SHORT RANGE AIDS TO NAVIGATION SYSTEMS

DESIGN MANUAL FOR RESTRICTED WATERWAYS

FINAL REPORT

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16. Abstract

This manual is intended to supplement the system design guidelines presented in Chapter 4 of the Aids to Navigation Manual - Administration (COMDTINST M16500.7). It provides procedures for designing or evaluating systems of aids in restricted waterways navigated by deep draft vessels. As such, it is an appropriate tool for use by the District Aids to Navigation Branch when conducting regularly scheduled waterways evaluations under the Waterways Analysis and Management System (WAMS) (COMDTINST M16500.11). Besides its structured approach to system design and evaluation, the manual provides a measure of quality for candidate aid configurations. This measure of quality is presented as an assessment of risk, providing the District or Headquarters analyst with an objective, quantifiable measure of effectiveness to support operational and budgetary decisions.

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EXECUTIVE SUMMARY

This manual is intended to supplement the system design guidelines presented in Chapter 4 of the Aids to Navigation Manual - Administration (COMDTINST M16500.7). It provides procedures for designing or evaluating systems of aids in restricted waterways navigated by deep draft vessels. As such, it is an appropriate tool for use by the District Aids to Navigation Branch when conducting regularly scheduled waterways evaluations under the Waterways Analysis and Management System (WAMS) (COMDTINST M16500.11). Besides its structured approach to system design and evaluation, the manual provides a measure of quality for candidate aid configurations. This measure of quality is presented as an assessment of risk, providing the District or Headquarters analyst with an objective, quantifiable measure of effectiveness to support operational and budgetary decisions.

HOW TO USE THIS MANUAL

The manual was prepared to serve a variety of designer objectives. Some possibilities are listed in the following table along with a sequence of sections essential and recommended to serve each objective. The first possible objective listed in the table is the design of new aid systems for a waterway, with or without the support of quantitative evaluation. The following cluster of objectives concerns the assessment and management of risk within a single waterway. These objectives are supported by quantitative procedures that are relatively simple. The third cluster of objectives involves the effects of changing circumstances within a single waterway. These objectives, involving more complex situations, require slightly more complex procedures. The fourth cluster of objectives involves the management of risk across a district with consideration of a number of waterways. These objectives require not only more complex procedures, but also more judgment on the part of the district system designer. The fifth and sixth clusters involve response to special needs that are beyond the general design, evaluation, and management of the aid to navigation system.

OVERVIEW OF THE CONTENTS

An annotated table of contents is presented, both to give the designer an overview and to help him find the material of his immediate interest.

SECTION 1. INTRODUCTION. This section is a brief introduction by the Office of Navigation, Short Range Aids to Navigation Division.

SECTION 2. THE BASIS OF THE DESIGN AND EVALUATION PROCEDURES. This section is a summary of the research on which the manual is based. It is meant to familiarize the designer with the assumptions, the methods, and the performance measures of the manual.

SECTION 3. SPECIFICATION OF WATERWAY CONDITIONS. This section contains guidelines for collecting relevant information on conditions in the waterway of interest. The information is essential in applying the procedures and recommendations of the manual to local conditions. Also in this section are

SEQUENCES OF SECTIONS RECOMMENDED FOR DESIGN/EVALUATION OBJECTIVES

	Sections								
	Introduction	Basis	Conditions	Design	Evaluation	Meeting Traffic	Reduced Visibility	Radio Aids	Risk Management
OBJECTIVES	1	2	3	4	5	6	7	8	9
1. To design new systems	o	o	●	●	o				
2. To seek uniform risk within a waterway	o	o	●	o	●				●
To prioritize work within a waterway	o	o	●	o	●				●
To justify reductions within a waterway	o	o	●	o	●	o	o		●
3. To evaluate design proposals or requests	o	o	●	o	●				o
To respond to changing needs	o	o	●	o	●				o
To justify reductions within a waterway	o	o	●	o	●	●	●		●
4. To prioritize work within a district	o	o	●		●				●
To seek uniform risk within a district	o	o	●		●				●
To justify reductions within a district	o	o	●		●	●	●		●
5. To ensure safety for sensitive cargo	o	o	●	o	●				o
To establish lower limit of risk for waterway	o	o	●	o	●				o
6. To ensure service for meeting traffic	o	o	●	o	●	●			o
To ensure service for reduced visibility	o	o	●	o	●		●	o	o

● Essential
o Recommended

instructions for dividing the waterway into "regions". All later sections assume that this has been done.

SECTION 4. DESIGN GUIDELINES FOR AIDS TO NAVIGATION SYSTEMS. This section is a systematic discussion of the general effects on performance caused by a variety of factors (e.g., channel characteristics, ship characteristics, aids). It is meant to educate the designer on those effects to help in the art of design and evaluation.

SECTION 5. EVALUATION PROCEDURES FOR AIDS TO NAVIGATION SYSTEMS. This section contains performance data and instructions for their use. It provides a measure of quality, the relative risk factor (RRF) for each region in the waterway under several conditions. It also allows for some comparisons of risk within a single waterway.

SECTION 6. SPECIAL GUIDELINES FOR THE MEETING TRAFFIC SITUATION. This section contains design guidelines and performance data for the meeting traffic situation. It provides assurance that the aids to navigation system will serve that more demanding situation.

SECTION 7. SPECIAL GUIDELINES FOR THE REDUCED VISIBILITY/RADAR SITUATION. This section contains design guidelines and performance data for the reduced visibility situation. It assumes aids arranged for visual piloting, equipped with passive reflectors, and used with conventional radar. The data include performance in zero visibility to use as a baseline for the evaluation of radio aids used in restricted waterways.

SECTION 8. EVALUATION OF RADIO AIDS PERFORMANCE. This section contains design guidelines and performance data for radio aids use in restricted waterways in the absence of any visual information. Data are included for performance with a variety of display formats. The conditions under which the data were collected are sufficiently similar to the visual and radar conditions that comparisons can be made.

SECTION 9. RISK MANAGEMENT PROCEDURES. This section combines recommended risk management objectives with recommended procedures using the relative risk factor (RRF) to meet those objectives. It follows the executive summary table as an outline.

APPENDIX A. Appendix A contains reproductions of selected data tables, data plots, and worksheets, arranged by sections. Together they provide a short summary of the manual. (They also provide replacement for lost materials.)

GLOSSARY. The glossary contains all the acronyms used and selected terms whose meaning is critical to understand the text.

BIBLIOGRAPHY. The bibliography contains the Commandant Instructions that were cited in the text; and all the project research reports, most of which were not cited.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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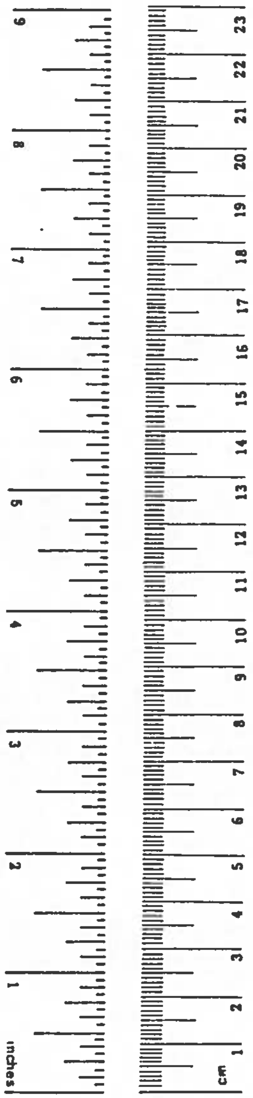
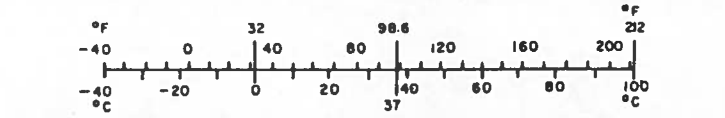
*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SECTION 1. GENERAL INTRODUCTION

Section 1

GENERAL INTRODUCTION

1.1 PURPOSE

This manual is intended to supplement the system design guidelines presented in Chapter 4 of the Aids to Navigation Manual - Administration (COMDTINST M16500.7). It provides procedures for designing or evaluating systems of aids in restricted waterways navigated by deep draft vessels. As such, it is an appropriate tool for use by the District Aids to Navigation Branch when conducting regularly scheduled waterways evaluations under the Waterways Analysis and Management System (WAMS). Besides its structured approach to system design and evaluation, the manual provides a measure of quality for candidate aid configurations. This measure of quality is presented as an assessment of risk, providing the District or Headquarters analyst with an objective, quantifiable measure of effectiveness to support operational and budgetary decisions.

1.2 BACKGROUND

For a number of years, we have recognized the lack of an objective method of assessing our program's aids to navigation needs. Decisions on aid placement, whether precipitating from ongoing system evaluation or responding to user requests or complaints, have been based largely on the experience and subjective judgment of the individual conducting the analysis. Vessel casualty statistics strongly attest to the effectiveness of the Short Range Aids to Navigation System as a whole, yet isolated shortcomings suggest we are clearly not functioning optimally. In a climate of increasingly tight fiscal scrutiny, the necessity for program-wide consistency and solid documentation of requirements was, and still is, apparent.

In response, a project was initiated in 1976, through the Office of Research and Development, to examine and measure the relationships between aids to navigation and navigation performance. The work was done by Ship Analytics, Inc. of North Stonington, Connecticut. A detailed study of 32 U.S. ports provided the background for the ships, waterways, and aids to navigation configurations which would shape the future of the project. This study revealed the range of ship sizes and types expected to be encountered, as well as the most common channel widths, depths and shapes. Existing aids to navigation layouts intended to accommodate these vessels and waterways were catalogued. Over the next six years, a series of controlled experiments was conducted to investigate vessel performance in response to varying levels of several environmental and aids to navigation variables. Most of the experiments were done using marine simulators, although significant at-sea data were obtained to help validate the findings. Specific variables studied included aid number, configuration, spacing, type, characteristic, and radar presentation. External variables included ship size, channel width, turn angle, wind and current, visibility, and meeting traffic.

