1300	27.2 Kts	100
Stop	1055	22.1 Kts	100
Astern:			
Dead Slow	1300	21.8 Kts	100
Slow	1900	31.8 Kts	100
Half	2000	33.5 Kts	100
Full	2150	36.0 Kts	100

Exercise start conditions

	Ship type	Heading	Speed	CPA	TCPA	Target Range	Target Bearing
Ex 1							
Own	Tanker	000	10k				
Targ'	Container	180	10k	0.9M	22min	7.42M	G7°
Ex 2							
Own	Tanker	000	10k				
Target	Container	180	10k	1.4M	22min	7.47M	G11°
Ex 3							
Own	Tanker	000	15k				
Target	Container	180	18k	0.9M	23min	13.98M	G4°
Ex 4							
Own	Tanker	000	10k				
Target	Jet-foil	042	30k	0.9M	22min	8.58M	R127°
Ex 5							
Own	Tanker	000	10k				
Target	Jet-foil	353	30k	0.9M	22min	7.65M	R177°
Ex 6							
Own	Tanker	000	10k				
Target	Container	091	20k	0.8M	25min	9.39M	R58°
Ex7							
Own	Container	000	20k				
Target	Ferry	084	18k	0.8M	21min	9.04M	R40°
Ex2x							
Own	Container	180	21				
Target	Tanker	000	15	1.4M	23min	14.01M	G6°
Ex3R							
Own	Container	180	21				
Target	Tanker	000	15	0.9M	23min	13.98M	G4°
Ex4R							
Own	Jet-foil	042	30				
Target	Tanker	000	10	0.9M	22min	8.58M	G11°
Ex5R							
Own	Jet-Foil	353	30				
Target	Tanker	000	10	0.9M	22min	7.65M	G4°
Ex7R							
Own	Ferry	084	18				
Target	Container	000	20	0.8M	21min	9.04M	G56°



Key to exercise result sheets

Exercise 1 (12 mariners)

I	A			B			C			D			E			F		
Usual action	N			Y			N			N			N			Y		
Risk	<$^3/_4$	N			Y		<$^3/_4$	Y		<1.0	Y			Y			Y	
Range	M	6.22	M	5.92	5.92	5.92	M	5.35	5.35	M	5.2	5.2	5.66	5.66	5.66	5.99	5.99	5.99
Sense	M	S	M	S	S	S	M	S	S	M	S	S	P	S	P	S	S	S
Scale	M	75	M	80	80	80	M	80	80	M	90	90	20	90	20	90	90	90
Engine	N			N			N			N			N			N		

I	G			H			R			S			T			U		
Usual action	N			N			Y			N			N			N		
Risk		Y			Y			Y			Y		0.7	N			Y	
Range	10.0	6.1	10.0	3.0	5.79	3.0	6.32	6.32	6.32	8.0	5.62	8.0	M	4.61	M	7.0	5.29	5.29
Sense	S	S	S	P	S	P	S	S	S	S	S	S	M	S	M	P	S	S
Scale	70	90	90	40	70	40	60	60	60	60	60	60	M	90	M	20	60	60
Engine	N			N			N			N			N			N		

Exercise 2 (8 mariners)

2	A			B			C			D		
Usual action	Y			Y			Y			Y		
Risk		Y			Y			Y			Y	
Range	M	M	M	M	M	M	M	M	M	M	M	M
Sense	M	M	M	M	M	M	M	M	M	M	M	M
Scale	M	M	M	M	M	M	M	M	M	M	M	M
Engine	N			N			N			N		

2	E			F			G			H		
Usual action	Y			Y			Y			Y		
Risk		Y			Y			Y			Y	
Range	M	M	M	M	M	M	M	M	M	M	M	M
Sense	M	M	M	M	M	M	M	M	M	M	M	M
Scale	M	M	M	M	M	M	M	M	M	M	M	M
Engine	N			N			N			N		

Exercise 2x (9 mariners)

2X	N			O			P			Q		
Usual action	N			Y			Y			Y		
Risk		Y			Y			Y			Y	
Range	M	7.19	7.19	M	M	M	M	M	M	11.37	11.37	11.37
Sense	M	S	S	M	M	M	M	M	M	S	S	S
Scale	M	60	60	M	M	M	M	M	M	60	60	60
Engine	N			N			N			N		

2X	R			S			T			U			F		
Usual action	Y			Y			Y			Y			N		
Risk		Y			Y			Y			Y			Y	
Range	10.0	10.0	10.0	M	M	M	M	M	M	M	M	M	9.88	9.88	9.88
Sense	S	S	S	M	M	M	M	M	M	M	M	M	S	S	S
Scale	60	60	60	M	M	M	M	M	M	M	M	M	40	60	40
Engine	N			N			N			N			N		

Exercise 3 (12 mariners)

3	A			B			C			D			E			F		
Usual action	N			Y			N			Y			N			N		
Risk	<3/4	N			Y		<3/4	Y			Y			Y			Y	
Range	M	11.92	11.92	7.22	7.22	7.22	M	7.91	7.91	9.94	9.94	9.94	10.59	10.59	10.59	6.0	8.07	8.07
Sense	M	S	S	S	S	S	M	S	S	S	S	S	P	P	P	S	S	S
Scale	M	75	75	60	60	60	M	80	80	60	60	60	15	60	15	60	60	60
Engine	N			N			N			N			N			N		

3	G			H			R			S			T			U		
Usual action	N			N			Y			N			Y			Y		
Risk		Y		<1/2	N			Y			Y		0.7	N			Y	
Range	10.0	8.05	8.05	5.0	5.08	5.0	7.57	7.57	7.57	10.59	10.59	10.59	M	M	M	7.07	7.07	7.07
Sense	S	S	S	P	S	P	S	S	S	S	S	S	M	M	M	S	S	S
Scale	35	60	60	40	75	40	60	60	60	30	60	60	M	M	M	60	60	60
Engine	N			N			N			N			N			N		

Exercise 3R (9 mariners)

3R	N			O			P			Q			R		
Usual action	Y			N			Y			Y			Y		
Risk		Y			Y			Y			Y			Y	
Range	7.44	7.44	7.44	10.0	6.9	10.0	9.85	9.85	9.85	8.7	8.7	8.7	10.15	10.15	10.15
Sense	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Scale	60	60	60	40	70	60	50	50	60	64	64	64	60	60	60
Engine	N			N			N			N			N		

3R	S			T			U			F		
Usual action	N			N			N			N		
Risk		Y		0.7	N			Y			Y	
Range	6.0	7.96	7.96	M	M	M	9.0	7.33	7.33	9.89	9.89	9.89
Sense	S	S	S	M	M	M	P	S	P	S	S	S
Scale	20	60	20	M	M	M	25	60	25	40	60	40
Engine	N			N			N			N		

Exercise 4A (8 mariners)

4A	A			B			C			D		
Usual action	N			N			N			Y		
Risk	$<^3/_4$	N			Y			Y			Y	
Range	M	5.56	M	M	4.71	M	M	5.10	5.10	3.15	3.15	3.15
Sense	M	P	M	M	P	M	M	P	P	P	P	P
Scale	M	30	M	M	50	M	M	40	48	45	45	45
Engine	N			N			N			+		

4A	E			F			G			H		
Usual action	N			N			Y			N		
Risk		Y			Y			Y		$<^3/_4$	N	
Range	3.0	4.78	4.78	M	3.25	3.25	6.73	6.73	6.73	M	4.97	2.5
Sense	S	S	S	M	P	P	S	S	S	M	S	P
Scale	50	50	50	M	48	48	66	66	66	M	40	20
Engine	N			N			N			N		

Exercise 4B (8 mariners)

4B	N			O			P			Q		
Usual action	Y			Y			Y			Y		
Risk		Y			Y			Y			Y	
Range	2.95	2.95	2.95	4.68	4.68	4.68	5.94	5.94	5.94	3.0	6.93	3.0
Sense	P	P	P	P	P	P	P	P	P	P	P	P
Scale	20	20	20	20	20	20	48	48	48	20	20	20
Engine	N			N			N			N		

4B	R			S			T			U		
Usual action	Y			Y			Y			Y		
Risk		Y			Y			Y			Y	
Range	4.9	4.9	4.9	4.23	4.23	4.23	4.88	4.88	4.88	M	M	M
Sense	P	P	P	P	P	P	P	P	P	M	M	M
Scale	40	40	40	40	40	40	40	40	40	M	M	M
Engine	N			N			N			N		

Exercise 4R (8 mariners)

4R	N			O			P			Q		
Usual action	(N)			N			N			N		
Risk	Y			Y			N			Y		
Range	4.21	4.21	4.21	7.86	7.86	7.86	M	8.00	8.00	8.26	8.26	8.26
Sense	S	*	S	S	P	P	M	S	S	P	S	S
Scale	40	*	40	20	22	22	M	10	10	20	50	10
Engine	Reduced Speed			N			Slow Down			N		

4R	R			S			T			U		
Usual action	Y			N			Y			Y		
Risk	Y			Y			Y			Y		
Range	7.17	7.17	7.17	3.0	4.97	3.0	5.56	5.56	5.56	4.16	4.16	4.16
Sense	S	S	S	S	S	S	S	S	S	S	S	S
Scale	33	33	33	20	60	20	28	28	28	18	18	18
Engine	N			N			N			N		

Exercise 5A (8 mariners)

5	A			B			C			D		
Usual action	N			N			Y			N		
Risk	$<^3/_4$	N	$<^3/_4$		Y			Y			Y	
Range	M	4.58	6.5	6.2	4.15	6.2	3.0	7.13	7.13	2.5	6.6	6.6
Sense	M	P	S	P	P	P	S	S	S	S	S	S
Scale	M	25	50	60	40	60	60	80	80	40	40	40
Engine	N			+			N			N		

5	E			F			G			H		
Usual action	N			Y			N			N		
Risk		Y			Y			Y		$<^3/_4$	N	$<^3/_4$
Range	3.0	4.43	6.0	2.1	2.1	2.1	5.0	3.25	5.0	M	3.03	3.03
Sense	S	P	S	S	S	S	S	S	S	M	P	S
Scale	20	40	20	25	25	25	30	50	50	M	40	35
Engine	N			N			N			N		

Exercise 5B (8 mariners)

5B	N			O			P			Q		
Usual action	Y			Y			N			Y		
Risk		Y			Y			Y			Y	
Range	2.6	2.6	2.6	2.48	2.48	2.48	1.5	4.69	4.69	4.36	4.36	4.36
Sense	S	S	S	S	S	S	S	S	S	S	S	S
Scale	30	30	30	20	20	20	40	21	21	10	10	10
Engine	N			N			N			N		

5B	R			S			T			U		
Usual action	Y			Y			N			Y		
Risk		Y			Y			Y			Y	
Range	3.01	3.01	3.01	3.43	3.43	3.43	M	3.22	3.22	M	M	M
Sense	S	S	S	S	S	S	M	S	S	M	M	M
Scale	30	30	30	20	20	20	M	60	60	M	M	M
Engine	N			N			N			N		

Exercise 5R (8 mariners)

5R		N			O			P			Q	
Usual action	Y			N			N			Y		
Risk		Y			Y			Y			Y	
Range	6.38	6.38	6.38	6.4	6.4	6.4	6.1	6.1	6.1	6.01	6.01	6.01
Sense	P	P	P	S	S	S	S	P	S	S	S	S
Scale	8	8	8	30	60	30	20	15	20	47	47	47
Engine	N			N			N			N		

5R		R			S			T			U	
Usual action	Y			N			N			Y		
Risk		Y			Y			Y			Y	
Range	5.18	5.18	5.18	6.3	6.3	6.3	3.0	4.32	4.32	3.68	3.68	3.68
Sense	S	S	S	S	S	S	P	S	P	P	P	P
Scale	63	63	63	30	60	30	10	60	10	13	13	13
Engine	N			N			N			N		

Exercise 6 (13 mariners)

6	A			B			C			D			E			F		
Usual action	N			N			N			N			N			N		
Risk		Y			Y			Y			Y			Y			Y	
Range	3	5.3	5.3	M	5.64	5.64	3.0	5.24	3.0	5.0	7.38	5.0	3.0	4.29	4.29	3.0	7.81	5.3
Sense	S	S	S	M	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Scale	91	$^{36}_{125}$	91	M	$^{30}_{130}$	$^{30}_{130}$	$^{180}_{360}$	$^{36}_{360}$	$^{180}_{360}$	$^{180}_{360}$	$^{180}_{360}$	$^{180}_{360}$	$^{38}_{154}$	$^{38}_{154}$	$^{38}_{154}$	$^{180}_{360}$	$^{35}_{125}$ 360	$^{35}_{125}$ 360
Engine	N			N			N			Slow			N			N		

6	G			H			N			O			P			Q			T		
Usual action	N			N			N			N			N			N			N		
Risk		Y			Y			Y			Y			Y			Y			Y	
Range	6.0	7.87	6.0	3.0	4.45	4.45	3.5	4.64	4.64	3.0	6.45	6.45	7.21	7.21	7.21	M	7.41	2.0	3.0	6.38	6.38
Sense	S	S	S	S	S	S	S	S	S	S	S	S	P	S	P	M	S	S	S	S	S
Scale	70	$^{35}_{70}$	70	90	90	90	$^{90}_{360}$	$^{40}_{90}$	$^{40}_{360}$	360	33	$^{33}_{360}$	60	$^{30}_{310}$	60	M	$^{57}_{360}$	360	360	$^{50}_{360}$	$^{50}_{360}$
Engine	Slow			Slow and stand-on						Target on beam and slow			Target on beam and slow			Slow			N		

Exercise 7 (13 mariners)

7	A			B			C			D			E			F			G		
Usual action	N			N			N			Y			N			N			N		
Risk	Y			Y			Y			Y			Y			Y			Y		
Range	3.0	7.61	7.61	2.5	5.27	5.27	3.0	7.39	7.39	5.0	6.52	6.52	3.0	5.0	5.0	2.95	2.95	2.95	8.0	5.76	5.76
Sense	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Scale	84	50	50	130	55	55	180 360	45	45	50	50	50	180 360	60	60	60 360	60	60	35	50	50
Engine	N			N			N			Option			N			N			N		

7	H			N			O			P			Q			T		
Usual action	N			Y			N			N			Y			N		
Risk	Y			Y			Y			Y			Y			Y		
Range	M	3.74	3.74	8.5	7.60	7.60	3.5	4.68	4.68	2.0	6.5	3.0	3.26	3.26	3.26	3.0	5.44	5.44
Sense	M	S	S	P	P	S	S	S	S	S	S	S	S	S	S	S	S	S
Scale	M	60	60	45	45	50	360	56	56	360	50	50 360	360	360	360	360	52	52
Engine	Option			N			N			N			Slow Down			N		

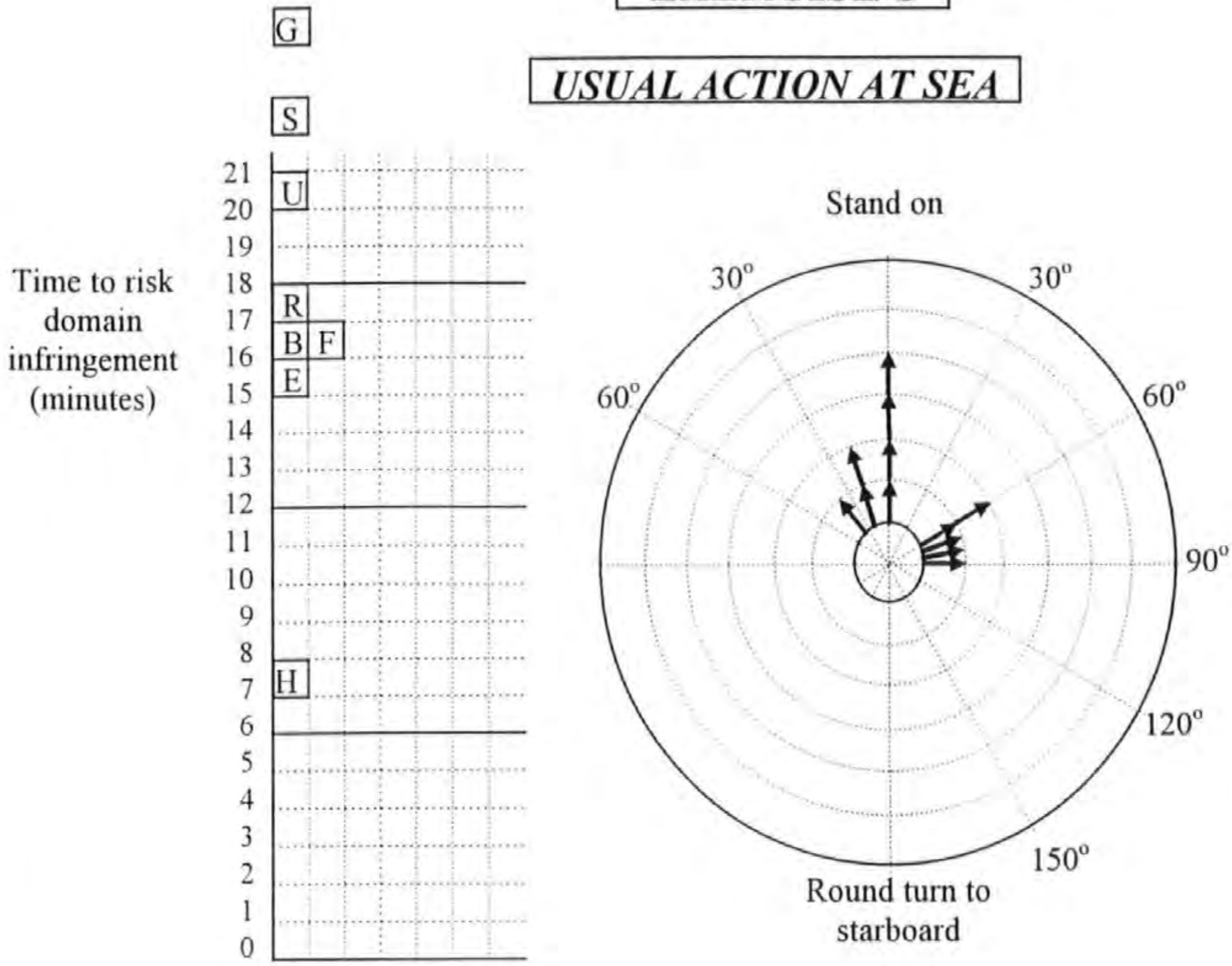
Exercise 7R (8 mariners)