1.3 METHODOLOGY

In the simulator experiments, various scenarios, representing different levels of these variables, were displayed in a conning officer's perspective over a wide angle screen. Experienced pilots were stationed in a life-size bridge mockup. They were tasked with navigating vessels through these simulated waterways, while a computer recorded their performance. The primary performance measure used was the crosstrack position of the ship's center of gravity with respect to the channel centerline. By replicating the experiments and observing the data obtained, the contractor was able to make substantial inference about the consequence on navigation performance of the information provided by the aids to navigation.

1.4 VALIDATION

To verify the simulator's ability to adequately represent real-life performance, at-sea data were collected from merchant vessels in Chesapeake and Narragansett Bays. Here, actual vessel transits were compared to those on the simulator. Subsequent data analysis supported the simulator's validity, lending credibility to the vast pool of experimental data.

1.5 DESIGN PROCEDURE

A significant portion of the work involved the development of a design process. Past aid system design lacked formal guidance, resulting in a high degree of inconsistency between waterways and a poor ability to assess system quality. Through careful study of vessel tracks and the pilots' behavior on the bridge, both on the simulator and at sea, critical locations were found where certain maneuvers through a channel could benefit most from the information provided by the aids. The design method derived by the contractor helps the District waterway evaluator identify these key locations, and recognize which aid configurations would best facilitate safe transit. We anticipate local peculiarities will preclude completely standardized systems, yet we should make significant progress towards that end. The method breaks the design process into manageable steps, intended to promote a systematic review and thorough treatment of even the most complex situations. The procedure for marking developed by Ship Analytics directly contributed to Chapter 4, Aids to Navigation Manual - Administration (COMDTINST M16500.7).

1.6 IMPLEMENTATION

As with the simulator validation, the validity of this design process was tested, both formally and informally. Simulation results and the first draft of this manual suggested two areas in Narragansett Bay where the existing system of aids showed room for improvement. Simulator and at-sea performance data were recorded from transits under the existing aid configuration. Then, following recommendations from the first draft of this manual, aid changes were made. At-sea performance was again recorded and compared with that before the aid change. Navigation performance improved as predicted, strengthening our confidence in the manual. Additionally, District and Headquarters staff members have applied the process informally to numerous user recommendations, requests, and complaints. Overall, the designs and solutions were very well received. Particularly noteworthy was the fact that the mere existence of a systematic design procedure tended to bolster our credibility and provide us with firm footing from which to negotiate with users.

1.7 EVALUATION PROCEDURE

Probably the most novel aspect of this work, however, is Ship Analytics' development of a statistic which estimates the probability of a vessel grounding given alternative aid arrangements in a waterway. This risk assessment tool, called the Relative Risk Factor (RRF), provides a quantifiable measure of the quality of an aid to navigation system. Though imperfect, the RRF has important applications. These will be detailed later in this manual.

SECTION 2. THE BASIS OF THE DESIGN AND EVALUATION PROCEDURES

Section 2

THE BASIS OF THE DESIGN AND EVALUATION PROCEDURES

2.1 INTRODUCTION

One of the Coast Guard's responsibilities is to provide an aids to navigation system that ensures safe and expeditious passage of deep draft vessels in restricted waterways. The fulfillment of this responsibility is a management problem that requires consideration of a wide range of factors, including the frequency and type of traffic in a waterway, the proximity to population and natural resources, the cost of establishing and maintaining an aid system, the competition for available Coast Guard resources, the needs and preferences of the users, and the effectiveness of performance associated with a particular aid system. The latter is the primary focus of this manual.

The objective of the U.S. Coast Guard's Performance of Aids to Navigation Systems project was to provide a process for the design and evaluation of aid systems. A systematic process requires objective, quantitative performance data. Controlled and replicated performance data is unobtainable at sea. Even simulator data is too difficult and too expensive to collect for every waterway and all possible conditions. Instead, the process described in this manual is based on "generic" performance data: that is, data on the general case that is not specific to any waterway but is applicable to a wide variety of related waterways and conditions. The components of the "system" formed by ship, channel, environment, and aid configuration were varied and tested on two marine simulators described later in this section. These data are the basis of the procedures described in this manual for specifying the requirements in a specific waterway, for designing aid systems to those requirements, and for evaluating existing and proposed systems. Because aid configurations were tested in combination with varying ship, channel, and environmental conditions, the data also provide a basis for suggesting operational limitations to supplement the aid factors in ensuring safety. The data are presented as a number of performance measures, with the final one being the "relative risk factor" (RRF) or the relative probability that there will be a grounding (or accident) under the conditions specified.

This section provides an overview of the research on which the manual is based and of the language and performance measures in which the findings are expressed. The presentation is meant to familiarize the system designer with the basis of the manual's procedures. This material is isolated in one section for two reasons: first, to allow a continuity for the discussion here; second, to prevent this background material from intruding in the more procedural, working sections of the manual.

2.2 CONDITIONS CONSIDERED FOR PERFORMANCE MEASUREMENT

At the beginning of the project, conditions were selected for inclusion and for testing by simulator. The conditions selected were either representative of conditions that appear in U.S. ports with a high frequency or representative of the highest risk "worst case" to be expected with any frequency. The intention was that a minimum of simulation provide data of the widest possible application.

2.2.1 The Waterway Characteristics

Channels 35 to 41 feet in depth were chosen to represent the shallowest channels transited by commercial ships in major U.S. ports. These were 500 to 800 feet wide, bracketing the majority of such channels. Performance data was extrapolated to higher-risk 300-foot channels but not to lower-risk wider channels. The turn angles tested were 15 and 35 degrees, representing the majority of existing turns. The data were used to represent turns of less than and more than 20 degrees, respectively. Two turn configurations were tested, noncutoff (dredged to form an abrupt angle) and cutoff (widened at the inside of the angle to allow more room for the turn). Performance in the cutoff was generalized to lower-risk bends.

2.2.2 The Ship Models

Three ship models were included in the simulator testing. They were as follows:

- a 30,000 dwt tanker, 595 feet long (between perpendiculars), 84 feet in beam, 35 feet in draft, with a 45-foot height of eye;
- a 52,000 dwt tanker, 653 feet long (between perpendiculars), 106 feet in beam, 33 feet in draft, with a 55-foot height of eye;
- an 80,000 dwt tanker, 763 feet long (between perpendiculars), 125 feet in beam, 40 feet in draft, with an 80-foot height of eye

Performance data collected with these three ships was interpolated and extrapolated for the manual to ships ranging from 30,000 to 110,000 dwt. It was assumed that tankers provide a conservative estimate of risk for most other ship types. No extrapolation was made to smaller ships because low risk makes them of less interest. Performance was not extrapolated beyond 110,000 dwt, because of the increasing risk associated with uncertainty about larger ships.

2.2.3 The Ship Operators

Since large, commercial ships in narrow channels in U.S. harbors are generally under the control of harbor pilots, these were the operators used during simulation. The performance data in the manual represents performance achieved by harbor pilots with active licenses and current experience. Other operators would not necessarily achieve the same performance under the conditions tested.

2.2.4 The Short Range Aids

Daytime conditions on the simulator were run with buoys 7 feet tall and positioned at the channel edge. There were no background objects to either contribute to or distract from the piloting situation. For nighttime conditions the buoys were lighted. For most nighttime simulations there were again no background objects. Some testing was done on the contribution of flash pattern in a situation with background lights visible. The findings on flash pattern are reviewed in Section 4. The simulator buoys were always on station and, at night, their lights were always operative. The buoys did not move with wave action, thus each flash was visible to the mariner. Instructions in Section 5 for applying the performance data assume that the buoys tested represent any aid that is visible at the distance specified and that unlighted buoys are never visible at night. The instructions assume that the buoys tested represent any aid that is positioned at the channel's edge and that the effectiveness of an aid deteriorates with distance from the channel's edge.

An analysis of aid arrangements in major U.S. ports supported the selection of aid arrangements and spacings that were representative of what exists. For simulator testing, the several turn configurations were marked with one, two, or three aids. (The arrangements are described and illustrated in Section 4.) In the straightaways, aids were arranged as gated (arranged in pairs on a line perpendicular to the channel axis), as staggered (arranged so that one aid at a time appears on alternate sides of the channel), or on one side of the channel. The possibilities are illustrated in Section 4. The alongtrack spacing of the aids was at either 5/8 or 1-1/4 nautical miles (nm). These two spacings bracket the majority of cases in U.S. ports, where the mean over all the arrangement possibilities is 1 nm.

Simulator testing was also done with ranges. The ranges were tested conservatively with no buoys present. Visibility was always sufficient for the use of the range. Range simulation was indifferent to day or nighttime conditions in that the range structures did not flash. The geography of the ranges tested was varied to affect the "sensitivity", or the ease with which an observer will detect the crosstrack error of his position ($K \approx 4.0$, $K \approx 1.0$). Section 5 repeats instructions found in Range Design Manual (COMDTINST M16500.4) for determining the sensitivity of a range of interest to select the appropriate performance data for application.

2.2.5 Visual and Electronic Piloting

The manual assumes that visual piloting is the basic process of navigation in restricted waterways. Observation and questioning of pilots at sea and on the simulator have identified this method as their preferred and dominant mode. Most of the simulation was done with adequate visibility for visual piloting. To ensure that the performance data could be interpreted unambiguously as visual performance data, radar was not available for most of the simulator transits. The data are, therefore, a conservative estimate of the quality of an aid system for visual piloting.

For most of the simulations "adequate" visibility was 1-1/2 nm. The term "visibility" is used because of its more common use, generally and in the maritime industry. The term "detection distance" is more technically correct. On the simulator an aid was available to the pilot 100 percent of the time at the distance specified. This was true whether it was unlighted or a lighted aid in the daytime or lighted at at night. (Conservatively, unlighted aids were never visible at night.) Notice that 1-1/2 nm visibility allows a view of at least one aid or pair of aids ahead when the spacing is 1-1/4 nm or less. Some simulated transits were also made with 3/4 nm visibility, allowing a view of an aid or pair of aids ahead only when the spacing is 5/8 nm. The findings across the various combinations of spacing and visibility support the assumption made in the manual that a conservative definition of adequate visibility for visual piloting is sufficient visibility to see all the aids in a turn or to see one aid or a gated pair of aids ahead at all times.