7R	N			O			P			Q		
Usual action	Y			Y			N			Y		
Risk		Y			Y			Y			Y	
Range	6.0	4.67	4.67	5.5	5.5	5.5	8.08	8.08	8.08	8.71	8.71	8.71
Sense	S	S	S	S	S	S	S	S	S	S	S	S
Scale	60	89	89	89	89	89	59	72	72	95	95	95
Engine	N			N			N			N		

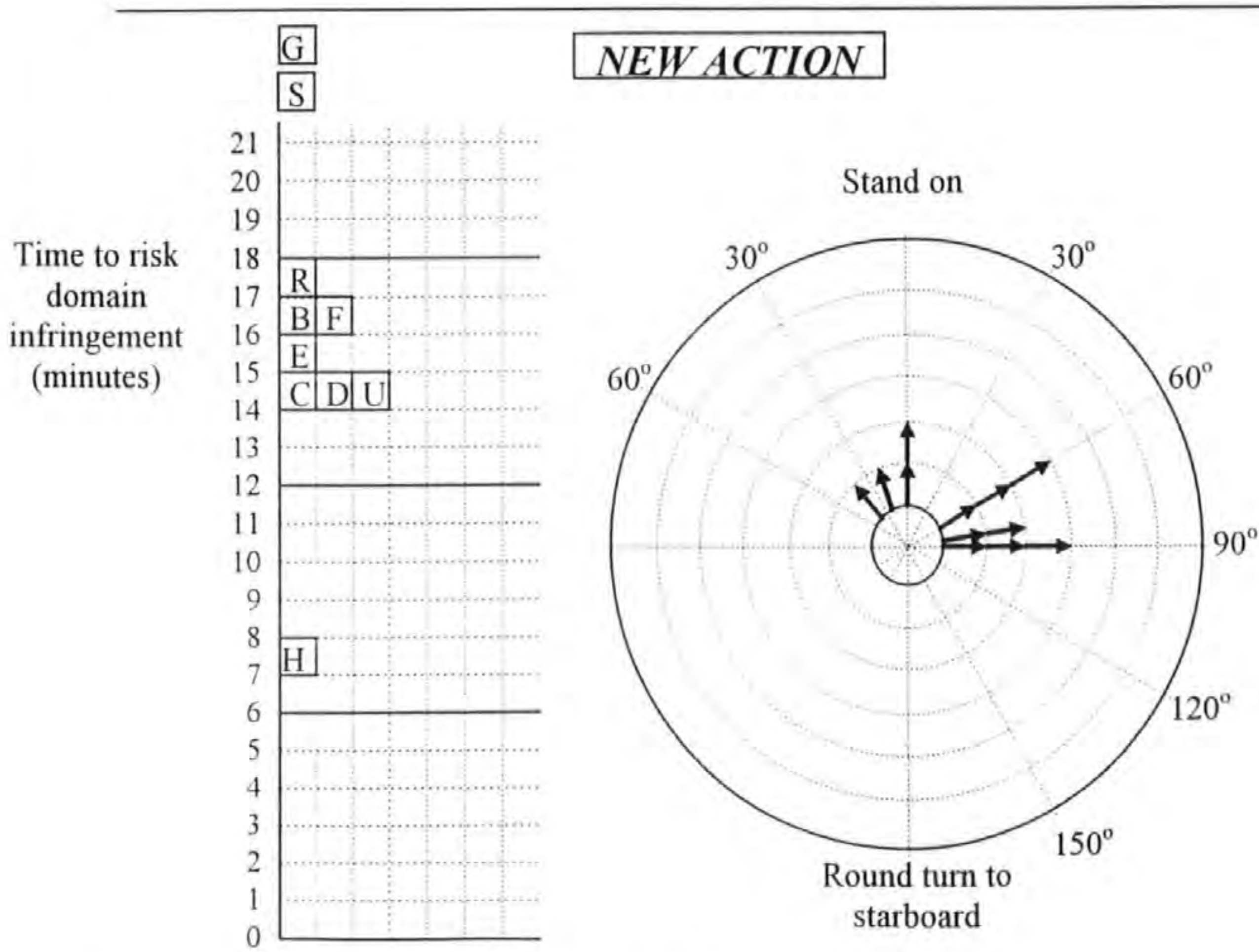
7R	R			S			T			U		
Usual action	Y			N			Y			N		
Risk		Y			Y			Y			Y	
Range	6.84	6.84	6.84	6.35	6.35	6.35	6.19	6.19	6.19	5.84	5.84	5.84
Sense	S	S	S	S	S	S	S	S	S	S	S	S
Scale	89	89	89	60	84	60	89	89	89	77	84	84
Engine	N			N			N			N		

EXERCISE 1

USUAL ACTION AT SEA

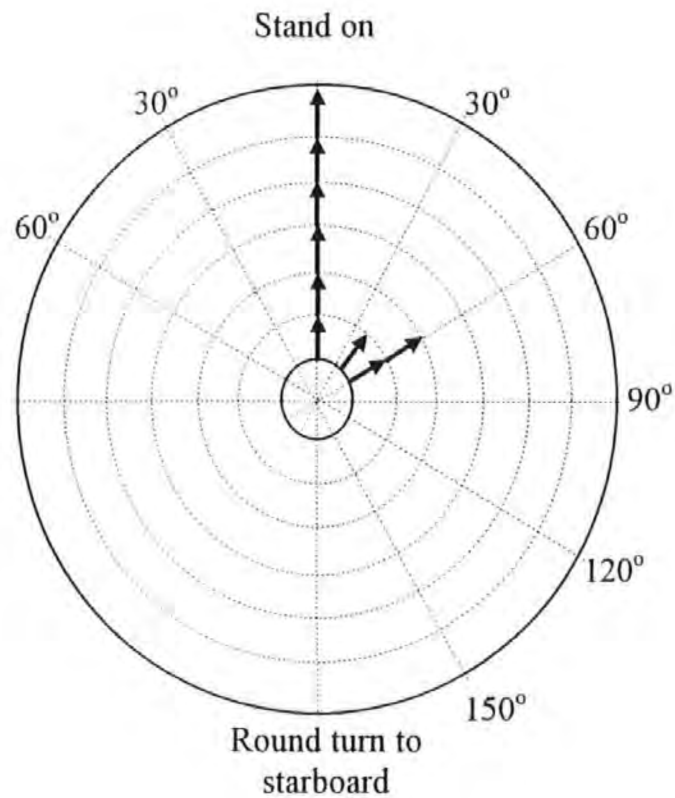


NEW ACTION

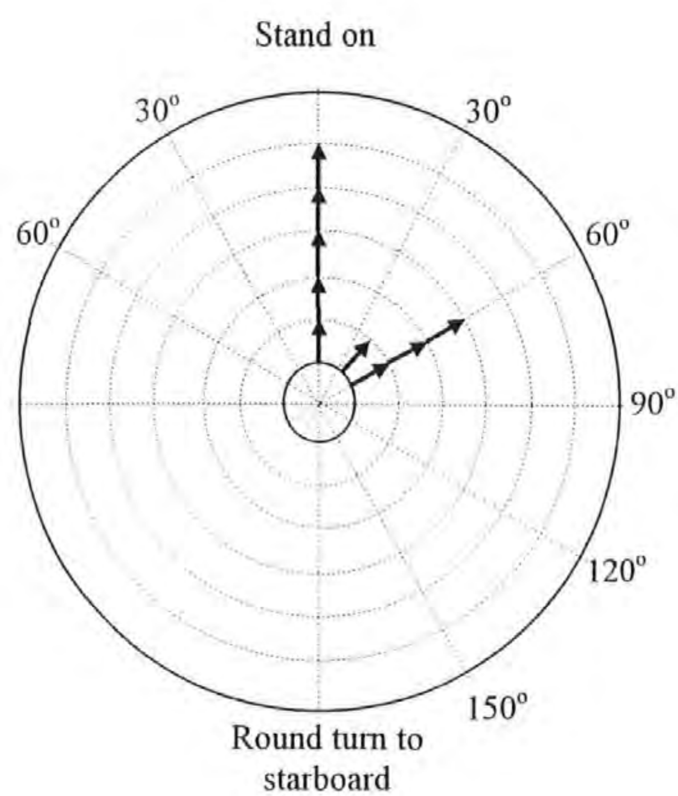


EXERCISE 2 X

USUAL ACTION AT SEA

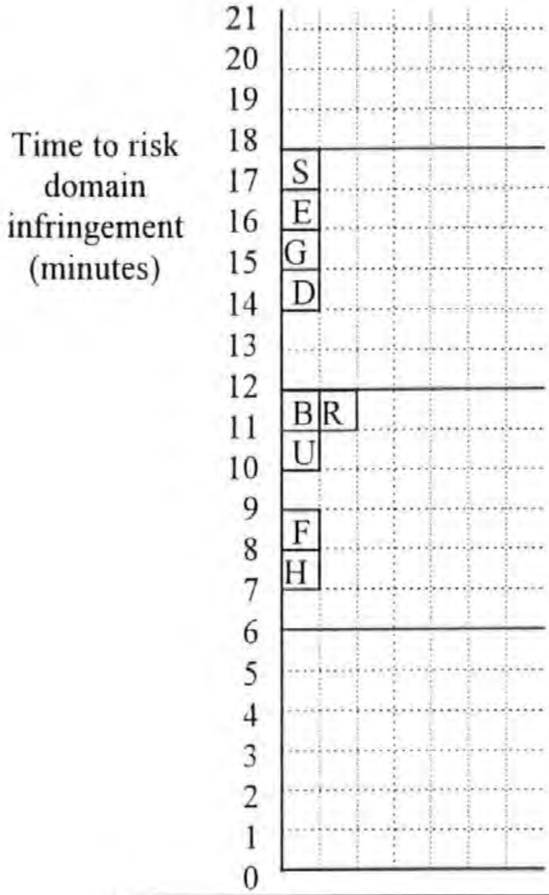


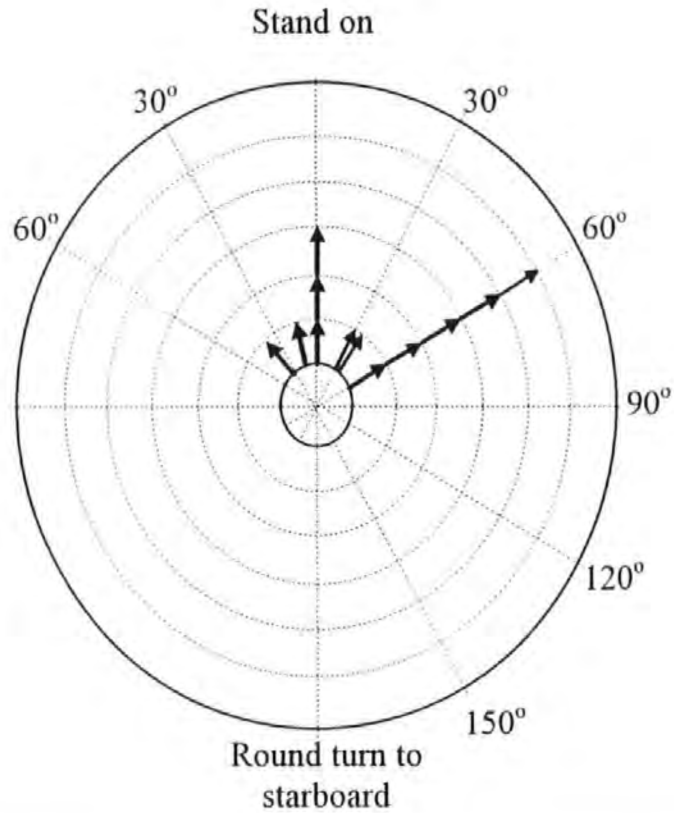
NEW ACTION



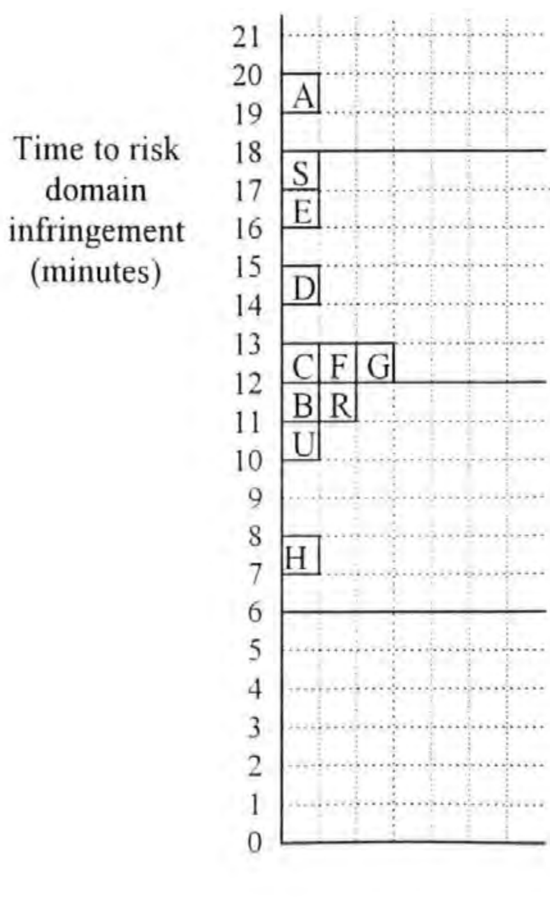
EXERCISE 3

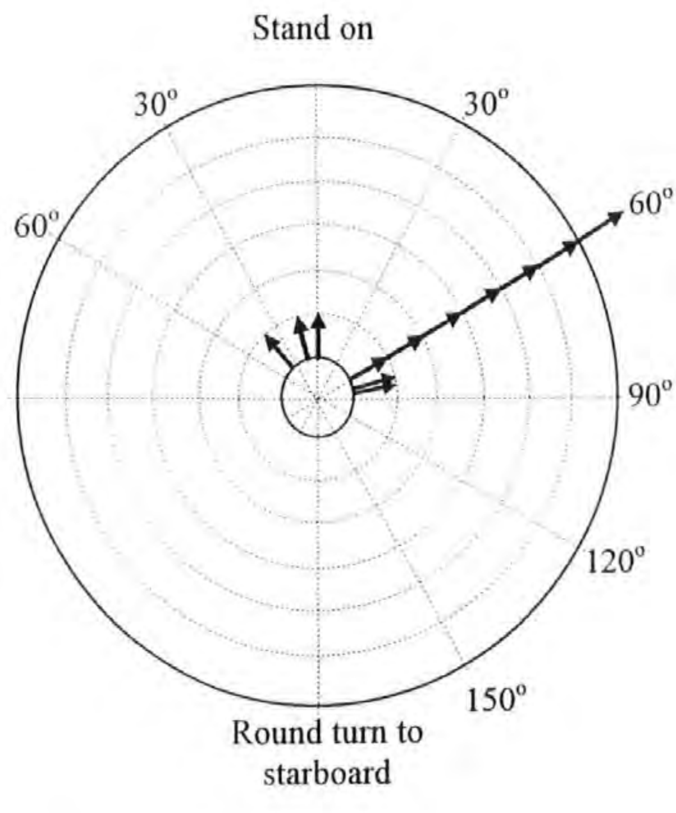
USUAL ACTION AT SEA





NEW ACTION

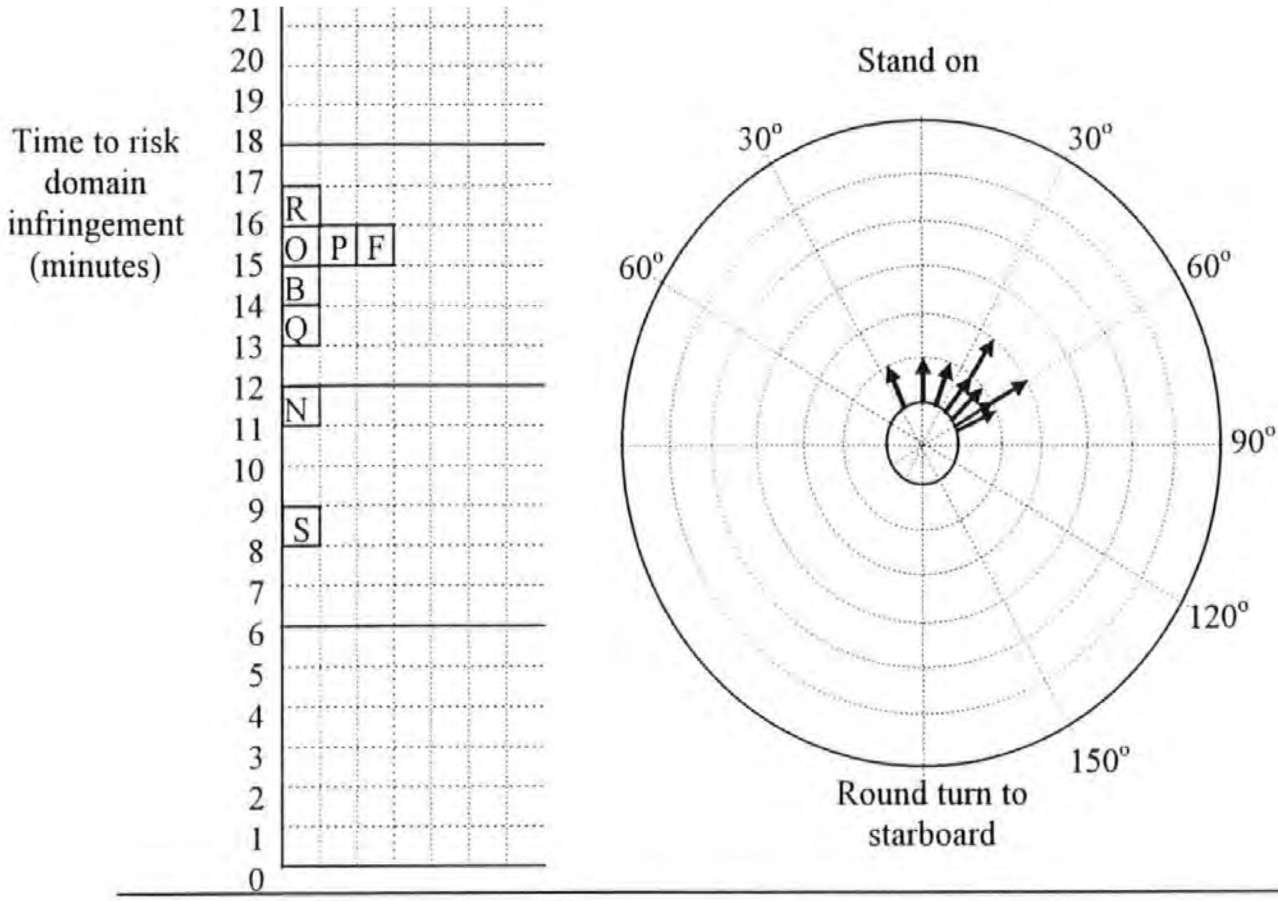




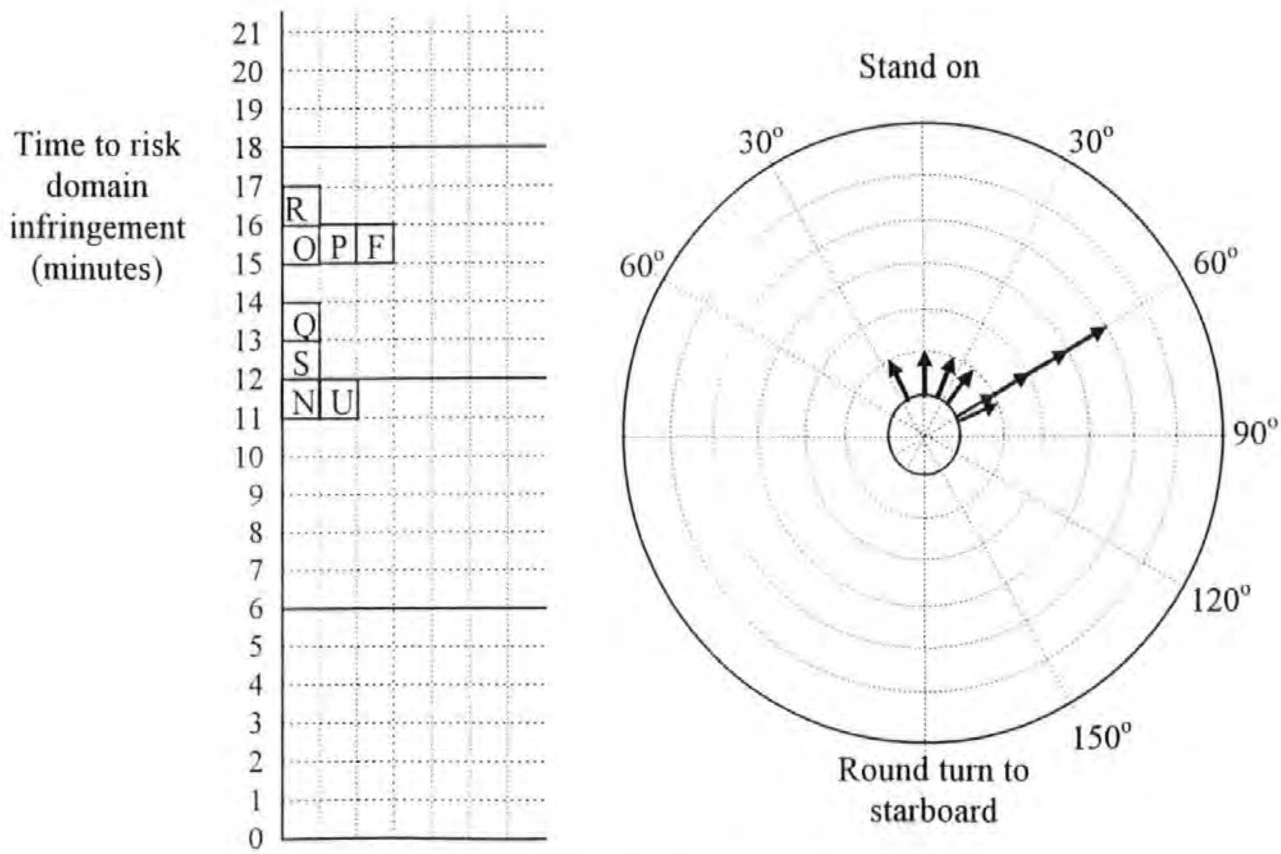
Appendix E

EXERCISE 3R

USUAL ACTION AT SEA

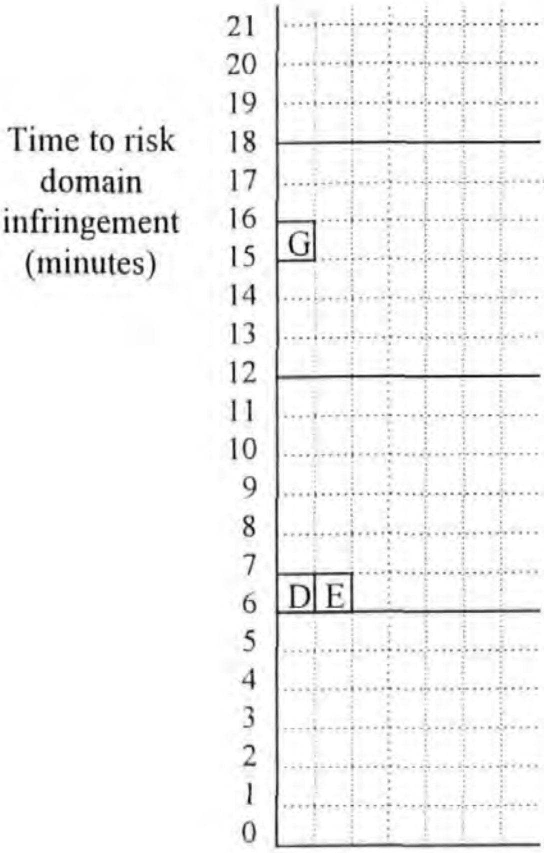


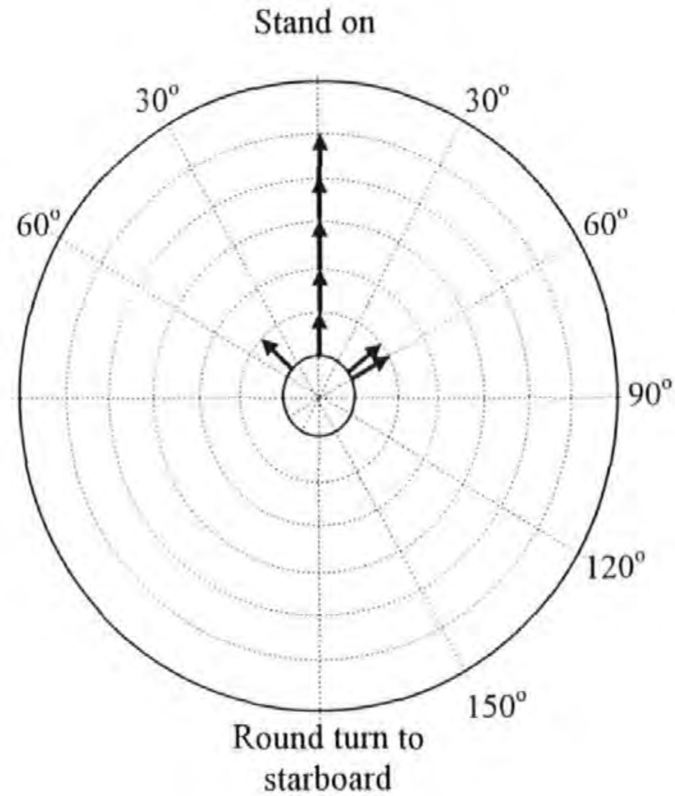
NEW ACTION



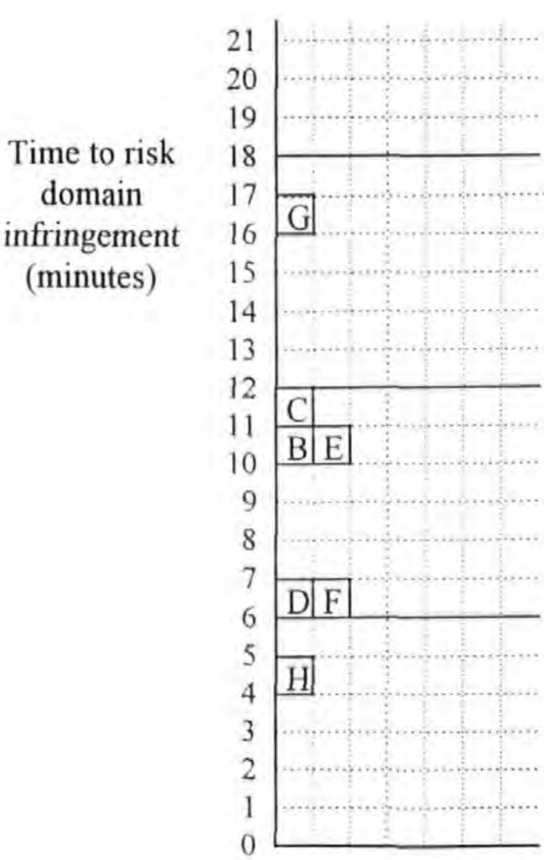
EXERCISE 4A

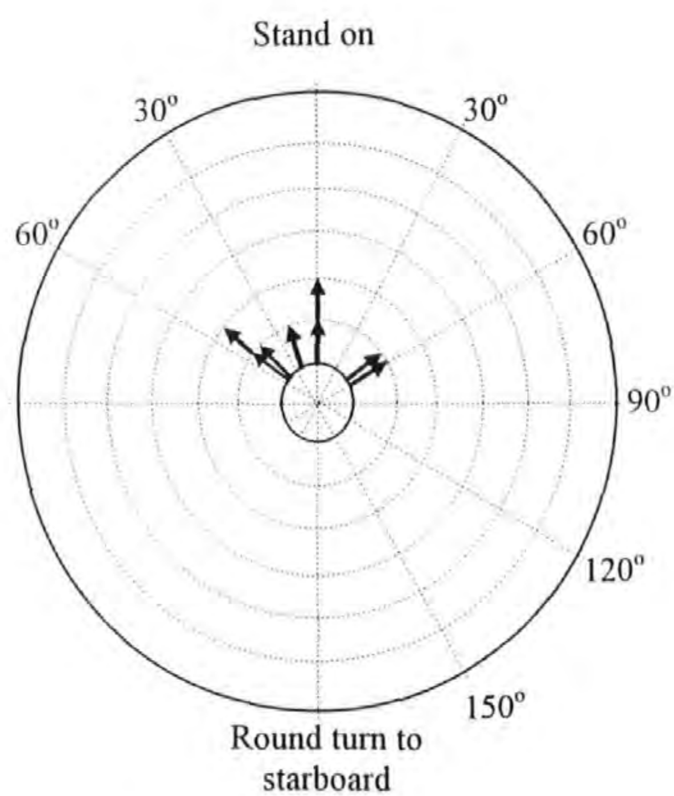
USUAL ACTION AT SEA





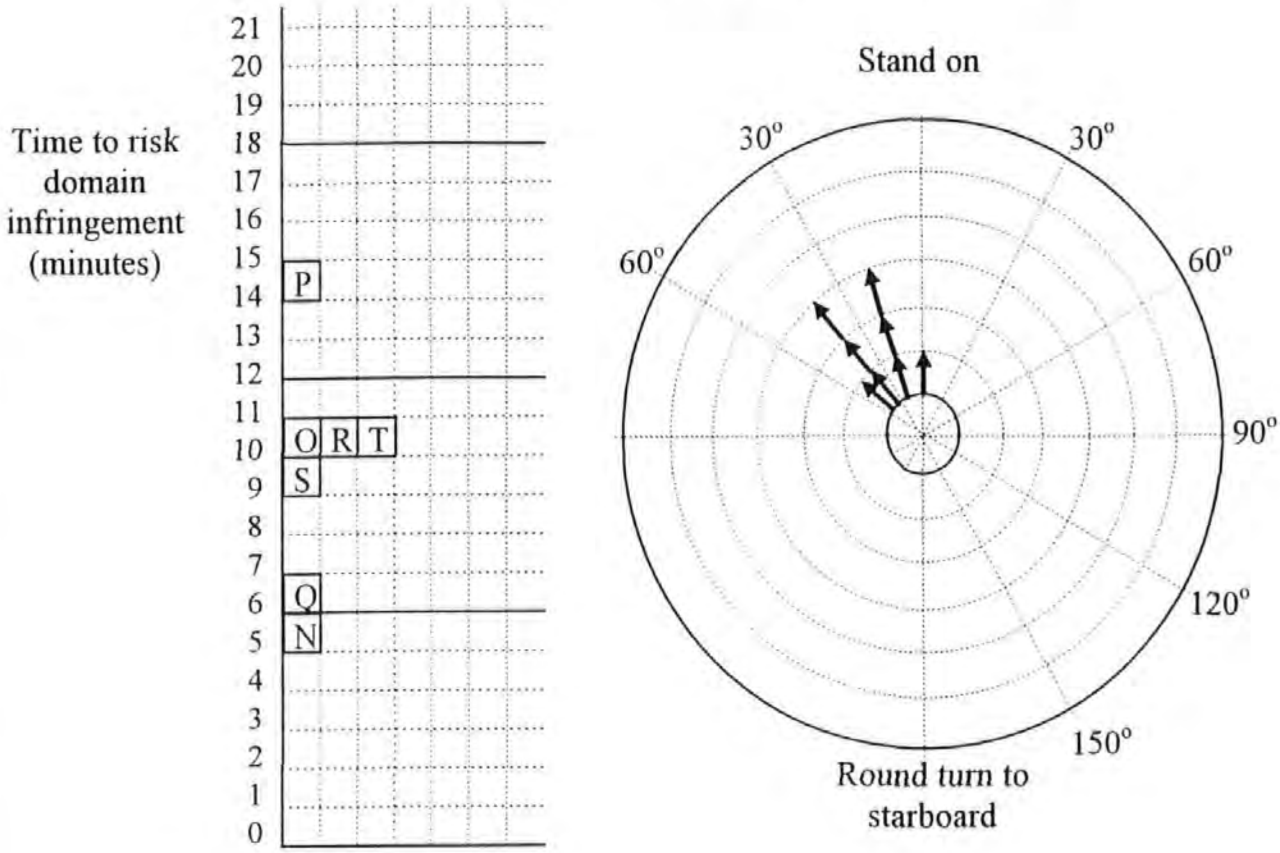
NEW ACTION



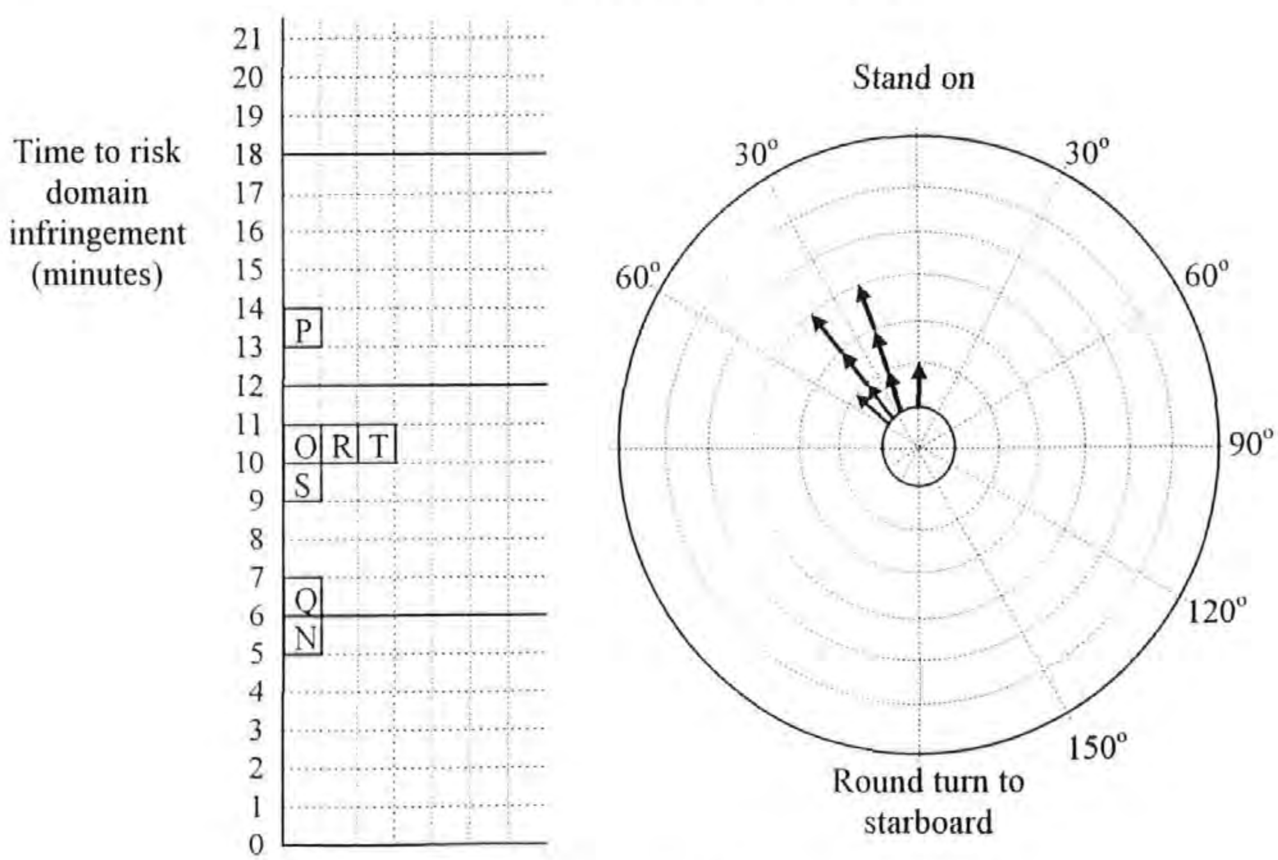


EXERCISE 4B

USUAL ACTION AT SEA

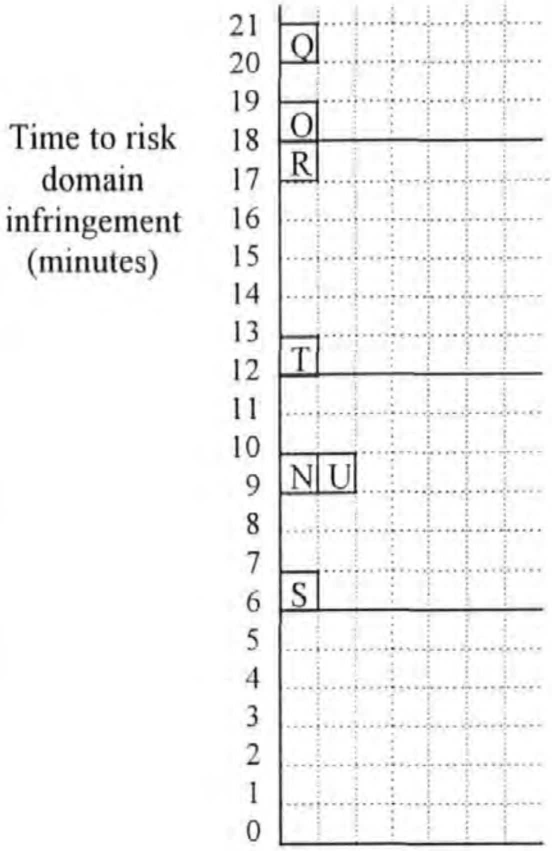


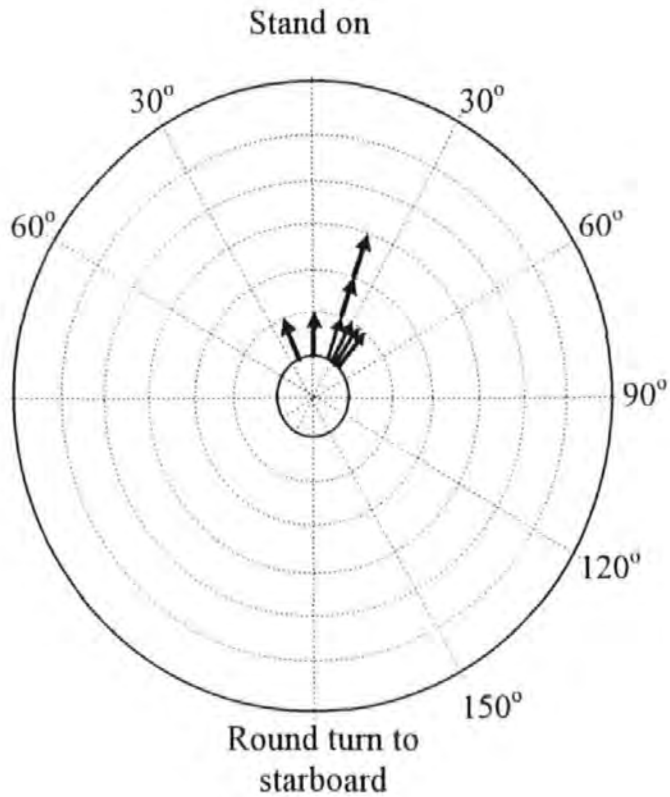
NEW ACTION



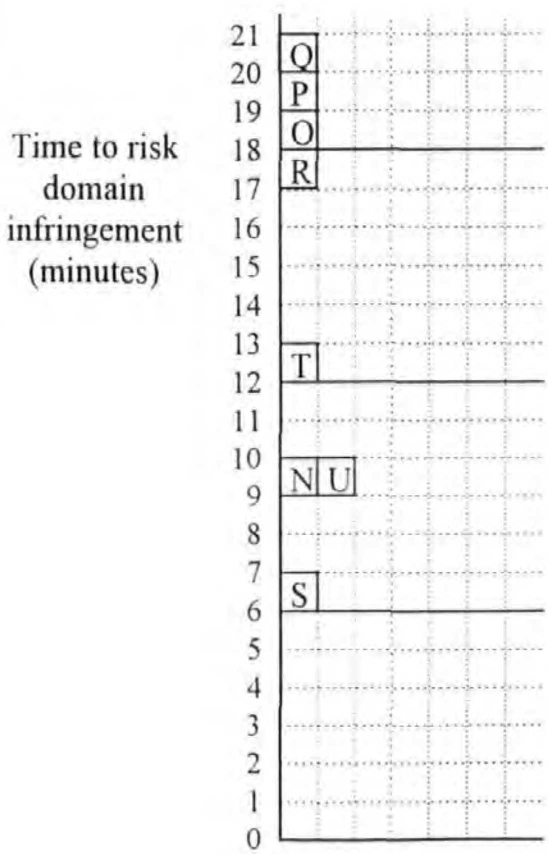
EXERCISE 4R

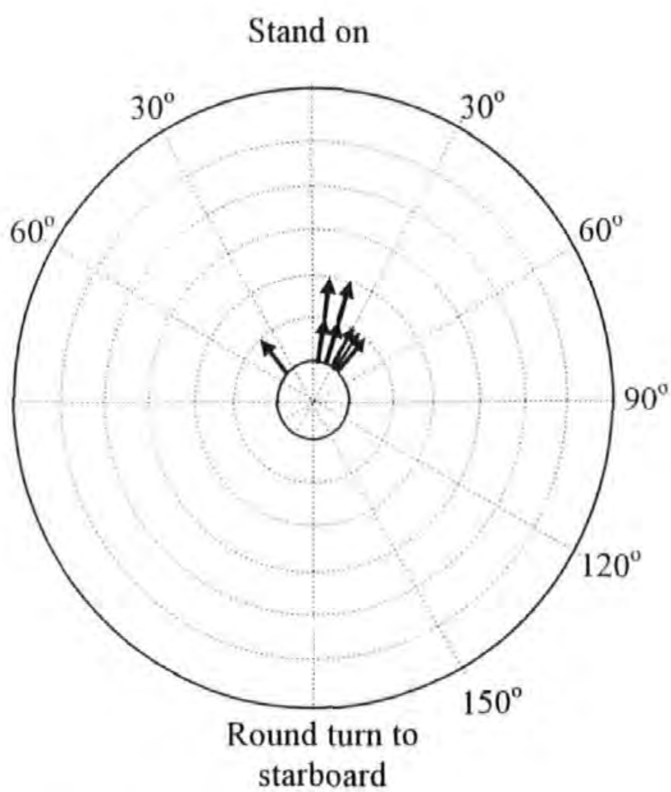
USUAL ACTION AT SEA





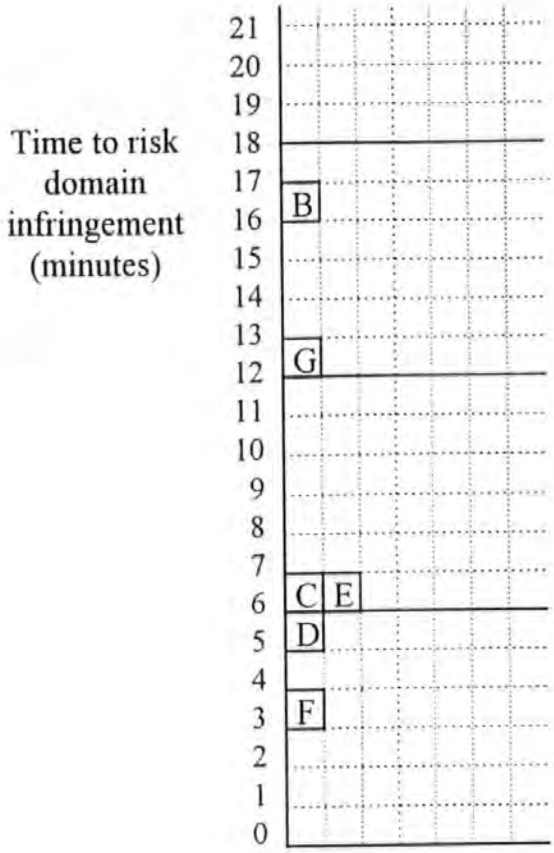