Conditions of extremely restricted visibility with radar in use where also tested by simulation and are included in the manual. A limited number of conditions were tested with 1/4 nm visibility, or visibility that allowed a view of an aid or pair of aids when close and passing but not much ahead; and zero visibility that forced complete dependence on the radar. Based on these data, special guidance for the design and evaluation of systems in waterways where such visibilities are frequent are included in Section 7.

Conditions of zero visibility and radio aids (Loran C) piloting with varying display formats (graphic, perspective, and digital displays) were also tested by simulation. Performance data for evaluating radio aids piloting as an alternative are included in Section 8.

2.3 SIMULATOR MEASUREMENT OF SYSTEM PERFORMANCE

2.3.1 The Simulators Used

Performance data on aids to navigation systems was collected on two simulators. One was the Maritime Administration's Computer Aided Operations Research Facility (CAORF) at Kings Point, New York. This simulator is accepted as a standard for the marine simulation industry. The second was a lower-cost simulator built for this project at Ship Analytics, Inc., North Stonington, Connecticut. Both are full bridge simulators: a model of a ship's bridge with real or realistic controls and indicators, and screens providing a wide-angle field of view forward and abeam. The indicators available to the pilot during the present project were a gyro-repeater, a shaft revolutions-per-minute indicator, and a rudder angle indicator. The controls were a helm unit, with a helmsman, and an engine order telegraph. Radar was not available unless it was specifically the focus of the experiment. A computer(s), using interchangeable ship hydrodynamic models, responds to the ship controls by making appropriate changes in the indicators and in the visual scene. Simulations in the two facilities were based on the same ship hydrodynamic models. For the same conditions, performance data collected on the two simulators proved comparable. CAORF's greater capability for a complex visual scene was used only for the meeting traffic situation, which is discussed in Section 6.

2.3.2 Characteristics of the Simulator Data

The design of the simulator tests, or experiments, determined the type of performance data that was collected and how it can be interpreted. Some aspects of the experimental design that are relevant to the use of data in the manual follow.

1. The experimental scenarios were designed with a mix of piloting tasks. In each scenario under the channel, ship, environmental, and aid conditions to be tested, the pilot was instructed to maneuver the ship to the centerline of the channel, to maintain the centerline, to execute a turn by his own technique, to maneuver back to the centerline with a crosscurrent and then to maintain the centerline with that crosscurrent. The instructions to reach and maintain the centerline provide a conservative (demanding) test of the aids and facilitate measurement and analysis. Performance for the several maneuvers required in the experiment, turn, recovery, and trackkeeping, differed in dependence on aids. Turn performance is most dependent on aids; recovery, somewhat less dependent; and trackkeeping is relatively insensitive to aids. The difference in the aid requirements of these maneuvers form the basis for the procedure in Section 3 for dividing a waterway into regions, with different aid requirements.

2. The experiments were designed with the assumption that only relatively difficult shiphandling conditions would demonstrate the quality of an aid system by forcing the pilot to rely on the aids for accurate and timely information. For most simulations, there was a minimal underkeel clearance and the ship speed was 6 knots through the water. These conditions were not a problem while maneuvering and trackkeeping without the crosscurrent. Performance was uniformly very good during those maneuvers. However, the turn, and maneuvering and trackkeeping with crosscurrent showed the effects of these conditions; performance was poorer and did differentiate among conditions. Performance measured with a crosscurrent on the simulator is, of course, an estimate of performance in the real world with a crosscurrent. But more importantly, it is a conservative estimate of the quality of an aid system. It represents the engineer's "design conditions" that allow a safety margin for the low frequency, unexpected event. For the design and evaluation process described in the manual, it allows differentiation among conditions. Examples of the several kinds of performance data are given in Section 2.5.

3. In all the experiments, the visual scene was relatively simple compared to at-sea conditions. The visual scene consisted of the ship's bow (and sometimes, wings), a line demarcating the sea and sky, and the aids. The available cues for depth or distance were the location and apparent size of the aids, and some detail to the aids. There were no landmasses or additional man-made objects; or texture or variation to the water. Only aids provided the pilot with the information he needed to judge the position, velocity, and acceleration of his ship. The measured performance is an unambiguous and conservative measure of the quality of the aid system for the specified conditions. That is, if the performance data are in error in measuring the quality of an aid system, they underestimate it. Any design adjustments made as a result will mean a reserve of safety for infrequent conditions, not unnecessary risk.

4. For most of the simulator testing there were no bank effects in the channel. The pilots were deprived of them as a source of information that might help them keep the ship in the channel and were forced to rely only on the visual information provided by the aids. Performance data with bank effects were also collected on the simulator for comparison. The finding

was that pilots tend to keep their ships further away from the channel edge when there are bank effects, decreasing their risk of grounding. Performance data collected without bank effects and with a forced reliance on the aids provide a relatively accurate estimate of risk for a waterway without perceptible banks. For waterways with banks the data are conservative and provide a design condition or safety margin. The system designer must use judgment about the importance of bank effects in his own waterway and the accuracy of the performance data.

For a special analysis of the meeting situation that contributed to the discussion and data presented in Section 6, the intent was to provide a realistic-to-conservative estimate of the risk of collision. For that analysis bank effects were present in the simulation. There, the assumption was that the banks would constrain the ship's approach to the channel edge and limit its ability to avoid an oncoming traffic ship. (When bank effects were present, there were also passing ship effects.) The meeting data provide a conservative estimate of the risk of collision for waterways without banks and a more realistic estimate of this risk for a waterway with banks.

5. The pilots' lack of "local knowledge" of the artificial channel also adds to the conservatism of the performance data. Of necessity, the pilots had a minimum of expectancies about waterway elements and no well-rehearsed sequences of helm orders. Instead, they were forced to rely heavily on the aids for information as the ship transited the channel.

2.4 QUALITATIVE DESCRIPTION OF SYSTEM PERFORMANCE

While the primary objective of the research was to provide quantitative performance data, it is also useful to express the findings as a qualitative description of the processes involved. A variety of data were available during the project: these included ship track and ship status data, the pilots' helm orders, discussions with the pilots, experience in applying the data to sample waterways, the simulator validation (Section 2.6), and the model implementation (Section 2.7). The findings are more complex than can be expressed as tables of numbers. Description of the process appears throughout the manual but especially as the design guidelines in Section 4. What such description lacks in precision, it gains in ease of use and in applicability to varied waterway conditions. It should be emphasized that the quantitative performance data and the qualitative description of the process are not independent of each other. System designers will observe that the recommendations of the design guidelines in Section 4 are supported by the performance measures presented in Section 5.

2.5 QUANTITATIVE MEASUREMENT OF SYSTEM PERFORMANCE

The primary performance data of the simulator testing was the crosstrack position of the ship's center of gravity collected at short intervals as a function of its alongtrack progress through the transit. These data went through several levels of development to increase their usefulness for system performance evaluation. These steps are described here in an order that parallels instructions for system evaluation in Section 5.

2.5.1 The Means and Standard Deviations

For most of the conditions tested, eight pilots made transits of the waterway under identical conditions. At short intervals in the transit, the mean and standard deviation of the eight crosstrack positions were calculated. The mean (MN) is a measure of the placement of the set of tracks in the channel. The standard deviation (SD) is a measure of dispersion or variation of the set of tracks. It is defined by the formula:

$$SD = \sqrt{\Sigma x^2/N} \qquad (2\text{-}1)$$

where

$x = X - MN$, each individual score minus the mean

N = the number of scores

Sample data presented in Table 2-1 illustrate the ability of these measures to indicate performance. These measures were taken during the maneuver to the centerline with more and less effective aids and without and with crosscurrent. Notice that both aids and current have effects on the pilots' ability to take the ship to the centerline. The crosscurrent has its effect on the mean, keeping the set of tracks downcurrent from what is intended. The aids have their effect on the standard deviation: there is more variation in the tracks in the approach to the centerline under the less effective aids. (The aid arrangements are described in Section 4.) Both measures are needed to describe performance and both measures contribute to the measure of risk described in Section 2.5.3.

TABLE 2-1. PERFORMANCE INDICATED BY MEAN AND STANDARD DEVIATION OF THE CROSSTRACK POSITION OF EIGHT TRANSITS

	Recovery			
	Without Crosscurrent		With Crosscurrent	
	MN[1]	SD[2]	MN	SD
gated aids	7	39	97	34
long-spaced staggered aids	5	65	94	70

NOTES:
1. Means (MN) are expressed as feet from channel centerline.
2. Standard deviations (SD) are in feet.

2.5.2 The Correction Factors for Ship Size and Channel Width

The research was designed to provide data of the widest possible application from a minimum of simulator testing. One method used to achieve this goal was the use of "correction factors" to allow the extension of the data to conditions other than those tested. Two of the factors of central interest in the research were continuous, quantitative variables appropriate for such treatment. They were ship size and channel width. The majority of the simulator testing used "baseline" values of a 30,000 deadweight ton (dwt) tanker in a 500-foot channel to test other factors (such as aid configuration, day/night, etc.). Examples of the baseline data appear in Table 2-1. During the experiments, selected conditions were also tested with two other ship sizes, a 52,000 and a 80,000 dwt tanker. Therefore, for selected conditions, performance data, represented by means and standard deviations, were available for three ship sizes. The relationship between performance and ship size was interpreted as being linear. The relationship between baseline performance for the 30,000 dwt ship and performance for any larger ship can be expressed as a ratio. This ratio, calculated for conditions for which there are data for a larger ship or ships, is assumed to be appropriate for "correcting" performance data for conditions in which there are only data for the 30,000 dwt ship. The correction factor for the 80,000 dwt ship is calculated from the empirical data as follows:

$$CF_{80} = \frac{Y_{80}}{Y_{30}} \tag{2-2}$$

where

CF_{80} = the correction factor for 80,000 dwt ship performance
Y_{80} = empirical data for the 80,000 dwt ship
Y_{30} = empirical data for the 30,000 dwt ship

Correction factors for other ship sizes are calculated as follows:

$$CF_i = 1 + \frac{CF_{80} - 1}{(50)} (X_i - 30) \tag{2-3}$$

where

CF_i = the correction factor for any ship size in 1,000 dwt
X_i = ship size in 1,000 dwt

The correction factors obtained are provided as multipliers to apply to the larger body of data available for the 30,000 dwt ship. Examples are shown in Table 2-2.