NEW ACTION

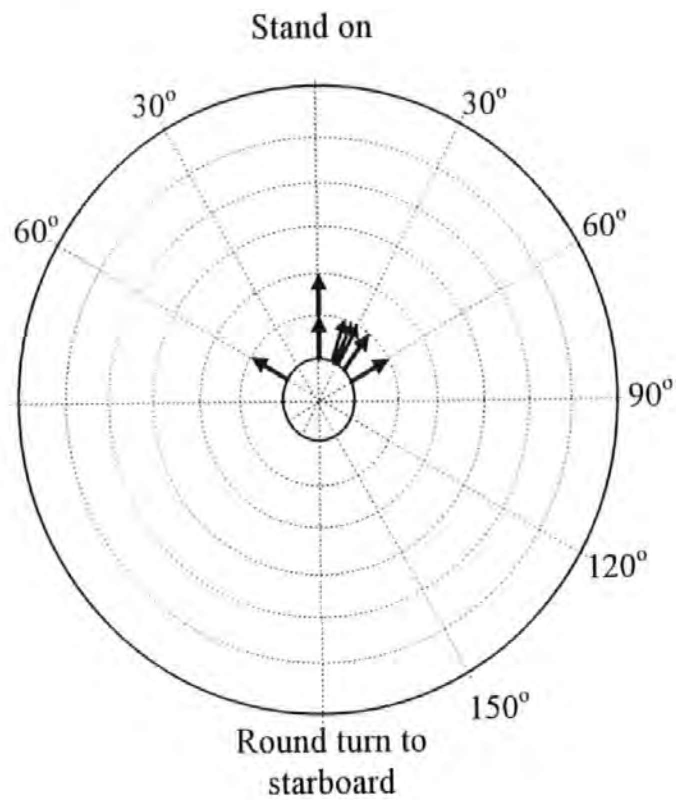




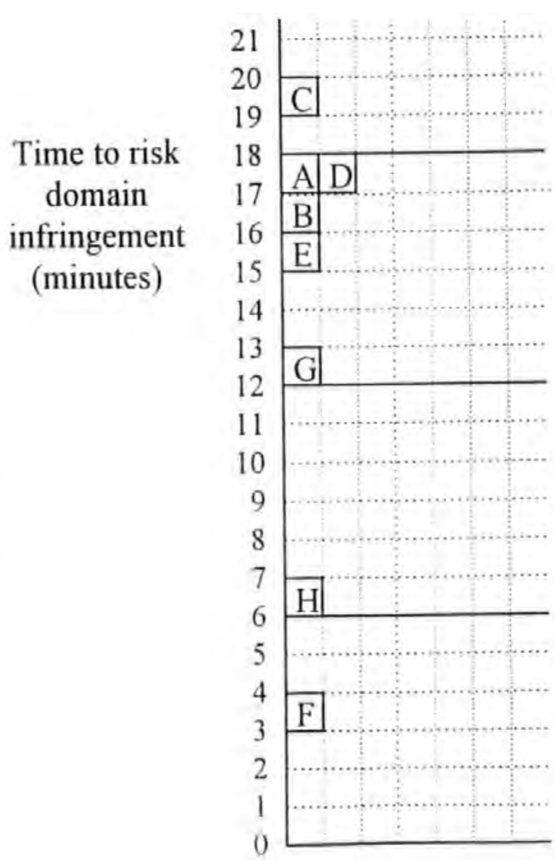
EXERCISE 5A

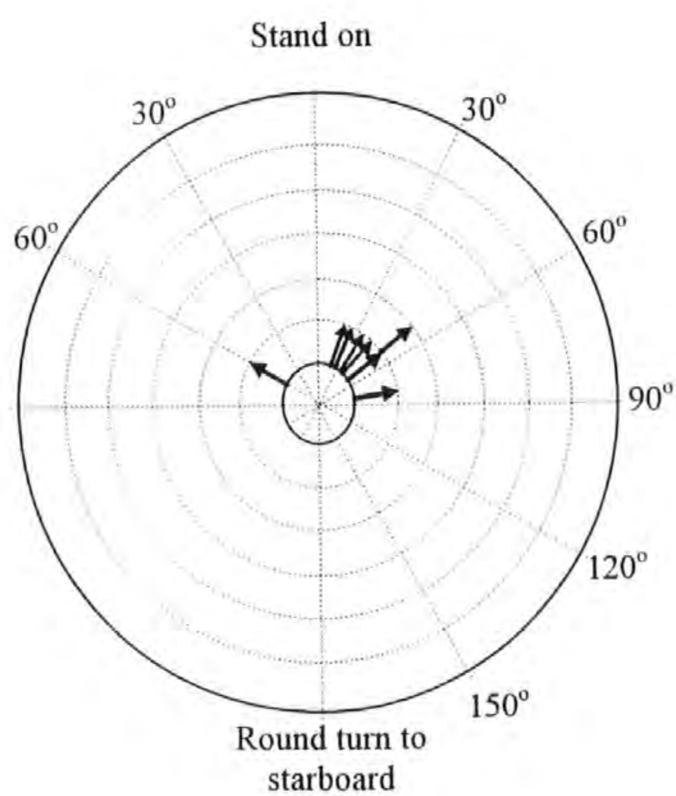
USUAL ACTION AT SEA





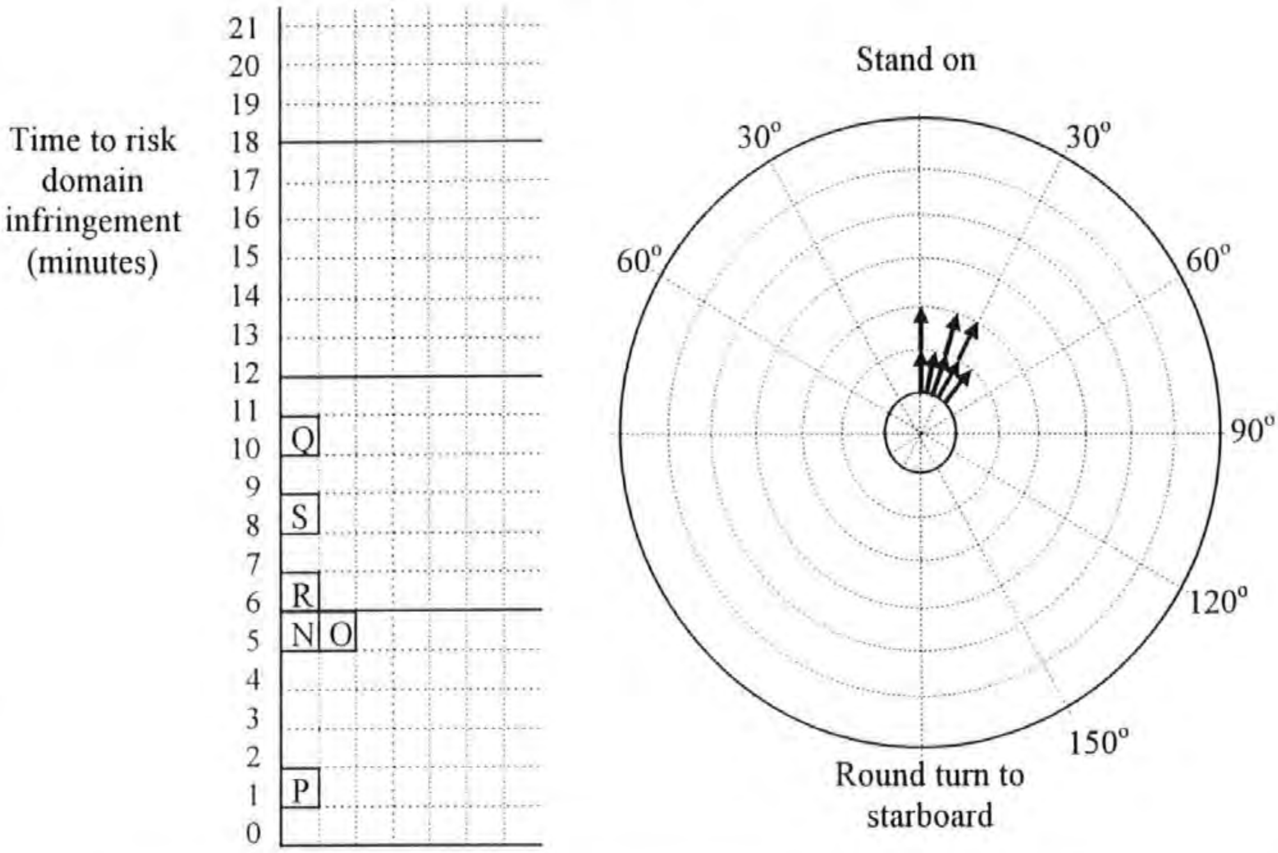
NEW ACTION



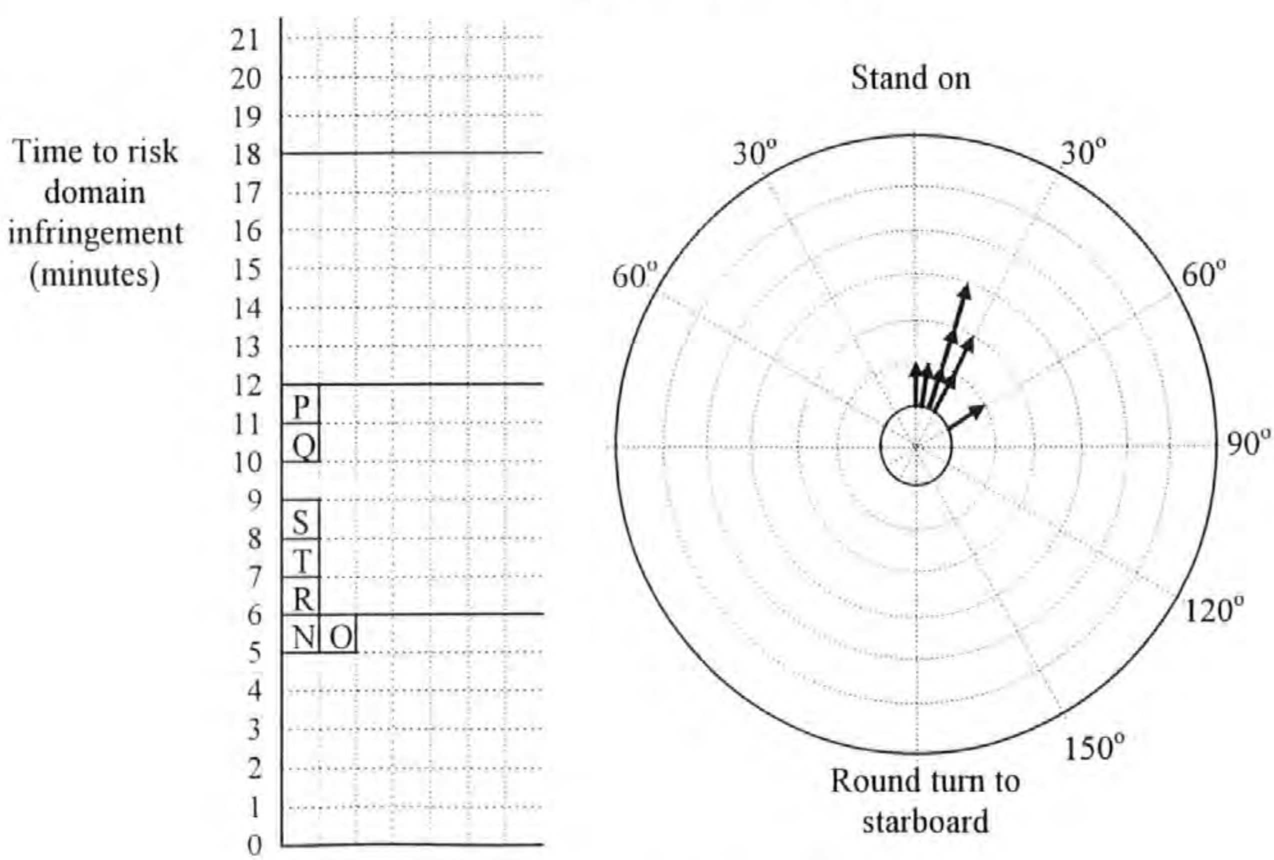


EXERCISE 5B

USUAL ACTION AT SEA

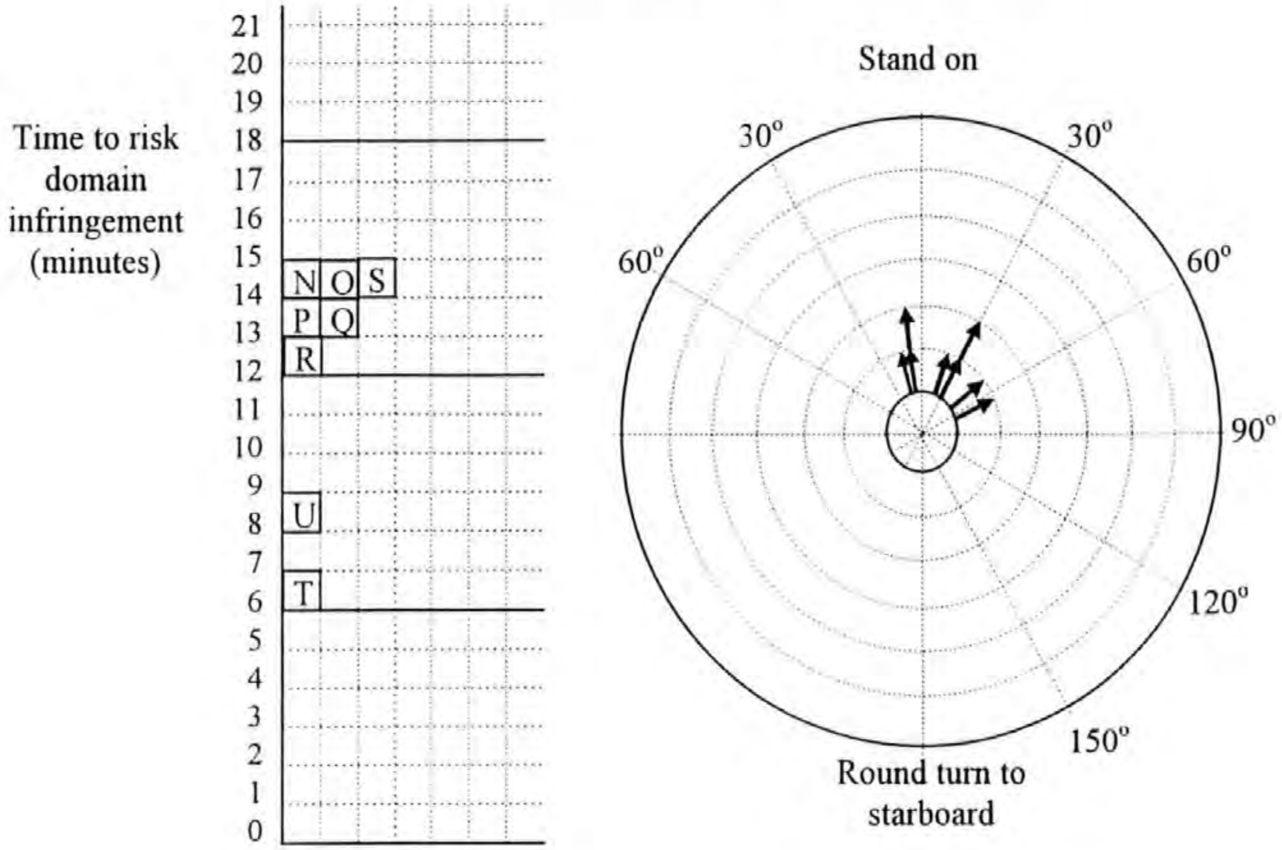


NEW ACTION

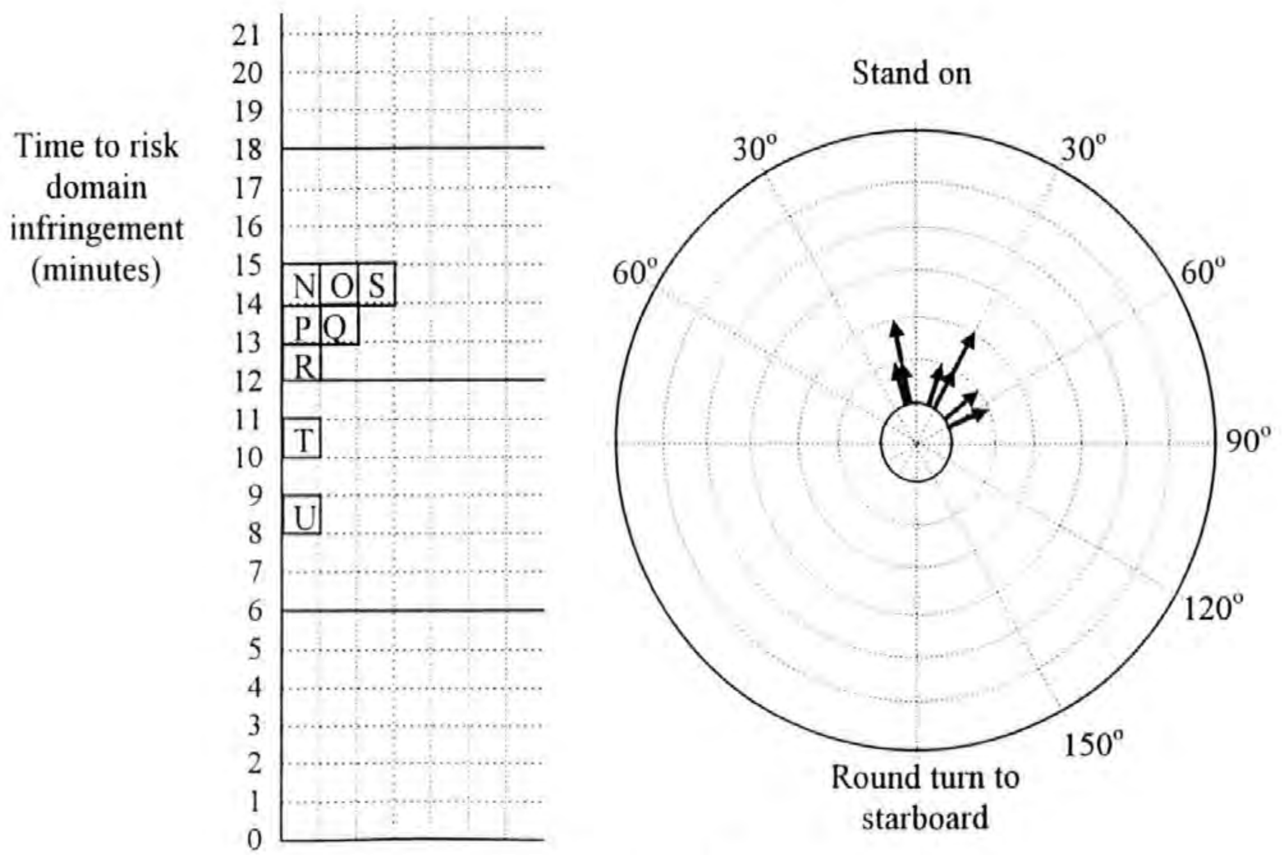


EXERCISE 5R

USUAL ACTION AT SEA

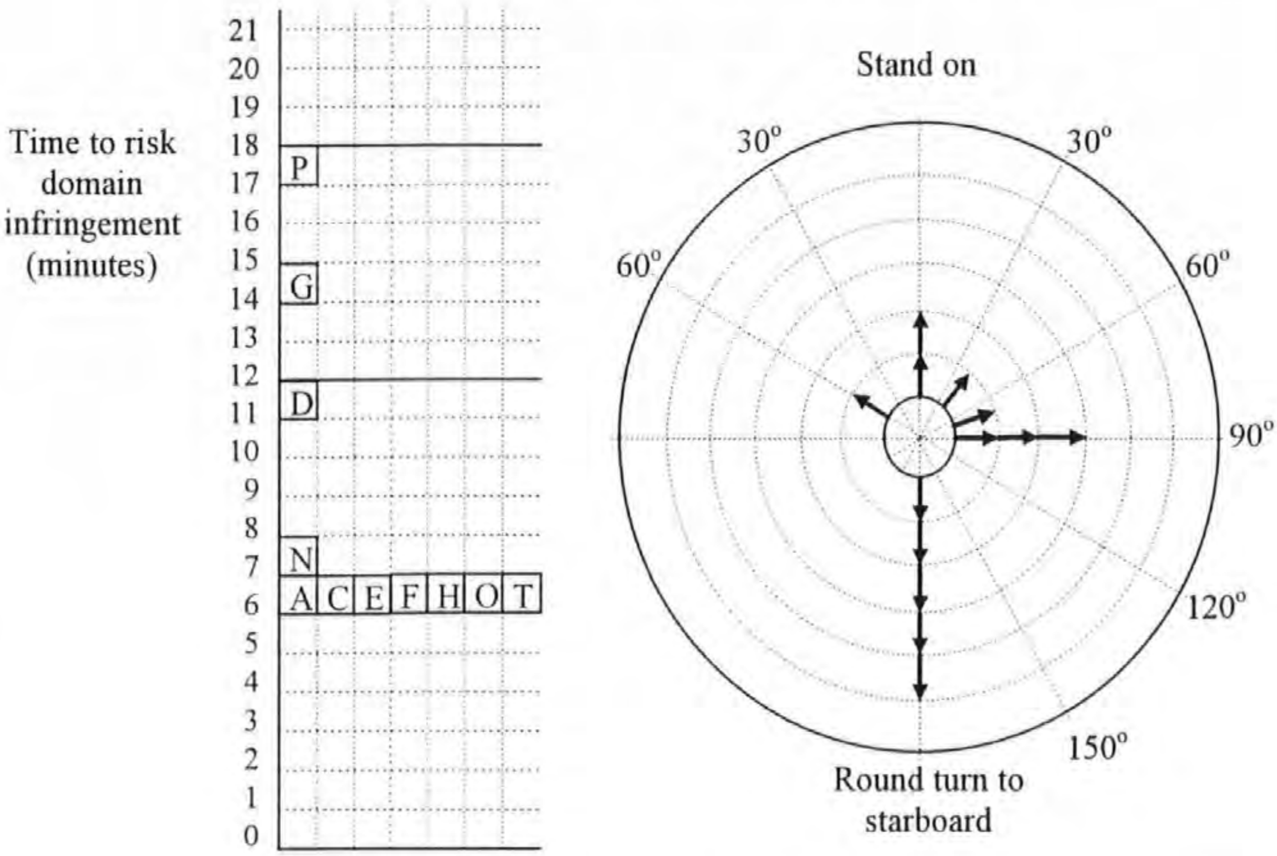


NEW ACTION

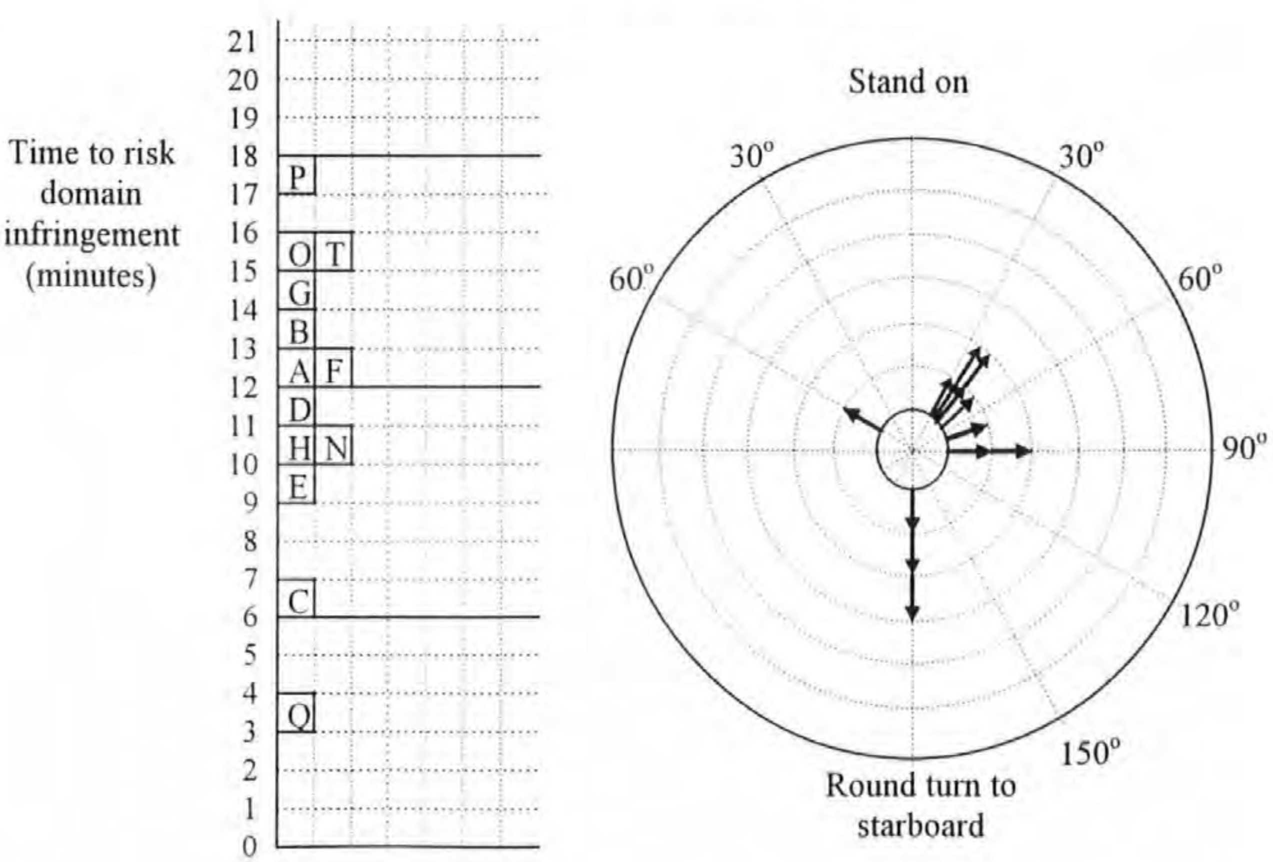


EXERCISE 6: PRIMARY MANOEUVRE

USUAL ACTION AT SEA

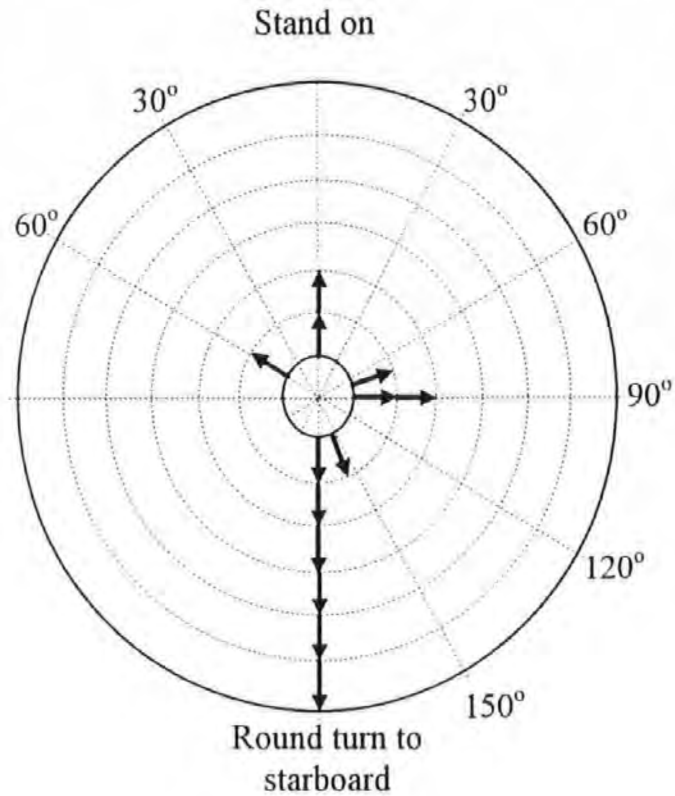


NEW ACTION

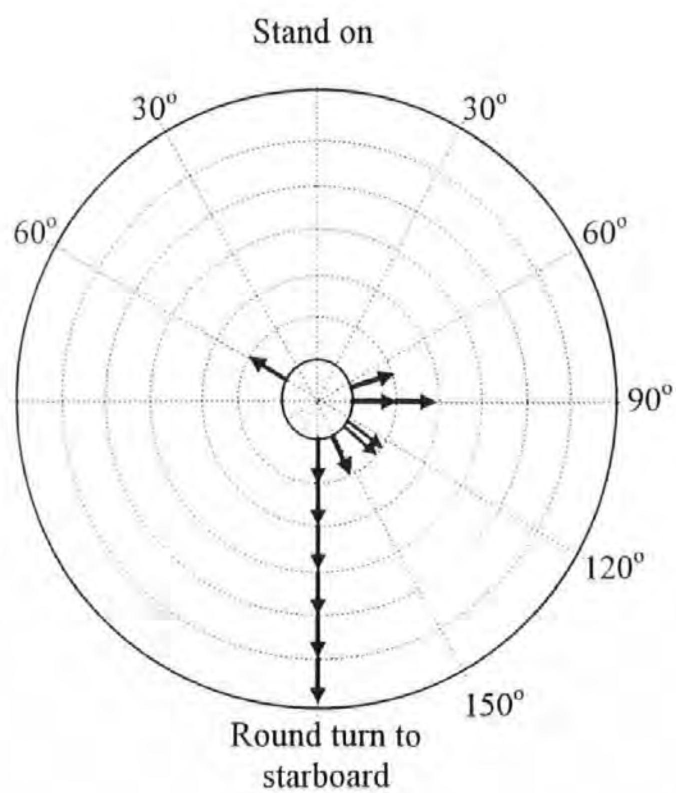


EXERCISE 6: SECONDARY MANOEUVRE

USUAL ACTION AT SEA

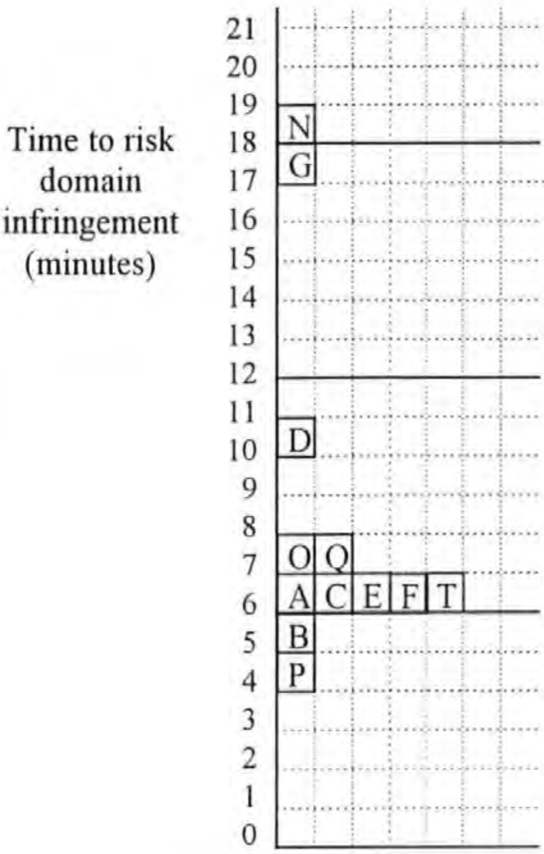


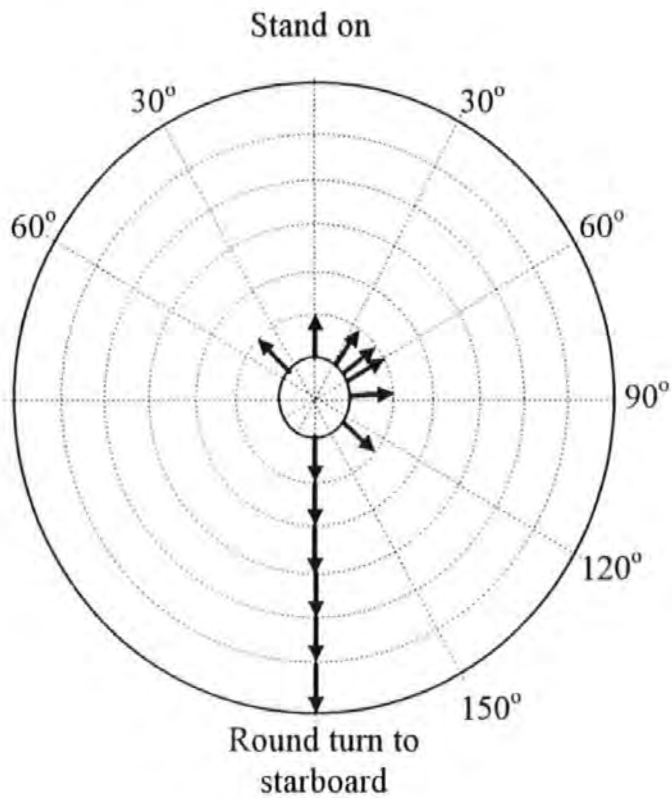
NEW ACTION



EXERCISE 7

USUAL ACTION AT SEA





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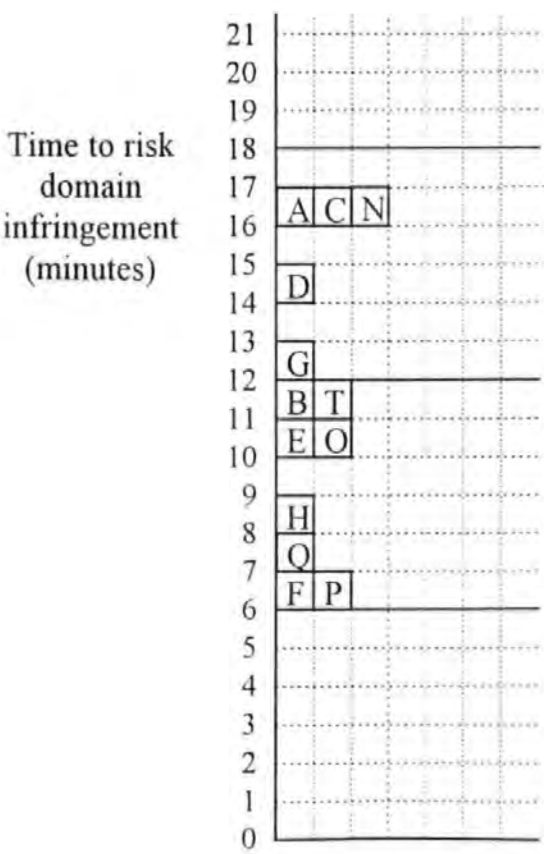
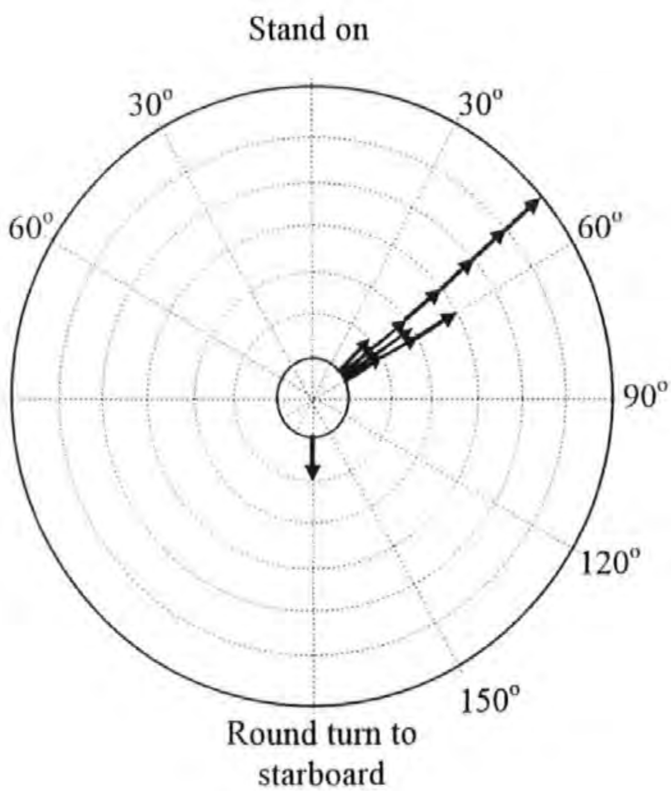
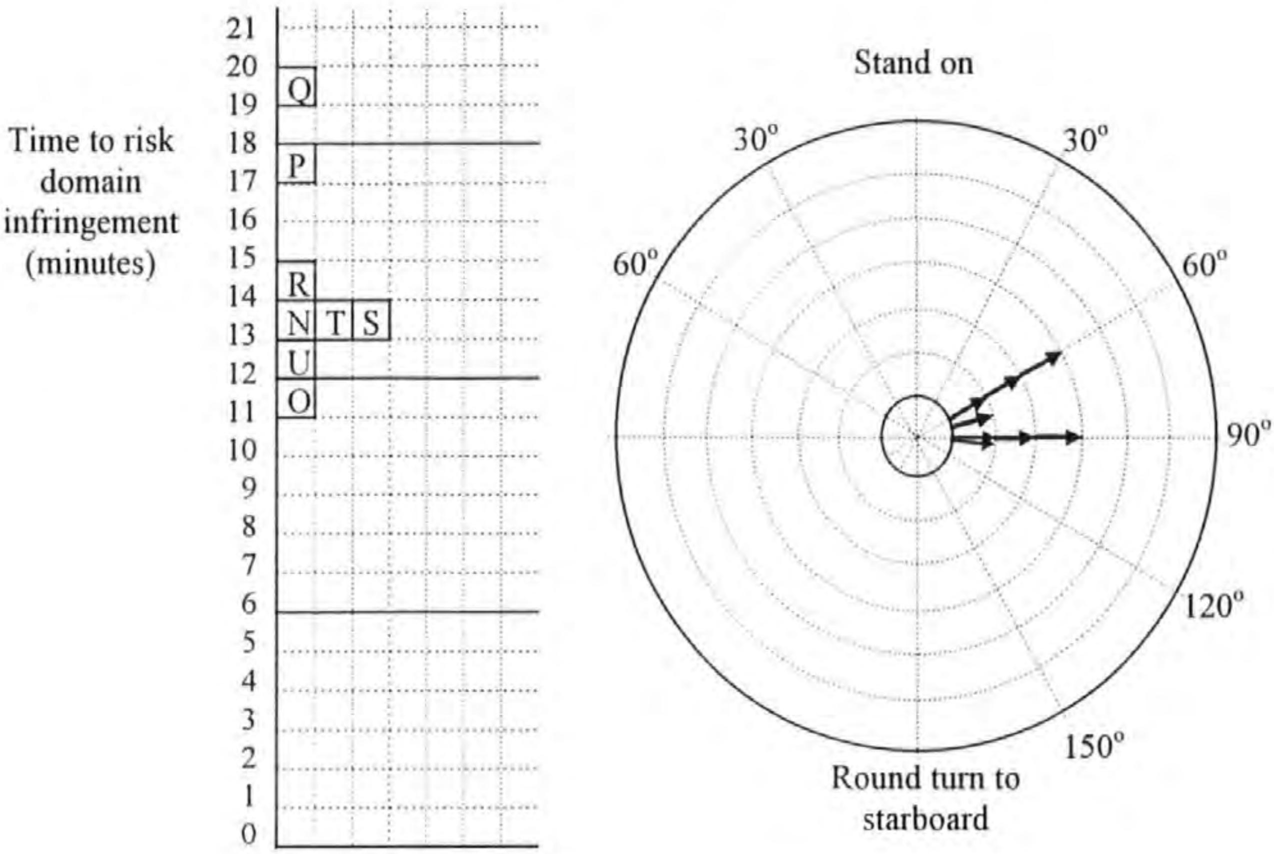


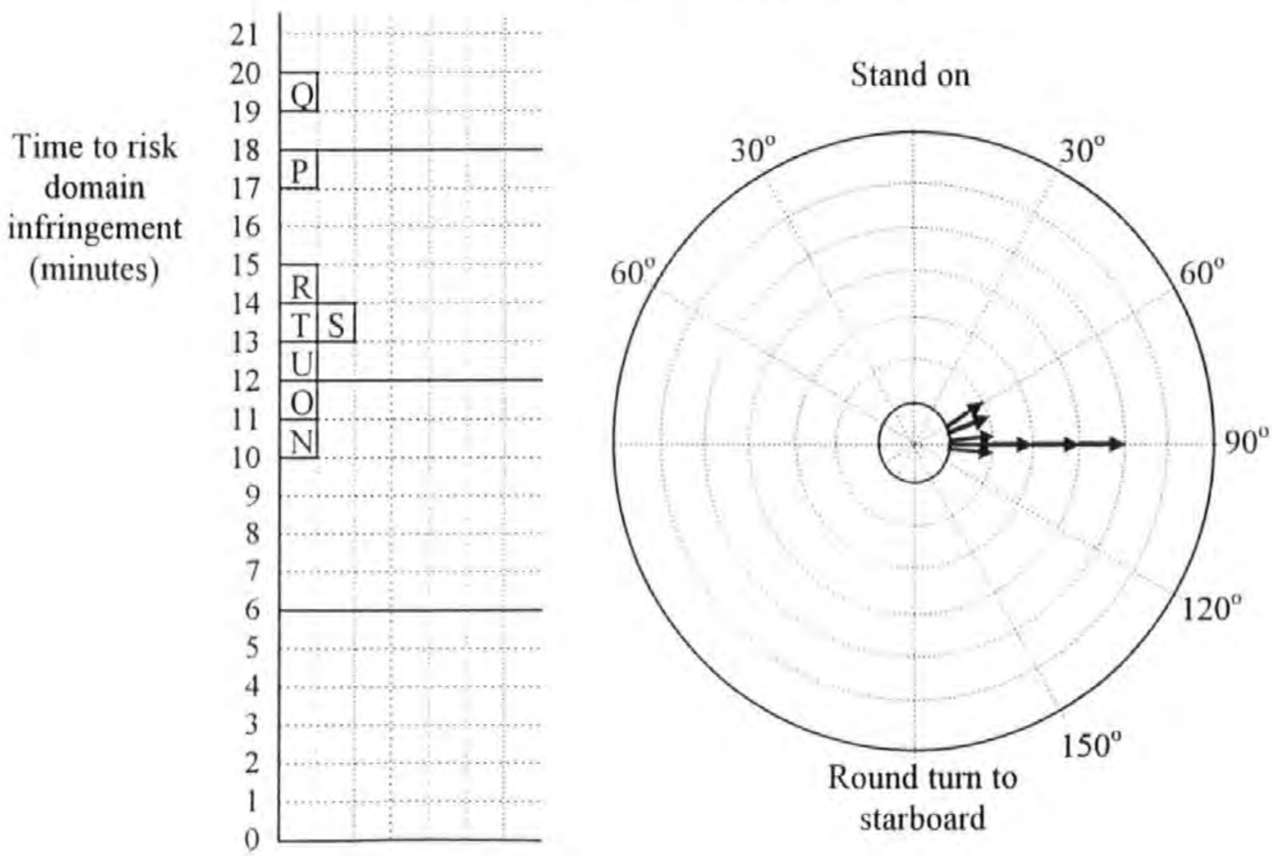


EXERCISE 7R

USUAL ACTION AT SEA



NEW ACTION



COMPARISON DATA

Kemp experiments

Kemp conducted various encounter experiments in the early 1970's on a simulator at the City of London Polytechnic (Guildhall University). The details and results of experiments of particular interest for comparison in this thesis are set out below.

End-on or nearly end-on encounters

The experiments of interest are those which Kemp conducted with "experienced" subjects. The subjects were Merchant Navy officers all with at least Class 2 certificates of competency. All were male and within the age range 24-40. The encounters were conducted on a marine radar simulator. Visual detection was not simulated.

Five standard encounters were used with a single target ship on a parallel and opposite course to the subjects ship in every case. One encounter was end-on with a cpa of zero. The four other encounters had a green to green passing distance incremented in ½ M up to a cpa of 2.0M. In every trial the target ship was made to maintain course and had a constant speed of 10 knots. The subjects were each given in turn the five encounters though not necessarily in the same order.

The subjects ships were simulated to be of 10 000 tons gross with a full speed of 15 knots. The initial speed was 10 knots. The subjects had the facility to increase or decrease speed as well as to alter course either way. Action in the encounters is recorded in Table F.1

Subject	End-on	0.5M offset	1.0M offset	1.5M offset	2.0M offset
1	S	S	S	M	M
2	S	S	S	P	M
3	S	P	P	M	M
4	S	S	P	P	P
5	S	S	S	P	M
6	S	S	S	P	M
TOTAL	6S:0M:0P	5S:0M:1P	4S:0M:2P	0S:2M:4P	0S:5M:1P

Figure F.1
Results of experiments by Kemp for reciprocal course encounters
Source: Author based on Kemp

Key: **S** alteration to starboard
M course maintained
P alteration to port

Wang experiments

Experiments by Wang are reported in Zhao. The experiments appear to be identical to the those carried out earlier by Kemp. The encounters are reciprocal course, end on and green to green with separations of ½ mile intervals up to 2 miles. The encounters were in "restricted visibility" and it is assumed that the subjects were presented with the situation in a ship simulator with radar. The results are set out in Table F.2 below.