For channel width it was assumed that the relation of these measures to increasing channel width was linear and that the change was always less than the change in the room available:

$$CF_i = 1 + 0.5 (W_i - 500)/300 \tag{2-4}$$

where

CF_i = the correction factor for any channel width
W_i = channel width

TABLE 2-2. SAMPLE CORRECTION FACTORS FOR RECOVERY

Ship Size (1,000 dwt)[1]	Correction Factor MN[2]	SD[3]
30	1	1
50	1	1.17[4]
Channel Width (feet)		
500	1	1
600	1.17	1.17

NOTES:
1. dwt, deadweight ton
2. Means (MN) are expressed as feet from the channel centerline.
3. Standard deviations (SD) are expressed in feet.
4. It is a coincidence that both ship size and channel width correction factors are 1.17.

Correction factors are provided as multipliers to apply to the larger body of data available for the 500-foot channel. Examples are also shown in Table 2-2.

The sample data in Table 2-1 represent a 30,000 dwt ship in a 500-foot wide channel. These data can be corrected to represent a 50,000 dwt ship in a 600-foot channel by applying the correction factors in Table 2-2. The results appear in Table 2-3. Notice that for the recovery maneuver, only the standard deviation increases with ship size but both mean and standard deviation increase with channel width. Section 5 presents tables of baseline data for the 30,000 dwt ship in the 500 foot channel and correction factors for correcting these data. It should be remembered that corrected data are not associated with the same degree of certainty as the originally measured performance data.

TABLE 2-3. A SAMPLE OF CORRECTED DATA

	Ship Size (1,000 dwt)[1]			
Channel Width (feet)	30 MN[2]	SD[3]	50 MN	SD
500	7	39	7	45.63
600	8.19	45.63	8.19	53.39

NOTES:
1. dwt, deadweight ton
2. Means (MN) are expressed in feet from the channel centerline.
3. Standard deviations (SD) are expressed in feet.

In the draft manual published in 1982,[1] ship speed was also treated with a correction factor. Subsequent experimentation has supported the conclusion that speed has a small and inconsistent effect on performance and that a correction factor is both unnecessary and inappropriate. Speed is discussed in Section 4.

2.5.3 The Relative Risk Factor (RRF)

The means and standard deviations used to describe performance in he simulator experiments were used in the calculation of a final measure of the quality of an aid system, the relative risk factor (RRF). The RRF has a number of advantages over the simpler measures. First, it is more inclusive. It includes the contribution of the mean and standard deviation of the set of tracks; and of the ship size, ship aspect in the channel, and the channel width. Second, based on the assumption that the set of tracks comes from a normal distribution, it is expressed as a probability and is interpretable as an assessment of the risk of grounding. The measure is sufficiently complex that it deserves a separate discussion. This discussion is taken largely from the 1982 draft manual where the RRF was first introduced.

2.6 THE RELATIVE RISK FACTOR (RRF)

The ultimate use of the aid system performance data is in risk management techniques, some of which are suggested in Section 9. Risk management techniques require a measure of aid system quality expressed as an assessment of risk. The performance data are expressable by such a measure.

2.6.1 Quantification of the Risk of an Accident

A very basic assumption of the program is that there exists a dependent relationship between the risk of accidents and the aid to navigation system. The better the aid system design, the lower the risk of accidents. The relationships of aids to the pilot's ability to stay inside the channel and avoid a grounding accident is most obviously related to the aids and is continuous throughout a transit in restricted waterways. But it is assumed that the design of aid systems, by the same principles, is also related to other types of accidents: that is, collisions and rammings. The pilot's ability to avoid accidents (collisions, rammings, and groundings) depends (not entirely, of course) on the aid system and its effectiveness in enabling him to make accurate and timely judgments of his position, velocity, and acceleration. In avoiding groundings, he must be able to make these judgments relative to the edges of the channel. In this process, the channel edge itself is not visible and the aid system (whether visual aids, radar, radio aids, or some combination) is all he has. In avoiding collisions and rammings, the pilot must make his judgments relative to some moving or fixed object. The object to be avoided serves the function of an aid, but is not sufficient under all conditions in restricted waterways. An

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[1] W.R. Bertsche, M.W. Smith, K.L. Marino, and R.B. Cooper. "Draft SRA/RA Systems Design Manual for Restricted Waterways." GD-D-77-81. U.S. Coast Guard, Washington, D.C., February 1982, NTIS AD-A113236.

aid system that helps the pilot determine his status contributes to his ability to avoid any type of accident.

Quantification of this relationship has previously been difficult due to the low occurrence of accidents relative to the number of transits (typically one accident for every 10,000 transits). Additionally, accident statistics could not be related to aid system designs because of the large number of factors contributing to the accident, such as human error, equipment failure, visibility, light, traffic, etc.

The aids to navigation project has provided a set of piloting performance data which can be used to provide a "relative" indication of the risk of an accident as a function of aid system design. This data was compiled on a shiphandling simulator designed specifically to quantify the relationships between aid system designs and the risk of accidents. The "relative" characteristic of this data must be stressed in that the data are indicative of the differences in the risk of accidents as a function of alternate aid system design characteristics. Too few samples were run on the simulator to attempt to predict occurrences on the order of one every 10,000 transits.

The measure derived to quantify the relative risk of accidents is the "relative risk factor." This factor represents an estimate of the probability that a portion of the ship will cross a channel edge. It is based on an assumption that ship tracks are normally distributed about a mean track. It is suggested that the relative risk factor is directly proportional to the probability of grounding and that changes in the relative risk factor are proportional to changes in the actual probability of grounding:

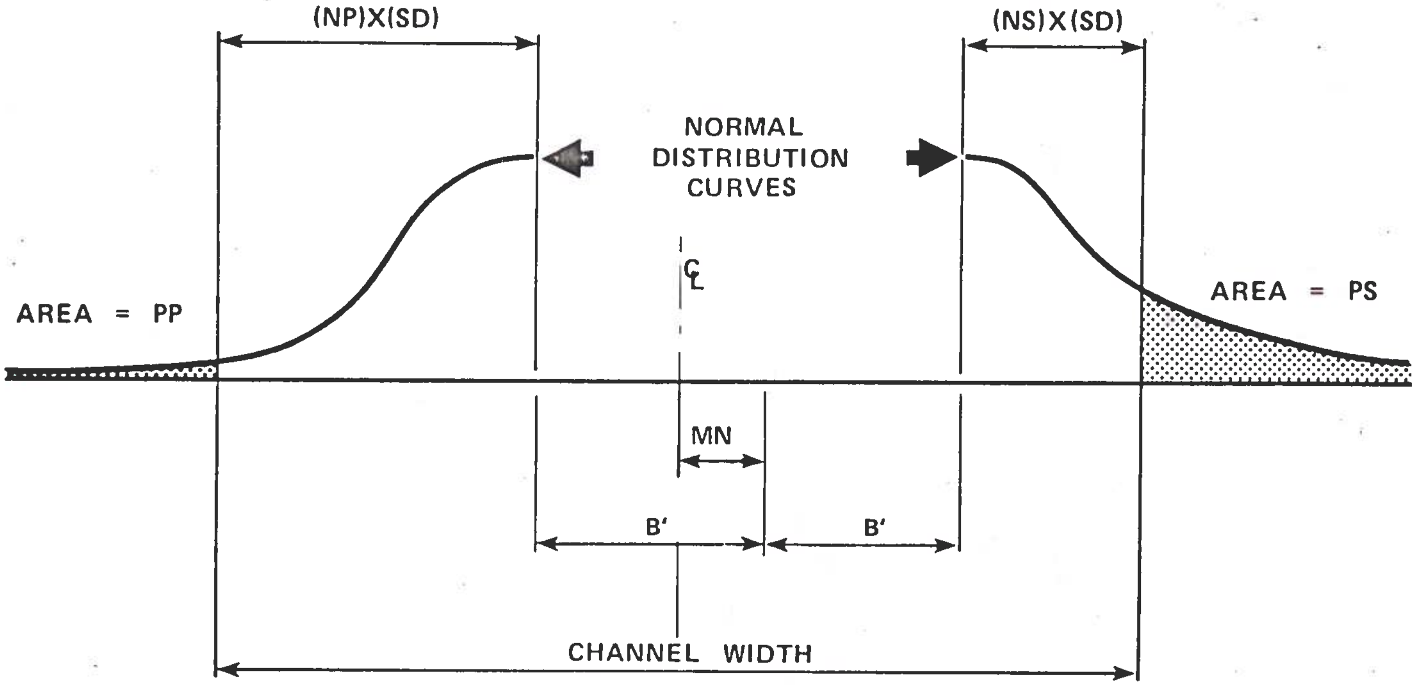
$$RRF = (K)(PG) \qquad (2\text{-}5)$$

where:

RRF: relative risk factor
PG: probability of grounding
K: correction factor

Given these assumptions if the relative risk factor is increased by a multiple of 10 with increased buoy spacing, then it is assumed the actual probability of grounding will be increased by a multiple of 10 also.

The relative risk factor, although not a direct measure of the probability of an accident, can be satisfactorily applied to the design of aid systems when one design is being compared to another. Designs which achieve a minimum relative risk factor can be assumed to provide the maximum safety possible relative to other designs. Designs which achieve relative risk factors equivalent to those for existing channels can be assumed to exhibit the same safety record as the existing channel under similar environmental conditions.



RRF = PP+PS

Figure 2-2. Derivation of Relative Risk Factor Based on the Assumption of Normal Distribution repel the ship from the bank with no control input from the pilot. The main body of performance data does not presently account for this effect.

Although the above considerations prohibit the strict interpretation of the relative risk factor as the probability of grounding, it is seen that in all cases the relative risk factor is a conservative indicator of the probability of grounding. Thus, the RRF contains a built-in safety factor when it is used in a design context. This safety factor is likely beneficial since it allows for a variety of piloting contingencies to be accommodated (e.g., unseasonable tidal currents, piloting errors, passing ship hydrodynamic effects, operation of ships larger than the norm, excessive winds, very limited visibility, unique bottom contours).