Subject	End-on	0.5M offset	1.0M offset	1.5M offset	2.0M offset
1	S	S	S	S	S
2	S	S	S	P	M
3	S	P	P	M	M
4	S	P	P	M	M
5	S	S	S	S	S
6	S	S	P	P	M
7	S	S	P	P	P
8	S	S	S	P	M
9	S	S	S	P	M
Total	9S	7S:2P	5S:4P	2S:2M:5P	2S:6M:1P

Figure F.2
Wang's reciprocal course experiments
Source: Author based on Zhao

<u>Corbet questionnaire</u>

Corbet reports on a questionnaire survey of mariners' actions in reciprocal course encounters. The questionnaire was given to trainees at the end of radar simulator courses. The "trainees" were all experienced watchkeeping officers with either Class 1 or 2 certificates of competency. The encounters were presented as radar plots which included end on and green to green offsets of ½ mile, 1 mile and 2 miles.

Detailed circumstances of the case were given which included:

open sea;
restricted visibility and no target lights visible;
engines at Half Ahead and on Standby;
own ship: 15 000 tons displacement cargo vessel, 500 feet overall;
speeds: Full Ahead 16 knots
Half Ahead 12 knots (initial speed).
target vessel speed is 12 knots (inferred from plot)

"Each trainee was asked in each case to state the <u>initial</u> action which, in his opinion, should have a reasonable chance of success in avoiding a close quarters situation yet at the same time would put his own vessel in a position which would enable him to cope satisfactorily with any development which could be foreseen under the existing circumstances of each case." The results of the questionnaire have been tabulated below (Table F.3) for the purposes of this thesis.

		End-on		Green		to		Green	
	CPA	Zero		0.5 M		1 M		2 M	
Starboard	90° or more	57		76		35		1	
	50° to 89°	35		6		2		0	
	<50°	14		2		0		0	
Total	**Starboard alteration**	**106**	**98.2%**	**84**	**77.8%**	**37**	**34.3%**	**1**	**0.9%**
Port	90° or more	0		7		10		4	
	50° to 89°	0		5		13		4	
	<50°	0		1		4		8	
Total	**Port alteration**	**0**	**0%**	**13**	**12.0%**	**27**	**25.0%**	**16**	**14.8%**
Stand-On		**0**	**0%**	**3**	**2.7%**	**17**	**15.7%**	**71**	**65.7%**
Reduction	of speed only. Total	0	0%	5	4.6%	23	21.3%	17	15.7%
Stop	take all way off	0	0%	0	0%	0	0%	1	0.9%
Undecided		2	1.9%	3	2.7%	4		2	1.9%
	Grand Totals	108		108		108		108	
Manoeuvre	**Sense as rounded %**	**98S**		**78S:3M:12P**		**34S:16M:25P**		**1S:66M:15P**	

Figure F.3

Selected results from Corbet Questionnaire

Source: Author based on Corbet

The questionnaire was carried out during the period 1980-81 and involved 108 subjects. Corbet provides data from a "similar" survey conducted in 1968-9 with 41 subjects. Table F.4 below presents the data comparison.

	0.5M		1.0M	
	1968-69	1980-81	1968-69	1980-81
Altered to starboard	36.6%	77.8%	2.4%	34.3%
Altered to port	53.7%	12.0%	41.5%	25.0%
Reduced speed only	7.3%	4.6%	19.5%	21.3%
Stood-On	2.4%	2.8%	36.6%	15.7%

Figure F.4

Corbet questionnaire: comparing surveys from 1968-9 and 1980-1

Source: Corbet

Redfern experiments

Redfern conducted encounter exercises on the navigation simulator at the University of Plymouth for a watchkeeper behaviour study for the Dept. of Transport, UK, in 1993. The details and results of experiments of particular interest for comparison in this thesis are set out below.

Action by Head on Vessel - Open Sea

"Two scenarios EDTP23 and EDTP24 sought to check watchkeeper action when meeting another vessel very fine to starboard in the open sea. In both cases the closing speed was the same, but own vessel type and speed differed".

EDTP23

Initially, own ship, a container vessel at 21 knots, had another vessel OS2, ahead at a range of 12.4M. Observation would confirm the closing speed to be 36 knots and that there was a negative cpa of four cables, passing starboard to starboard.

"Action was taken at an average 7.3M within the limits of 8.9 to 5.0 miles. One subject experienced steering difficulties, but in post exercise report stated that had he had been able to do so he would have altered course 10° to port at a range of five miles so as to increase the starboard to starboard pass off distance. A second subject altered course 20° to port at a range of 7.2 miles when the relative bearing of OS2 was green 3°. Contact by vhf was attempted in order to advise the other vessel of his intentions. Both actions, intended and executed, were in contravention of Rule 14. The remaining seven subjects properly altered course to starboard in good time, achieving positive cpas in the range six cables to 2.4 miles, with an average of 1.5 miles".

EDTP 24

Initially, own ship, a tanker at 15 knots, had another vessel, OS2 ahead at a range of 12.4 miles. This situation is identical to EDTP23 except that the ship types and speeds are reversed.

"Action was taken at an average 6.4 miles, and within the limits of 5.2 to 8.9 miles. Such action was on average one and a half minutes later than in EDTP23. This is not seen as significant. On this occasion eight subjects altered course to starboard, achieving new cpas in the range of five cables to 1.7 miles, with an average value of one mile. One subject altered course 15° to port, when OS2 was on a relative bearing of green 4° and at a range of 5.5 miles. Again the stated reason was to increase the starboard to starboard passing distance. That between the two scenarios 17% of the set of well trained and qualified subjects elected to ignore the requirements of Rule 14 must be a cause for concern. There were no special circumstances, and in all three cases the alterations were not substantial.

Action by Stand-on Vessel - Open Sea

EDTP01

"Subjects were advised that engines were not at immediate readiness in the open sea situation". Initially, own ship, a container vessel at 20 knots, had a target at 8.8 miles, approximately four points on the port bow. "Systematic observation would show the bearing at first to be steady, that it was closing at some 24 knots, and that without action their would be a negative cpa of three cables, the target passing crossing own ship head at a range of four cables".

"All 15 subjects monitored the developing situation. Action was taken under Rule 17 by 14 watchkeepers at ranges between 4.4 and 0.4 miles. The mean range was 2.2 miles with a time to cross ahead of 3.75 minutes. One watchkeeper took no action, stating he accepted the four cables pass ahead range, but had the engines been available he would have slowed down"..

"The action taken by seven of the subjects was a round turn to starboard, often after first steadying on a course parallel to the threat. One subject altered course to port at a range of 1.7 miles and a second made a small, and late alteration to starboard which resulted in a collision". The port alteration was unintentional, and caused by unfamiliarity with the equipment.

EDTP01		
Action	No.	%
A/c starboard	6	40
A/c port	1	7
Round turn starboard	7	46
No action	1	7
Total	15	100

Table F.5
Action taken by mariners in exercise EDTP01

Source: Redfern

Action by Give Way Vessel Crossing - Open Sea

EDTP02

"Subjects were advised that engines were not at immediate readiness in the open sea situation". Initially, own ship, a ferry at 18 knots, had a target, OS2, at 8.8M range approximately four points on the starboard bow, and on a steady bearing. "Observation would show that the closing speed was 24 knots and that if no action was taken a negative cpa of three cables would result, with own ship passing four cables ahead of the target".

"The situation was complicated by the presence of a second vessel, T3, crossing from starboard which posed a no immediate threat, having an earlier and negative cpa of two miles, but could influence the time at which action was taken".

"Action was taken at an average 4.8M range from OS2, with limits of 1.8 to 6.3M. Only two subjects waited to pass ahead of T3 before taking action to avoid OS2. Two altered course to port, including one of those making a late manoeuvre, in contravention of Rule 15. Thirteen subjects made substantial alterations of course to starboard, the average value being 76°, making their intentions quite clear to all other participants".

COLLISION AVOIDANCE, COLLISION REGULATIONS AND TECHNOLOGY

Perkins, C.J. and Redfern, A.

In: NAV 93, Practical Navigation - The Application of Advanced Systems, Conference of the Royal Institute of Navigation, London, 1993.

Abstract

This paper considers the legislative change that would be necessary if an artificially intelligent automatic collision avoidance system were to be implemented.

The requirement for pre-implementation legislative change is illustrated using marine radar as an example. Possible future technologies are discussed. Elements in and the nature of the current collision regulations are considered with respect to automatic sensor and processor limitations.

1. Introduction

The application of artificial intelligence to ship operation is increasingly attractive, and work in this area is already being carried out. The problem is usually tackled as a means of replacing man by machine within the existing legislative framework. This paper discusses the legislative changes that would be necessary in order to apply artificial intelligence to automatic collision avoidance.

Technology and legislation have been introduced in order to reduce the likelihood of collision. For the introduction of technology to be of proper benefit it must be compatible with the legislative framework. When marine radar was first used it was not fully integrated with the collision regulations. This had unfortunate consequences. If today or tomorrow's advanced systems are to be benefited from, appropriate legislation must exist.

2. A precedent for change

The application of technology has often taken place with inadequate prior consideration of operational factors. Though the application may have brought about an overall increase in safety and efficiency, the full potential of the new technology is not initially realised. In some cases the new technology can be shown to have caused accidents which would otherwise not have occurred. In the wake of such accidents retrospective legislation and training are introduced. The application of radar to marine collision avoidance is clearly a case of this kind.

Marine radar development accelerated during the 1939-45 war. By 1944 most combatant vessels including convoy escorts were equipped with surface search radar. The primary purpose of the radar was the detection of enemy submarines. Convoy escorts were also able to make use of the radar for keeping themselves on station and keeping the blacked out convoy in formation[1].

The convoy escort was required to be within 500 yards of her assigned station in the anti-submarine screen. It was often necessary to zigzag, altering course every few minutes in order to maintain position. Each new course required the solution of a relative motion problem, that of intercepting a radar target. It was also necessary to intercept column lead ships and stragglers when the convoy began to lose its formation.

The wartime Naval watch officer became skilled at collision avoidance/rendezvous navigation using radar information. He received radar training and was supported by a bridge team of several trained men.

After the war radar became commercially available and merchant ships began to be equipped. The training given to
merchant marine watchkeepers was initially scanty. If radar plotting was carried out, this was a task additional to their other duties for which they received no extra support.

The introduction of radar was a great advance in eliminating risk of collision. It might have been considered a panacea, but this was not to be. Collisions still occurred involving radar equipped vessels, giving birth to the term "radar assisted collision".

In the classical case of the radar assisted collision the two vessels were initially passing clear. Only after acting on radar information did one or both vessels bring about a collision situation. The following statements were both made by Lord Justice Willmer during judicial proceedings concerning separate collision cases. "...this is an unhappy case of a collision between two well-found ships, both equipped with every modern aid to navigation, including radar. It is a melancholy reflection that the collision would probably not have happened if the ships had not been equipped with radar."[2]. "It was a collision which should never have happened at all; and one can quite confidently say that it would not have happened if the ships had not been equipped with radar..."[3].

The problem in general was an inadequate appreciation of the relative motion problem. This was often evident by a scarcity of plotting or no plotting at all. In response to the occurrence of this type of collision, various changes in training and legislation were made.

In 1956 Britain required evidence of competence in radar use before the issue of a second mate's certificate [4]. British law requires that "while a ship which is required to be fitted with a radar installation is at sea and a radar watch is being kept, the radar installation shall be under the control of a qualified radar observer...."[5]. A "qualified radar observer" has undergone a course which includes plotting; understanding the need to plot, and the limitations of the radar installation.

The 1948 revision of the collision regulations did not mention the use of radar. Subsequent revisions in 1960 and 1972 recognised the influence of radar and included recommendations on the use of radar information first in an annex, and then in the body of the rules.

Radar as a case in point shows that the introduction of new technology changes operating procedures for which commensurate training and legislation is required, in order to maintain or increase a level of safety.

3. Future technology

Technology that could influence collision avoidance in the future includes advanced communications and artificial intelligence. These technologies have the potential to revolutionise current operations and greatly reduce collision incidents.

3.1 Automatic cooperative communication systems

Cooperative communications exist when two parties act to aid a communication. It has been considered that the essentials for avoiding collision included "communications, either to agree or indicate action"[6].

Cooperative communication is promoted in the current regulations. For instance Rule 8, Action to avoid collision, part (b) " Any alteration of course and/or speed to avoid collision shall if the circumstances of the case admit, be large enough to be readily apparent to another vessel observing visually or by radar...". Lights, shapes and sound signals are all used to cooperatively communicate. VHF radio telephone is commonly used to aid collision avoidance.

In the future it is likely that the principle of cooperative communication will be strengthened by the adoption of systems which are automatic and have a dedicated channel of communication. Vessel Traffic Services (VTS) of the future require improved cooperative communications in order to provide a quality traffic image and individual ship identification [7,8]. Following the Exon Valdez stranding an Automatic Dependent Surveillance system is now mandatory for tankers in Prince William Sound. The system can provide the VTS centre with information which includes time, position by differential GPS; speed and course over the ground and ship identification [9]. The sharing of this type of information is of benefit not only to VTS but also independent collision avoidance.

Many parties have reported on automatic cooperative communication systems[10,11,12,13,14]. These systems have the potential to exchange almost any information between suitably equipped ships. The information exchange could provide knowledge of target's classification, reinforce data from primary radar and ARPA, and even target manoeuvring intentions. The application of advanced automatic cooperative communications has a great potential influence on the application of artificial intelligence in collision avoidance.

3.2 Artificial intelligence applications

One definition of artificial intelligence is "the study of the computations that make it possible to perceive, reason and act"[15]. The abilities to perceive, reason and act are all requirements for successfully avoiding collision. It may follow that collision avoidance is a suitable application for artificial intelligence. But why should man be aided or replaced by machine?

Collisions between vessels occur resulting in loss of life, environmental damage by pollution and a wasting of resources. It is regularly noted that human error is the largest factor in marine accidents[16]. If the collision regulations were applied as intended then collision would be a rare occurrence.

Human frailties in terms of collision avoidance include lack of understanding of agreed conventions and inadequate judgement particularly during times of stress (due to work overload or boredom). The application of an intelligent machine could overcome these human frailties. A machine's understanding of conventions can be tested and its judgement is not susceptible, as is human judgement, when under stress. Many projects have been or are developing some form of artificial intelligence to deal with the collision avoidance scenario.

Most recently projects have been of an expert system knowledge based approach [17,18,19]. Expert systems are written to solve problems which can be defined by a particular domain of knowledge. "An expert system uses a compilation of the knowledge of one or more expert persons and through a computer program, performs the decision making as if the expert people were actually performing the task"[20].

The application of expert systems to collision avoidance can be seen in two guises. The machine processor can offer advice to the mariner or it can control the vessel, automatically implementing collision avoidance manoeuvres.

3.2.1 Advisory systems

Most of the expert system applications for collision avoidance have been promoted in the form of advisory systems. The machine will process the input data and will output some form of useful information. ARPA processes raw radar data and outputs various predicted mathematical relationships between the vessels. The expert system may define risk of collision; qualify encounters according to the collision regulations, and then recommend action to avoid collision.

An advisory system might be considered attractive because it may possibly be installed on a vessel without reference to legal constraints. By considering the expert system merely an aid to navigation, the responsibility remains with the human navigator. Also, by leaving the responsibility with the human navigator, the limitations of automatic sensors may be deferred.

The application of an advisory system may be limited due to difficulties reconciling human assessment with machine advice when they differ. The reconciliation is an additional task, and

possibly a difficult, or even an impossible task for the watchkeeper. The expert system needs to present the reasoning behind its conclusion in human reasoning terms. Many expert systems that are being developed concern themselves with producing expert human behaviour rather than human reasoning [21].

The alternative application of expert systems avoids problems of having two "Captains" on the bridge. An automatic collision avoidance system removes the human element from the operation.

3.2.2 Automatic collision avoidance system(ACAS)

In an ACAS the entire collision avoidance operation is carried out by the machine system. The input data is acquired automatically, then processed before appropriate control functions are automatically initiated. By definition human input is not required in an automatic system.

An automatic system would provide a major component in an unmanned bridge. It may be seen as a step towards an unmanned vessel though it is only a minor component in that scenario. A likely initial application of an ACAS is to provide a temporarily unmanned bridge during relatively low key parts of a voyage.

An ACAS equipped vessel would operate in the same theatre as manually operated vessels. The two modes of operation would need to be compatible as would any rules or legislation governing that operation.

4. Legislative change required

If an automatic collision avoidance system is to be applied then the current collision regulations require alteration. The required change is due to limitations of both automatic sensor and processor.

4.1 Sensor limitations

The current collision regulations reflect the use of human vision in collision avoidance. An automatic system would need to mimic human vision if it were to comply with the current regulations. The technology that is available at present and in the near future, does not and is unlikely to, mimic human vision to a sufficient extent [22,23]. The technology that is likely to be used in place of human vision is primary radar and, or some form of cooperative communications system.

4.1.1 Primary radar

Primary radar(radar) is compulsory on merchant vessels greater than 1600 GRT [24]. It has become a well used tool for the watchkeeper. For collision avoidance it is used alongside a visual lookout, and in cases of restricted visibility it is often the only reliable tool. Under the present regime radar compares poorly with human vision in 3 instances:

(i) it does not detect all the targets that human vision can;

(ii) it does not distinguish between vessels by class (as required by Rule 18 Responsibilities between vessels);

(iii) and it does not distinguish between vessels in sight of one another or not in sight of one another.

Nb. Processed radar data can provide target aspect however this is historic information. Visually observed target aspect is instantaneous information. The difference between the two methods of acquiring target aspect will influence the collision avoidance operation in some circumstances.