2.6.3 Calculation of the Relative Risk Factor (RRF)

The calculation of the RRF begins with the selection of baseline values for the mean crosstrack displacement (MN) and the crosstrack standard deviation (SD) for each region. These values are selected from simulator data and are dependent on the aid configuration and the environmental conditions. The baseline values of MN and SD are adjusted for the ship size, and channel width of the candidate channel. The adjusted values, MN' and SD', are used together with the ship and channel dimensions to calculate the probabilities of the ship's hull crossing either edge of the channel. The relative risk factor is calculated as the sum of these probabilities.

The adjusted mean and standard deviations are calculated as the product of the baseline values times correction factors associated with ship's size and channel width. Equations 2-7 and 2-8 indicate the calculations which must be made for each region:

$$MN' = (MN)(MCSHP)(MCWID) \tag{2-7}$$

$$SD' = (SD)(SCSHP)(SCWID) \tag{2-8}$$

where:

MN: Baseline mean crosstrack position (feet)
SD: Baseline crosstrack standard deviation (feet)
MCSHP: Mean correction factor for ship size
MCWID: Mean correction factor for channel width
SCSHP: Standard deviation correction factor for ship size
SCWID: Standard deviation correction factor for channel width

The probabilities of the ship's hull crossing the channel edges are calculated based on the number of adjusted standard deviations which fall between the ship's extreme points and the channel edges. One half the adjusted beam (B') is calculated with the pivot at the center of the ship for simplicity. Equations 2-9, 2-10, and 2-11 indicate the calculations required to determine these multiples:

$$B' = (L/2)(VX/VMIN) + (B/2) \tag{2-9}$$

$$NS = [(W/2) - (MN') - (B')]/(SD') \tag{2-10}$$

$$NP = [(W/2) + (MN') - (B')]/(SD') \tag{2-11}$$

where:

B': Ship's beam adjusted for crab angle (feet)/2
L: Ship's length (feet)
VX: Cross channel component of current (knots)
VMIN: Ship's minimum transit speed (knots)
B: Ship's beam (feet)

and

NS: Number of SD' between the extreme starboard point of the ship's hull and the starboard channel edge (may be negative)
NP: Number of SD' between the extreme port point of the ship's hull and the port channel edge (may be negative)
W: Channel width (feet)

The probabilities of crossing the port and starboard edges of the channel are calculated based on the equations for the normal probability distribution. The probabilities can be obtained using the values provided in a table in Section 5 of the present manual. The relative risk factor is calculated as the sum of the probabilities (Equation 2-6).

$$RRF = PS + PP \tag{2-6}$$

The sample calculation in Table 2-4 will serve to relate the RRF to the sample data in Section 2.5. The baseline data used are taken from Table 2-1 for recovery with gated aid and a crosscurrent. For that case the mean is 97 feet and the standard deviation, 34 feet. These values are not adjusted for a change in ship size or channel width. The beam is adjusted for a crosscurrent. (Directions for doing this are in Section 5.) The RRF is found by first calculating the number of standard deviations that will fit in the channel to starboard and to port. The table in Section 5 was used to find the associated probabilities and these two probabilities were added to find the total risk of a grounding for the sample case. The RRF values for all four cases in Table 2-1 appear in Table 2-5.

2.6.4 Relative Risk Factor (RRF) Plots

Plots were prepared for critical or frequent conditions to save the system designer the tedium of calculating the RRF for all conditions that might be of interest to him. A sample of such a plot appears as Figure 2-3. This plot represents one case of baseline data taken from Table 2-5, performance during recovery with gated aids and crosscurrent. The RRF for this condition, 0.0019, appears on the plot as the entry for a 30,000 dwt ship in a 500-foot channel. The means and standard deviations for this baseline case were corrected for five ship sizes and six channel widths as indicated in the plot. In order to calculate the RRF, it was necessary to standardize the ships. For each ship size indicated by deadweight tonnage,

TABLE 2-4. SAMPLE CALCULATION OF RELATIVE RISK FACTOR (RRF) IN THE RECOVERY REGION

SHIP PARAMETERS

Ship size	30,000 deadweight tons
Ship length	590 feet
Ship beam	85 feet
Crosstrack current velocity	0.25 feet
Transit speed	6 knots
B' (feet)	54.79 feet

CHANNEL PARAMETERS

Channel width	500 feet

SAMPLE CALCULATION OF RRF: Crab angle, 2-5 degrees; gated aids; day

[W/2) - (MN) - (B')]/(SD) = (NS)
[(500/2) - (97) - (54.79)]/(34) = (2.89)

[(W/2) + (MN) - (B')]/(SD) = (NP)
[(500/2) + (97) - (54.79)]/(34) = (8.59)

(PS) + (PP) = (RRF)
(0.0019) + (0.0000) = (0.0019)

reminder:
W: channel width
MN: mean
B': adjusted beam/2
SD: standard deviation
NS: SDs to starboard
NP: SDs to port
PS: prob to starboard
PP: prob to port
RRF: relative risk factor

TABLE 2-5. MEAN, STANDARD DEVIATION, AND
RELATIVE RISK FACTOR (RRF) FOR SAMPLE CASES

	Recovery					
	Without Crosscurrent			With Crosscurrent		
	MN[1]	SD[3]	RRF[3]	MN	SD	RRF
gated aids	7	39	0.0000	97	34	0.0019
long-spaced staggered aids	5	65	0.0018	94	70	0.0735

NOTES:
1. Means (MN) are expressed as feet from channel centerline.
2. Standard deviations (SD) are in feet.
3. Sample calculations for the relative risk factor (RRF) appear in Table 2-4.

a length, beam, and crab angle adjustment were selected. The selected values appear in Section 5 with the set of plots from which the sample was taken. Notice that the RRF gets larger with ship size and larger with decreased channel width. Ship size is the dominant effect. And the larger the ship size, the less of an effect there is for channel width.

A set of such plots is provided in Section 5 for the turn and for the recovery regions with crosscurrent, the regions most critically dependent on the aids, for a variety of aid configurations and for day and night when the differences in performance are meaningful. These plots are intended to allow the system designer to do a preliminary analysis of his waterway, and possibly the only analysis of his waterway, without the need for calculating the RRF. The plots also serve as a graphic illustration of the quality of an aid system. Comparing the plots for alternative aid systems finds the plots for more effective arrangements filling the page while the plots for less effective arrangements crowd the top of the page.

2.7 VALIDATION OF SIMULATOR PERFORMANCE

To ensure confidence in the simulator and in the performance data collected on that simulator, the Coast Guard has made a considerable investment in the validation of the simulator. Performance data were collected at sea in two different waterways for comparison to data collected during simulation of those waterways. This validation was unique in that it was designed specifically to support the experimental testing of aid systems and this manual based on that testing. The waterway selected, the aid arrangements present in them, the ships that transited those waterways, the pilots who handled the ships, the maneuvers required, and the performance measures collected were all typical of the conditions tested and represented by the manual data. A sample of the validation data is included here to illustrate the relationship between at sea and simulator performance.

The first sample of at-sea data was collected in Chesapeake Bay in the approach to Baltimore, Maryland. This approach is an 800-foot wide channel

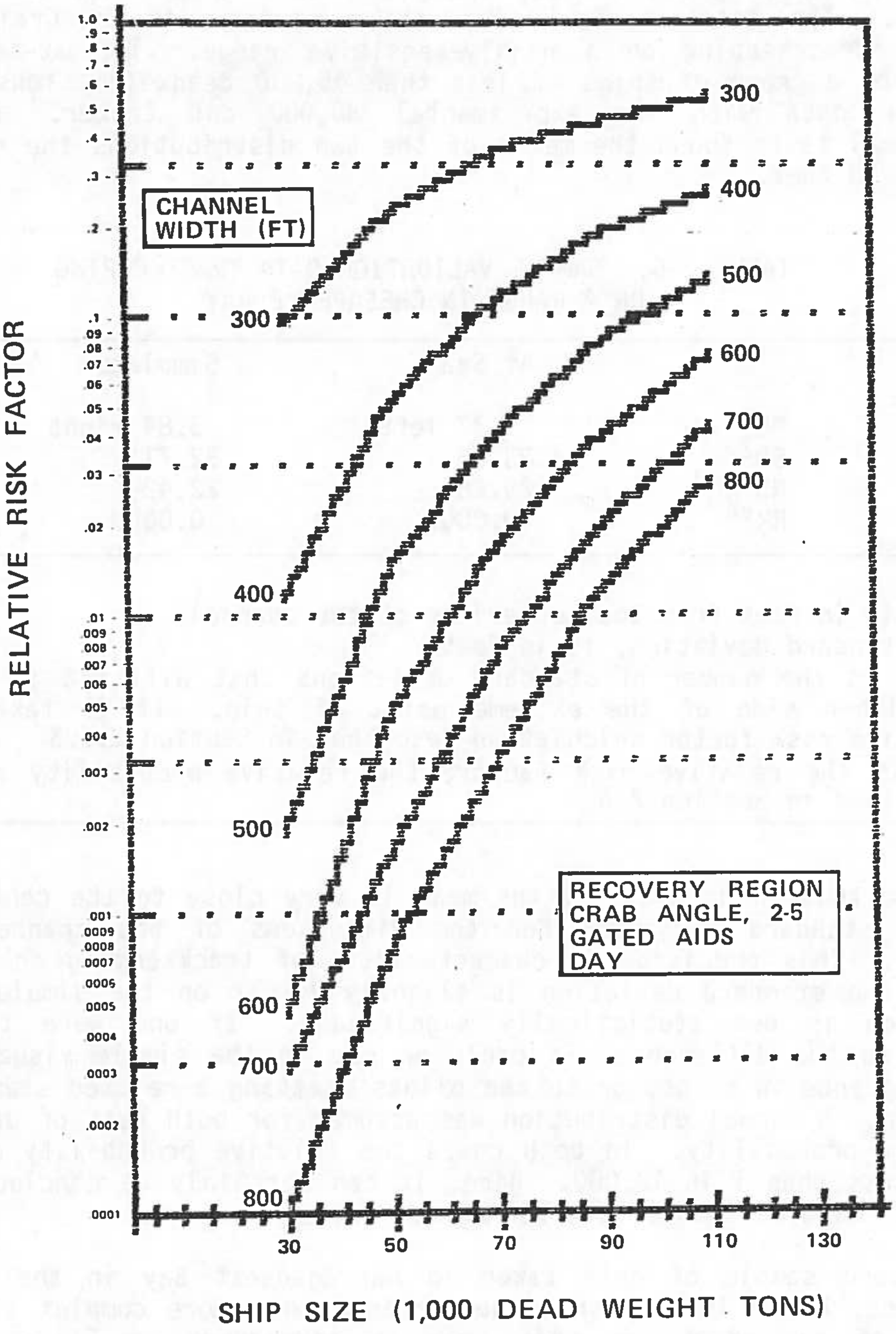


Figure 2-3. A Sample Relative Risk Factor Plot
(The condition illustrated is recovery with gated aids in the daytime.)

marked by ranges and buoys and transited by a large variety of ship types. Observers rode ships, recorded pilot behavior and, using Raydist, recorded the ship track. A simulation of the channel represented by buoys and ranges was prepared on the USCG/SA simulator and "transited" by members of the Association of Maryland Pilots, Inc., the same group that did the at-sea transits. The data in Table 2-6 shows performance in Craighill Upper Entrance trackkeeping on a highly-sensitive range. The at-sea data was taken with a group of ships of less than 45,000 deadweight tons (dwt); the simulator data with the experimental 30,000 dwt tanker. Conservative statistical tests found the means of the two distributions the same with an error of 50 feet.