4.1.1.1 Target non-detection

Radar may detect a target when the radar transmission response which is reflected from the target is greater than the background noise. Target response depends on among other factors target material and size. In general a stronger response is obtained from larger metallic vessels rather than smaller wooden or plastic vessels. Typical of poor radar targets are some fishing boats and some yachts. Background noise depends on among other factors, sea state in close proximity to the vessel and precipitation including rain, hail and snow anywhere within the detection range. Despite the use of various radar system adjustments and modern filtering techniques non-detection remains possible.

While there is a possibility of non-detection the concept of "single responsibility" used in the present regulations may be inappropriate. In many cases the current collision regulations assign responsibility to one vessel to keep out of the way of the other. The former is termed the "give-way vessel" and the latter the "stand-on vessel". The stand-on vessel is initially required to "keep her course and speed" while the give-way vessel has a largely free choice of manoeuvres with which to keep clear. If it becomes apparent that the give-way vessel is not taking appropriate action in compliance with the rules then the stand-on vessel may manoeuvre. If this stage is reached then the regulations have "failed" in the first instance and a dangerous situation exists due to the unpredictability of the give-way vessel. This stage is always reached when the stand-on vessel is not detected by the give-way vessel.

A system of rules which safely assigns responsibility to both vessels(dual responsibility) is needed when non-detection is possible.

4.1.1.2 Responsibility by class

There is some benefit if the vessel in the best position to manoeuvre is able to take the initiative [25]. Vessel manoeuvrability is clearly a factor in collision avoidance. In an attempt to make use of the manoeuvrability concept the collision regulations divide vessels into discrete hierarchical classes. Rule 18, Responsibilities between vessels, requires that under particular circumstances a power driven vessel should keep out of the way of a vessel not under command; a vessel restricted in her ability to manoeuvre; a vessel engaged in fishing, and a sailing vessel. The shapes and light configurations which indicate vessel status are designed for consumption by human vision, but are of no use for radar observation. Unless vessel classification could be communicated in a satisfactory way then vessels could not always be given this type of privilege.

4.1.1.3 Action according to visibility state

When vessels are in sight of one another in most instances the current rules prescribe responsibility for keeping out of the way to one vessel only. When vessels are not in sight of one another in an area of restricted visibility, both are required to manoeuvre. The concept of a vessel being in sight or not is easily dealt with when using human vision. Radar however cannot mimic the human faculty of sight.

4.1.2 Cooperative communications

The future use of cooperative communications as previously described could compensate for some of the limitations of radar. Radar non-detection could be compensated by transponder technology emitting vessel position. Transponder technology also allows responsibility by class. The concept of a vessel being in or not in sight is not provided by automatic cooperative communications.

4.2 Processor limitations

4.2.1 The ordinary practice of seamen

To comply with the collision regulations it is necessary to adopt the ordinary practice of seamen. "Nothing in these Rules shall exonerate any vessel, or the owner, master or crew thereof, from the consequences of any neglect to comply with these Rules or of the neglect of any precaution which may be required by the ordinary practice of seamen, or the special circumstances of the case"[26].

The marine collision regulations as written do not explicitly indicate how the navigator should behave. The exact science of collision avoidance only begins to be explained when a collision incident is dissected during judicial proceedings. The regulations are limited to the following:

the regulations indicate some of the factors that should be considered for vessel navigation and collision avoidance;

in some instances they assign responsibility to one vessel for keeping out of the way of the other, and in one instance they describe the sense of course alteration for both vessels;

in some instances they proscribe some manoeuvres.

The regulations themselves do not entail a complete rule-base. They lack various instructions which include:

the sense of course alteration in many cases;

the extent of course or speed alteration;

the timing of course or speed alteration.

In law and in the regulations the missing parts of the rule-base are described as the "ordinary practice of seamen". The ordinary practice of seamen is only described exactly when a particular incident is under judicial scrutiny. Masses of case law exists which describes the ordinary practice of seamen for specific incidents. The ordinary practice of seamen can only be described for specific cases because it depends on the specific or special circumstances of the case.

The operational complexity of collision avoidance and infinite number of possible encounter situations makes a general and a total definition of the ordinary practice of seamen difficult to construct. The difficulty in defining this aspect of collision avoidance on-line is likely to be a problem for an artificially intelligent system.

When it is possible to construct an artificially intelligent system which is faultless with respect to the regulations and judicial procedure, it will also be possible to use that system as the oracle in judgement of collision cases. This may or may not be practical. There are no human systems which are faultless with respect to the regulations and judicial procedure (though fault is only noted in the case of a collision). It is likely that it is impossible to make a machine that is theoretically faultless under the present regime.

4.2.2 The nature of rules

"...accepting a regime of rules necessitates tolerating some number of wrong results - results other than those that would have been reached by the direct and correct application of the substantive justifications undergirding the rule."[27].

The preceding statement indicates that rules are general and can only be applied in a useful way when the circumstances of the case match the rule. The regulations themselves recognise that their application to specific cases, may not always serve to aid the safety of vessels. A departure from the rules is allowed, indeed required when necessary to avoid immediate danger.

"In construing and complying with these Rules due regard will be had to all dangers of navigation and collision and to any special circumstances, including the limitations of the vessels involved, which may make a departure from these Rules necessary to avoid immediate danger"[28].

Any collision avoidance system (artificially intelligent or otherwise) must not only encompass circumstances which fall within the ordinary rules, but it must also encompass all other situations. The system must obey the regulations and avoid collision.

5. Conclusion

If the potential benefits of applying artificial intelligence to marine collision avoidance are to be realised, then legislative change must occur. In the past technology has been applied for collision avoidance without necessary prior consideration of operational factors. This resulted in particular collision incidents and general unsafe practice. The problem was remedied by post-implementation legislation and training. It is clear that the application of an automatic collision avoidance system could not legally occur without pre-implementation legislative change.

The legislative change relates to the automatic sensors that may be used and the nature of the automatic processor. Sensor limitations bring into question the concepts of single responsibility; responsibility by class, and a vessel being in or not in sight. The nature of the automatic processor challenges the role of the collision regulations in the judicial system.

At the Institute of Marine Studies, University of Plymouth, research is being conducted concerned with the legislative change that would be necessary to implement an automatic collision avoidance system.

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Requirements for coordination and the application of an automatic collision avoidance system

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ABSTRACT

This paper is concerned with the legislative change which would have to take place if an automatic collision avoidance system were to be implemented.

The principle of complementary action, and the role of coordination in achieving that action is considered. Current collision avoidance practice is discussed, noting the coordination attributes of the International Regulations for the Prevention of Collision at Sea, and the responsibility placed on the mariner by the regulations. The processing element of an automatic collision avoidance system is considered in the light of current judicial practice.

The paper concludes that the implementation of an automatic collision avoidance system is incompatible with the current collision regulations and the supporting judiciary. It is suggested that successful implementation will require the recognition of a discrete rule base.

1. INTRODUCTION. In the light of statistics which indicate that human error plays a part in the majority of marine accidents[1], it is not surprising that automation of ship board operations is increasingly attractive. Collisions between vessels at sea continue to occur despite considerable advances in navigation aids and several waves of

legislation. The consequences of collision, loss of life and resource, and resultant pollution, have encouraged many parties to work towards a solution to the problem. Most recently work has focused on the partial or full automation of the collision avoidance operation.

The work of computer programmers and engineers has considered the problem as one of replacing man by machine within the existing legislative framework[2,3,4]. This paper results from research which considers legislative changes, which would have to take place, if a fully automatic collision avoidance system were to be implemented.

The fact that legislative change is related to both the automatic system's sensors and processors has already been described[5]. This paper concentrates on the relationship between the International Regulations for the Prevention of Collision at Sea (COLREGS)[6] and the supporting judicial system, with the nature of the automatic processor. The first consideration is the need for complementary action between vessels and the role of coordination in achieving that action. The current operational scenario will then be discussed, indicating the merits of the COLREGS for coordination, and the responsibility placed on the human mariner by the COLREGS. The automatic system will be examined in the light of current operation.

2. COMPLEMENTARY ACTION. In general marine practice it is desirable for action to avoid collision to be complementary. Calvert[7] noted that an essential collision avoidance principle is to maintain or establish sight-line rotation. For net sight-line rotation both vessels actions must be considered. By avoiding

uncomplementary action, net sight-line rotation will occur with minimum effort, hence disturbing traffic flow least, and resultant gains in safety and efficiency.

Sight-line rotation may be anti-clockwise(positive) or clockwise (negative). Three complementary action strategies exist which will achieve net sightline rotation. In a particular encounter both vessels may adopt a convention of positive rotation; both vessels may adopt a convention of negative rotation, or one vessel will stand-on while the other is responsible for making the manoeuvre, and choosing the sightline rotation sense. It is clear that some form of agreement is necessary in order to apply the strategies.

Without a form of agreement what would be the nature of behaviour at sea? From his experimental evidence Kemp[8] has suggested that three main principles would apply:

"(a) Manoeuvres would be made to pass astern of the vessel being avoided.

(b) Manoeuvres would tend to increase whatever miss distance is originally estimated.

(c) There would be a reluctance to reduce speed."

None of these principles involves any coordination between the vessels. Only one vessel can pass astern of the other. Passing astern may be in conflict with the principle of increasing the existing closest point of approach (cpa).

If both vessels took action totally independently of each other, cancelling action would occur for 50% of the encounters. If a vessel can observe the action of the other then she can make her manoeuvre complementary with the action of the vessel which manoeuvres first. However, it is not always possible for a vessel to observe the actions of the other, and it is not satisfactory for a vessel to be waiting indefinitely for the other to show her intentions. A form of coordination is required.

3. COORDINATED ACTION. To achieve coordination a mutual perception of three elements in the encounter is needed. Each vessel must mutually perceive: the risk of collision; the strategy to be applied, and when manoeuvres are to be made. Unless these criteria are met then the target may appear as a rogue vessel and coordination may not ensue.

Cannel[9] has suggested that a solution to a coordination problem maybe found in three ways:

"(i) Agreement, specific agreement in an individual case.

(ii) Tacit agreement in a series of similar situations.

(iii) By the obvious salience of a particular solution."

Specific agreement in a particular case may only be reached if there is a suitable communication channel available. Vhf radio telephone(RT) sometimes provides a suitable link but does not constitute a general solution. It is noted that technology currently under discussion[10] may provide an opportunity for a general solution in the future.

A particularly salient feature in an encounter may provide a means of coordination. An initial cpa may suggest manoeuvres to increase the existing sightline rotation. Unfortunately most features are open to misperception. Truly salient features are not prevalent enough to offer a general solution.

Tacit agreement exists in the form of rules and conventions. The COLREGS are the rules and conventions which entail the tacit agreement for the collision avoidance scenario.

4. CURRENT PRACTICE. *Lack of coordination*. The mariner has a tacit agreement with other mariners that in the event of an encounter at sea, complementary action will be achieved through the COLREGS. An inspection of the COLREGS indicates that of the three coordination requirements, only strategy is covered. While recognising the importance of achieving a mutual perception of risk and when to make manoeuvres, the regulations do not provide a means of achieving this. The mariner must some how deal with these points if coordination is to be achieved.

Simulator studies[11,12,13], questionnaires[14], traffic studies[15] and incident reporting schemes[16], all indicate that mariners' perceptions of risk of collision, vary with the circumstances of the case and through the watchkeeping population. In the absence of a tacit agreement, mutual perception of risk of collision can only be achieved, if a communications channel for specific agreement exists. Vhf RT sometimes provides that means. Without a means to ensure a mutual perception of risk of collision, passing distances are exaggerated (when sea room allows) to compensate for the otherwise inevitable uncertainty.

Simulator studies also indicate that the point at which mariners will manoeuvre, varies throughout the watchkeeping population and with the circumstances of the case. Without a means of ensuring mutual perception of the situation, a vessel which is yet to manoeuvre, may be considered as a rogue. The watchkeeper is required to make manoeuvres "early" in order to overcome this problem.

The mariner and the law. In law, the "missing parts" of the collision regulations are given quantification when cases of collision come to court. Inspection of case law will show what is an acceptable passing distance, for risk of collision not to exist, in a particular set of circumstances. The distance will vary depending on the circumstances, but it will not vary depending on the particular mariner being tried. There are absolute values for risk of collision and by these the mariner will be judged. The same argument applies to the point at which manoeuvres are to be made.

In not quantifying many aspects of the collision avoidance operation the COLREGS avoid becoming infinitely complex. The possibility of creating rules which account for all possible circumstantial variables can only be considered alongside the concept of a supreme being. In court, the effect of circumstantial variables are considered retrospectively to one particular collision. The deliberation is carried out by several men with advisors, over a period of hours or days. At sea, to comply with the law, the individual mariner must make a correct judgement as to the effect of the circumstantial variables, on-line, over a period of minutes.

An absolute rule system. The generality of rules has caused Schauer[17] to note that "...accepting a regime of rules necessitates tolerating some number of wrong results - results other than those which would have been reached by the direct and correct application of the substantive justifications undergirding the rule". The current regulations imply this limitation of rules and yet will not accept a number of wrong results.

Rule 2(a) states that "Nothing in these rules shall exonerate any vessel, or the owner, master or crew thereof, from the consequences of any neglect to comply with these Rules or of the neglect of any precaution which may be required by the ordinary practice of seamen, or by the circumstances of the case"[18].

Rule 2(b) states that "In construing and complying with these Rules due regard shall be had to dangers of navigation and collision and to any special circumstances, including the limitations of the vessels involved, which may make a departure from these Rules necessary to avoid immediate danger"[19].

Rule 2 makes it clear that the mariner is required to know when the general rules are going to give Schauer's wrong result, and act upon that in order to avoid collision. The mariner is also required to find a solution to the collision avoidance problem in all "special circumstances". The regulations appear not to give the mariner any reprieve in the event of collision.

This concept of guilt, regardless of circumstances, presents a high level of personal accountability, and is laudable in that it probably promotes a high level of personal responsibility. However, this approach has been criticised for inhibiting the use of regulations to truly aid the mariner. The regulations have been described as being drawn up to suit the purposes of lawyers rather than mariners, distinguishing responsibility for collision rather than maximising operational guidance.

The COLREGS are worded and constructed such that in the event of a collision the mariner can be found at fault. Human error or incompetence is the apparent reason for the collision. The mariner may be demoted or removed from the watchkeeping population altogether. This system of justice may need review if an automatic collision avoidance system is to be implemented.

5. APPLYING AN AUTOMATIC SYSTEM. Technical work in the field of automatic collision avoidance is already being carried out. The attractions of the concept of an automatic collision avoidance system range from a reduced manual work load to the absence of human error.

A machine which will diligently follow its pre-programmed instructions may be tested prior to implementation. The substance of the computer program may be inspected, and the machine itself might be tested for at least the number of encounters which a human mariner would have during a life time at sea. Given success in the tests, the machine will be deemed competent and issued with the appropriate certificate. The machine's competence will remain constant throughout its life time.

The human watchkeeper is also tested for competence. This usually entails a few hours of verbal questions on the application of the collision regulations. Given success in this examination the human is deemed competent and issued with a certificate. Human competence is likely to vary throughout a lifetime, however the certificate is likely to remain valid to retirement unless a collision occurs.

Despite being tested to a level of undoubted satisfaction, the machine will not be able to account for all the circumstantial variables which are implied by the COLREGS. The machine's program may be massive but is finite. Action initiated by the machine, is limited in useful application, by the finite scope of the program.

Learning. The human may also be limited by the scope of his knowledge. The city dweller transported to the jungle may find most of his knowledge and skills useless in the new environment. Humans do however have an ability to learn. It appears that the human mariner is expected to deal with extraordinary and complex circumstances by some learning process.

Some computing techniques exhibit a learning facility. This concept may offer many advantages in automatic system development. The on-line use of such a system could produce the best or the worst aspects of human processing. Such technology would add a further dimension to the issue of responsibility and liability.

A discrete rule base. Leaving aside the concept of a learning computer, it is apparent that the machine of limited program is not compatible with the nature of the COLREGS. To use a machine with a strictly limited rule base in the face of the absolute rule system of the COLREGS would risk a collision which could not be defended in law. Knowingly operating with a machine which could not comply with the law in circumstances which may be encountered, would be to court criminal liability. For the automatic system to be properly used, the COLREGS and supporting judiciary would need to legitimise the machine's limitations. This would require a discrete rule base.

The discrete rule base will form the basis of the machine's program, and will be that which the machine is tested against. For testing, the rule base will have quantification of many aspects of the collision avoidance operation. This must include some form of quantification of risk of collision and when manoeuvres are expected to be made. It appears that the ingredients for coordination might be provided through legislation in a discrete rule base. The human application of such a rule base is the subject of experimental research at the University of Plymouth.

6. CONCLUSION. The COLREGS do not in themselves provide a framework which will allow two vessels to coordinate action. The wording and construction of the COLREGS implies that the human mariner is responsible for avoiding collision in all circumstances. An automatic collision avoidance system could not be constructed to take account of all circumstances. Therefore the implementation of an automatic collision avoidance system is not compatible with the current collision regulations and the supporting judicial system.

It is necessary to recognise that it is impossible for a collision avoidance system, manual or automatic, to be wholly compatible with an absolute rule system. It is not appropriate therefore, to simply make the vessels involved in a collision responsible, when judged by an absolute rule system. The implementation of an automatic system can only be possible when the fundamental limitations of the system are recognised by the judicial process, and an appropriate form of responsibility and liability is adopted.

It is suggested that appropriate responsibility will be judged against a discrete rule base. When circumstances arise outside the remit of the rule base then liability could not fairly be criminal. Civil liability might remain with those traditionally held responsible, but this may not necessarily be the best solution.

In formulating a discrete rule base which is suitable for testing an automatic system against, it will be necessary to quantify certain collision avoidance parameters. In doing so there may be a opportunity to move towards regulations which allow the mutual perception between vessels which is necessary for coordination. Experiments using a navigation simulator are being carried out at the University of Plymouth to investigate this possibility.

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