TABLE 2-6. SAMPLE VALIDATION DATA TRACKKEEPING ON A RANGE IN CHESAPEAKE BAY

	At Sea	Simulator
MN[1]	5.37 left	3.84 right
SD[2]	23.96	32.71
NS+NP[3]	29.88	22.42
RRF[4]	0.0000	0.0000

NOTES:

1. Mean is in feet from the centerline of the channel.
2. SD, standard deviation, is in feet.
3. NS+NP is the number of standard deviations that will fit in the channel to either side of the extreme point of ship. It is taken from the relative risk factor calculation described in Section 2.6.3
4. RRF is the relative risk factor, the relative probability of grounding described in Section 2.6

Notice that in both cases, the mean is very close to the centerline with a small standard deviation for the dimensions of the channel and ship involved. This precision is characteristic of trackkeeping on a sensitive range. The standard deviation is slightly larger on the simulator but the difference is not statistically significant. If one were to attribute meaning to the difference, it could be due to the simple visual scene, to the difference in ships, or to the pilots' setting a relaxed standard on the simulator. A normal distribution was assumed for both sets of data in order to find a probability. In both cases the relative probability of grounding is for less than 1 in 10,000. Here, it can certainly be concluded that the simulator data can substitute for at-sea data.

A second sample of data taken in Narragansett Bay in the approach to Providence, Rhode Island, shows performance in a more complex situation. A section of the chart for this area is reproduced as Figure 2-4. This channel is 600 feet wide with a number of turns that are cutoff or widened by dredging, and is marked with buoys and with structures off the channel edge. The ships tracked, using differential Loran C, were tankers very much like the experimental 30,000 dwt tanker model. A simulation of the waterway represented by the aids only was prepared on the USCG/SA simulator for members of Northeast Marine Pilots, Inc., the group tracked at sea. The data sample is for the pullout and recovery from the second turn upbound on the chart. That turn is a 37-degree turn to the left that is cutoff but is marked by gated buoys as if it were not. The data in Table 2-7 represent daytime performance when the unlighted gated buoys ahead are visible. Conservative statistical tests found the means the same with an error of approximately 50 feet.

At sea the tracks showed more use of the cutoff area for the turns while on the simulator tracks were centerline to centerline. (The "centerline" through the turn was a continuation of the straight segment centerline.) This slight displacement of the simulator track to the right of the at-sea track continues for most of the leg. The standard deviations are higher on the simulator. They were statistically different at some points in the leg but not at the points given in Table 2-7. The larger standard deviation illustrates the conservatism of the simulator data. The slightly poorer performance on this simulator might be attributable to poorer visual or other information, to a change in the pilots' standard, or to the ship model. The latter is less likely here than in Chesapeake Bay. The standard deviation is not consistently larger on the simulator than at sea. Occasionally, the magnitudes reverse. Of course, the at-sea data is dependent on the accuracy of electronic tracking. Again, a normal distribution was assumed for both sets of data in order to find a probability. In both cases the relative probability of grounding is less than 1 in 10,000 for the section of the transit illustrated. These data support a conclusion that the simulator data is very similar to at-sea data with some degree of conservatism or overestimation of risk.

Notice that all the RRF values from both samples of data are 0.0000 or less than 1 in 10,000. It is generally the case using either at-sea or simulator data that easy or realistic shiphandling conditions result in very low RRF values and little differentiation among conditions. In Section 5, which contains the bulk of the performance data, it is suggested that data taken with difficult to conservative "design conditions" be used for deciding among alternative system designs.

2.8 IMPLEMENTATION AS A TEST OF THE DRAFT MANUAL

The project included a test of the design and evaluation process, using the 1982 draft manual. A model implementation was meant to test and refine the process before this manual was written. Like simulator validation, the implementation ensures confidence in a rather novel tool. The implementation plan was to analyze a waterway, using both the manual and a waterway-specific simulation; to collect ship track data; to recommend changes for implementation by the district office in that waterway; and then to collect additional data to evaluate those changes. For economy of both at-sea and simulator data collection, the validation and implementation efforts were planned together. The Narragansett Bay sea and simulator data of Section 2.7 provided baseline or prechange data.

The original arrangement in the approach to Providence appears in Figure 2-4 in the discussion of validation. Three aid changes were recommended as a result of the analysis and a discussion with a variety of interested

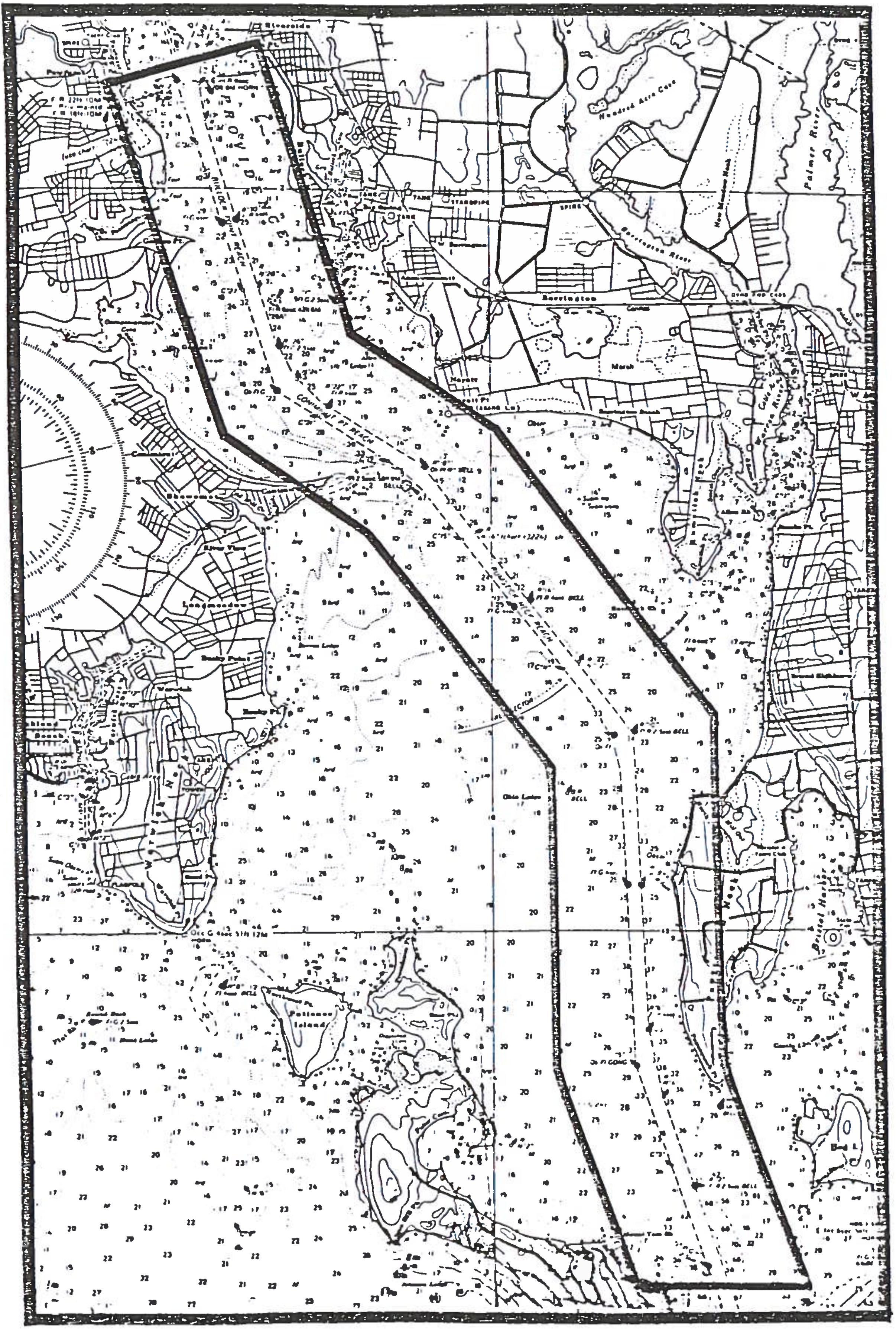


Figure 2-4. Pre-aid Change Configuration in Upper Narragansett Bay (Chart 13221, March 28, 1981)

TABLE 2-7. SAMPLE VALIDATION DATA FOR TURN PULLOUT AND RECOVERY IN NARRAGANSETT BAY

	At Sea	Simulator
pullout, 1900 feet beyond apex		
MN[1]	36.71 left	1.94 left
SD[2]	33.23	42.43
NS[3]	3.11	5.53
NP[4]	5.9	5.44
RRF[5]	0.0000	0.0000
recovery, 2500 feet beyond apex		
MN	10.85 left	32.19 right
SD	17.49	45.59
NS	15.34	4.94
NP	14.10	6.35
RRF	0.0000	0.0000
trackkeeping, 4750 feet beyond apex		
MN	0.61 right	27.78 right
SD	19.17	45.54
NS	34.40	5.04
NP	13.46	6.26
RRF	0.0000	0.0000

NOTES:

1. Mean is in feet from the centerline of the channel.
2. SD, standard deviation, is in feet.
3. NS is the number of standard deviations that will fit in the channel to starboard of the extreme point of ship. It is taken from the relative risk factor calculation described in Section 2.6.3
4. NP is the number of standard deviations that will fit in the channel to port of the extreme point of ship. It is taken from the relative risk factor calculation described in Section 2.6.3
5. RRF is the relative risk factor, the relative probability of grounding described in Section 2.6

groups. The changes implemented by the First District are shown in Figure 2-5. In the first turn an unlighted buoy was lighted with the expectation that the cutoff area would be used for a gradual turn at night as it was in the daytime. Performance was as the draft manual predicted. Pilots used the cutoff in the day regardless of aid marking. At nighttime, however, the turnmarking is critical because the cutoff is not used unless it is completely marked. Therefore, it was concluded that for best results at night, three lighted buoys should be used to mark the turn. In the third straight segment, Rumstick Neck Reach, the two unlighted gated pairs of buoys and the one lighted pair were replaced with two lighted gates to test the manual's generalizations that performance with gates is relatively indifferent to the spacing. Again performance was as the draft manual predicted. Pilot performance in the straight leg was not affected by changing gated buoy spacing. It was suggested, however, the gated buoys (or another aid) be placed so they provide pullout information for the turns which connect the straight legs. In the third turn, a lighted buoy was added to the inside apex to provide a buoy that the manual says is critical to turn performance. It was found that in the daytime performance was good before and after the aid change. At night, the mean improved after the aid change; however, the standard deviation was equivocal and probably supports a pullout buoy for difficult turns. This turn is difficult even though the angle is not large because it is the beginning of an S-shaped turn over a short distance.

In addition to providing an objective test of the manual's predictions for aid-system performance, the model implementation identified some of the issues involved in applying the manual to a waterway.

1. Factors that were not addressed in the experiments need to be considered as central to the implementation process. Examples of the factors that were relevant in the Providence approach were the presence or absence of background lighting in several regions of the waterway, the configurations of turns and lengths of reaches that led to pilot preferences as to where to meet or avoid meeting traffic, and the presence of shoals that affected the consequences of a grounding. The relevant factors will be different for each waterway and need to be considered in deciding just how conservative an aid system design should be.

2. Interested parties, such as representatives of the pilots' association, of the port, of shipping companies, of other users, should be contacted early in the process. This contact is both for the information they can provide on the waterway and on their needs, and to maximize their involvement and cooperation. Changing aid systems is ultimately a political process.

Section 3 suggests some factors that might need to be considered in adapting the design and evaluation processes to local conditions.

2.9 APPLYING THE MANUAL

The project methodology dictates how the findings should be used. The project began with a catalog of conditions in U.S. harbors and the selection of those conditions and factors that could most productively be investigated

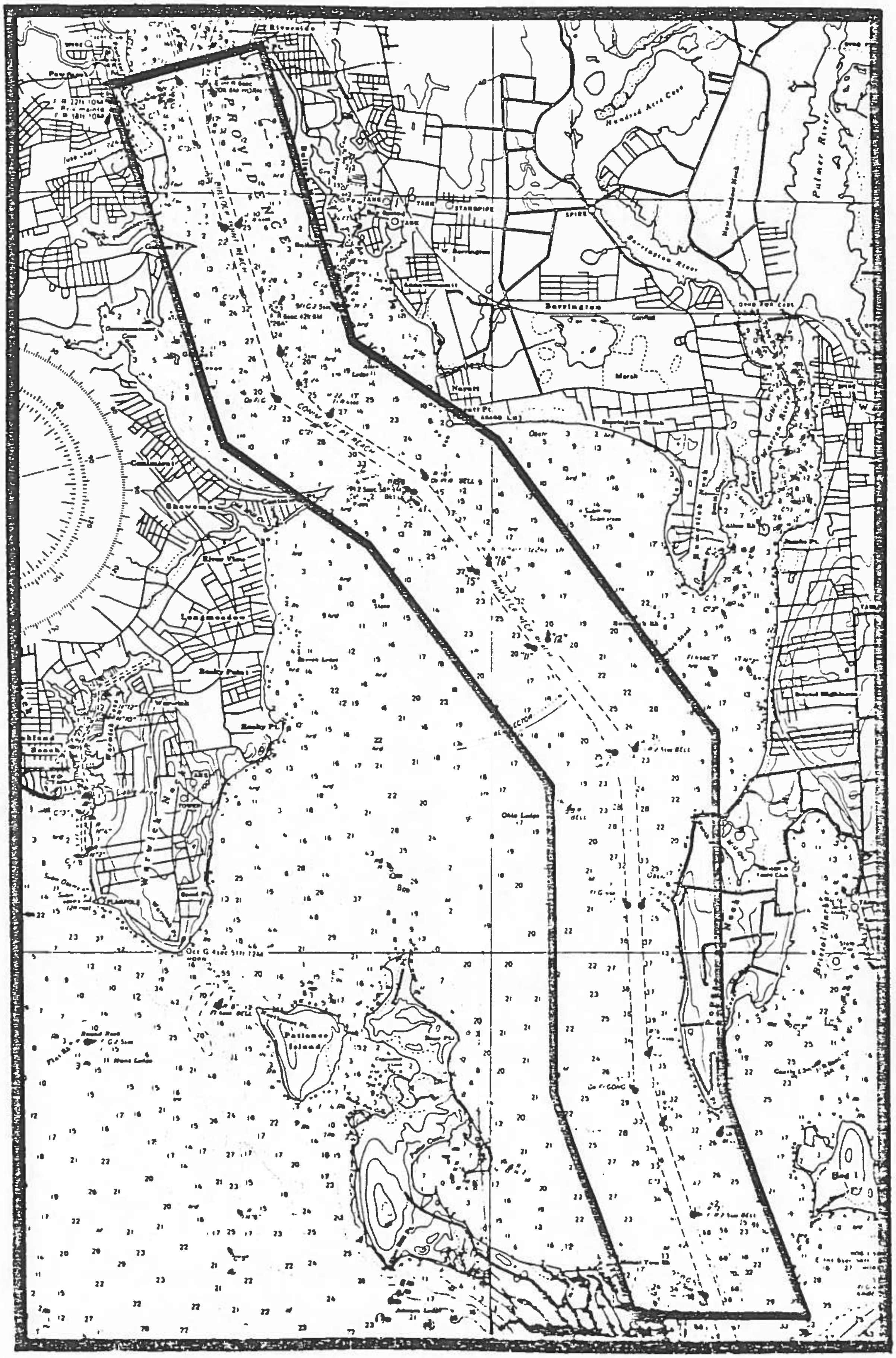


Figure 2-5. Modified Aid Configuration in Upper Narragansett Bay (April 1984)

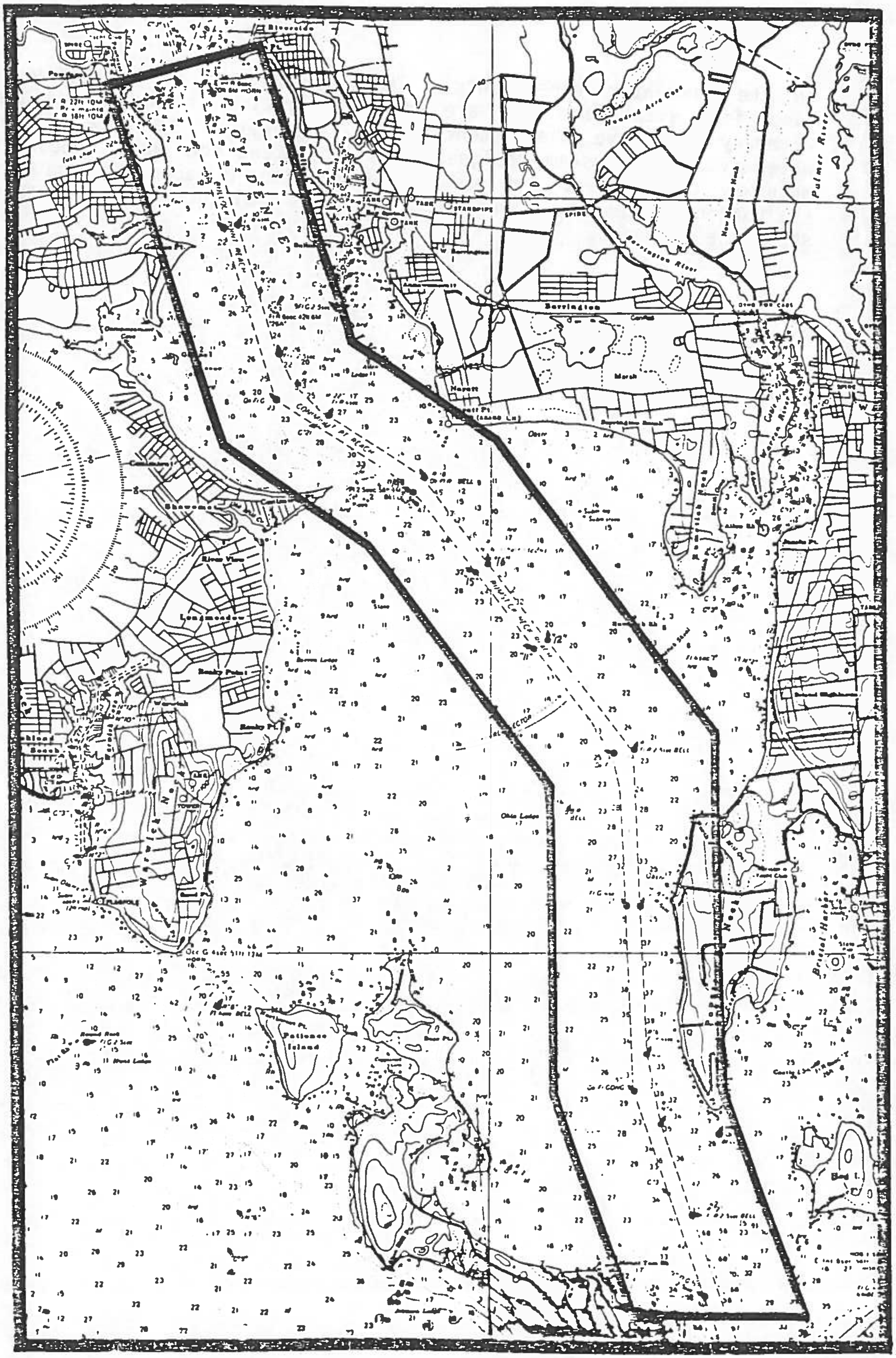


Figure 2-5. Modified Aid Configuration in Upper Narragansett Bay (April 1984)

in the simulator experiments. The experiments, of necessity, involved simplified situations that are not a simulation of the conditions in any waterway but have the potential for application to a wide variety of waterways. The system designer must understand the local condition in the waterway of interest and use his discretion in adapting the design and evaluation processes. Section 3 contains guidance on the factors that should be relevant.

SECTION 3. SPECIFICATION OF WATERWAY CONDITIONS

Section 3

SPECIFICATION OF WATERWAY CONDITIONS

3.1 INTRODUCTION

As a necessary first step in the design and/or evaluation of an aid system, the designer must familiarize himself with conditions in the waterway. One way would be to begin with obvious sources like the chart, light list, current charts or tables, and try a preliminary application of the manual's procedures. This will alert him to the issues relevant to the waterway and will increase his credibility in discussions. Another way would be to consult with those who are close to the waterway, such as Coast Guard personnel within the port or assigned to the buoy tender, the harbor master, the Vessel Traffic System, and local user groups, especially the pilots' association. Thorough familiarization has a number of purposes.

1. Gain local support. Consultation with the users does more than provide valuable and sophisticated information. Early user contact facilitates their cooperation and acceptance of change. Some changes may be as much political as they are practical. In addition to discussion, we recommend the designer ride with various commercial pilots. Viewing the waterway from their perspective allows better evaluation of their requests or recommendations and, again, increases the designer's credibility. Be cautioned that even members of the same association who are equally experienced with the same waterway will not attach the same importance to various aspects of local conditions. Also, the interests and preferences of the pilots may not be the same as those of other users; such as tug and barge operators, fishermen, or recreational boaters. For some issues it will be necessary to work with other groups.

2. Fit local conditions. Familiarity with the waterway is preparation for adapting the design procedures of Section 4 to local conditions. Section 4 is a procedure for relating the conditions in the waterway to potentially appropriate aid systems. The prepared designer will make better selections.

3. Select data for evaluation. Familiarity with the waterway is necessary for selecting the most appropriate performance data for evaluation in Section 5 and for interpreting that data in terms of local conditions.

4. Support system management. Gaining familiarity with the waterway is essential before applying the risk management procedures in Section 9. Therefore, several uses of a risk assessment measure, the Relative Risk Factor (RRF), are presented. One application involves comparing an aid system of unknown quality to one, in a similar waterway, which has an acceptable safety record. The critical factors identified in the following section will provide the basis for declaring two waterways as similar. Another application involves calculating a composite measure of risk, using weights for the existing proportion of higher and lower risk transits. Section 3.2.7 suggests some factors suitable for this purpose. In any application, intimate knowledge of the waterway and its users is essential.

3.2 FACTORS TO CONSIDER IN A SPECIFIC WATERWAY

The following subsections suggest factors that should be considered when applying the design and evaluation processes of the manual. These factors are not independent of each other.

3.2.1 Channel Dimensions and Characteristics

The geography of a harbor and the dredging scheme must be considered. These features include the following.

1. The depth of the channel and the ship's draft determine the underkeel clearance. The amount of water under the keel affects the controllability of the ship. When ship control is difficult, aid placement is critical.

2. The presence of significant bank effects helps keep the ship in the channel. But bank effects also encourage smaller passing distances between meeting ships. With bank effects, the recommendations and performance data are conservative with respect to the risk of grounding.

3. The composition of the bottom and the banks -- mud, sand, rock ledge -- determines the consequences of a grounding. In harbors with soft bottoms, large ships routinely meet in narrow portions of the channels. In harbors with rocky bottoms, pilots of large ships make great efforts to meet in the less restricted portions of the channel. For soft-bottom harbors the recommendations and performance data in the manual are very conservative with respect to grounding.

4. The width of the channel in relation to the beam of ships using the channel is critical in determining both the risk of grounding and the risk of collision. When channel width is called for in later sections, the relevant dimension may not be the channel width indicated on the chart, but instead the width that can be safely used by the ship selected as the design vessel.

5. The length of the reaches is a factor. Short reaches provide less time to achieve a steady heading before meeting traffic or beginning another turn. In the worst case, close turns may be treated as a continuous maneuver and should be marked as such. In this case pilots try to plan a meeting in a straighter part of a run, and meetings will be more frequent in those parts.

6. The greater the angle of a turn, the more difficult the maneuver and the more critical the aids. For a large turn angle, channel width and ship size become more critical. Turn angle determines the selection of performance data in Section 5.

7. Turn areas are sometimes widened by dredging beyond the width of the straight channel segment, usually by dredging away the inside apex of the turn. Such turns are referred to here as "cutoff" turns. These turns are executed differently than those that are not widened. While pilots generally try to avoid meeting traffic in a turn, if the extra space is wide

and long enough, they will use it as a meeting zone. The length and width of this extra space will be discussed in Section 5.2.3.

3.2.2 Environmental Conditions

Environmental conditions influence the controllability of ships and therefore indirectly the importance of the aids; or they may directly influence the availability of aids to the pilot. In either case, frequent unfavorable weather in a harbor suggests conservative selections in the application of the manual. Extreme weather conditions -- ice, rain, squalls -- are not directly addressed in the manual. However, there is discussion and performance data for radar in Section 7 and radio aids in Section 8. Environmental conditions that are relevant here include the following.

1. Current can have a major effect. Ideally, the designer should understand the currents in the waterway, its set (direction) and drift (speed) and the sections of the channel that are affected. Most critical is the presence of a significant cross channel or crosstrack component to the current. Such currents affect the controllability of the ship. They also prevent the parallel orientation of the ship to the channel axis which allows the pilot the most accurate perception of position. The designer may find it difficult to establish objectively whether there are such crosscurrents. The most appropriate substitute for objective data is the pilots' judgments that there is or is not a crosscurrent significant enough to affect piloting in any region of the waterway.

2. Wind also affects the controllability of ship. Wind may be a more or less important factor, depending on frequent ship types: for example, a loaded tanker is less affected than a car carrier with a large sail area. Wind is considered in Section 4.

3. Visibility is obviously an important factor in the effectiveness of aid systems. The designer should know the frequency of reduced visibility in his waterway. It may be less of a problem if it is limited in season or in time of day. The configuration of the land may determine where fog collects; there may be typical visibilities for channel segments that may influence the needed aid spacing. Visibility is considered in Sections 2, 4, 7, 8, and 9.

This manual is not concerned with meteorological visibility or the selection of aids of sufficient size and contrast to be detected. For such selection, see Aids to Navigation Manual - Technical (COMDTINST M16500.3) and Aids to Navigation Manual - Administration (COMDTINST M16500.7). This manual assumes that aids/buoys have been selected for conditions such that they are detected 100 percent of the time at one of four visibilities:

- distance long enough to detect both range structures (if present)
- 1-1/2 nautical miles (nm) or just longer than the longest aid spacing
- 1/4 nautical miles (nm) or just long enough to see all the buoys in a turn or both buoys of a gated pair at the same time

- zero nautical miles (nm).

4. There are major day to night differences in the performance of aid systems. Indeed, because of the use of unlighted aids or the presence of unlighted land features, there may be differences between day and nighttime systems. The designer should understand the operational practices in the waterway, and the frequency and types of ship that use it. Night operations will be more important the further north the harbor and the longer the nights. Conservatively, dawn and dusk may be considered night. Day to night differences in aid systems and their performance are considered in Sections 2, 4, 5, 6, 7, and 9.

3.2.3 Operational Practices

Operational practices in a particular port may have implications for aid system performance. Suggestions for factors that might be relevant follow.

1. Pilotage should be considered. The designer should know the association with jurisdiction, whether there is more than one, if and where their jurisdictions overlap, and whether there are separate associations of tug or docking pilots. He should know the types and frequency of sizable vessels that are not under pilot control: for example, military ships or integrated tug-and-barge units. If there is a meaningful segment of traffic that is not under pilot control, he should have contact with those operators. Differences in their training, in the size or height of eye of their vessels, or in their electronic equipment may make their needs different. The manual's design recommendations and performance data assumes licensed harbor pilots.

2. Traffic regulations or local practices may be relevant. The designer should know where the switch is to Inland Rules-of-the-Road, where the COLREGS Demarcation Line is, and whether there is a Vessel Traffic System. The design should contact the Captain of the Port to learn of special local regulations: as an example, the stopping of other traffic for the transit of a Liquefied Natural Gas (LNG) carrier. The pilots may have their own local practices as a response to local conditions like preferred places for meeting traffic. Such practices will influence aid system design and the selection of appropriate performance data.

3. Traffic information is essential. The designer should have information on the types and frequencies of large ships (over 1,000 deadweight tons (dwt)), on the frequency or likelihood of their meeting ships of comparable size, and of the speed at which they generally transit. He should know when and where large ships do not move independently but one assisted by tugs. There may be local constraints on the transits of some ships: for example, cargo ships may prefer to transit at night in order to arrive at dawn at the beginning of the dock workers' day. Traffic information is needed for the selection of a design vessel and performance data in Section 5 and for possible weighting of the risk for different size ships in Section 9.

3.2.4 Ship Size and Type

The ship being considered has a very major effect on aid needs and on measured performance. The designer should familiarize himself with the ship types that call in his waterway and with their frequency. It will simplify the process of aid system design and evaluation if he selects one ship. It might be the dominant size and type in a harbor: for example, tanker, coal or ore carrier, or cargo ship. Or it could be the largest frequent ship. Aids to Navigation - Administration (M16500.7), Chapter 4 states, in most cases, the largest ship size using the waterway should be used as the design vessel. (The present manual can also be used to compare the expected performance of different ship sizes under constant aid systems.)

The larger the ship for the waterway, the more critical will be the aid arrangement and the poorer the measured performance. What is "large"? Deadweight tonnage is the most immediate, useful measure of inherent controllability or maneuverability. The loaded draft determines whether the ship can use the waterway at all, whether underkeel clearance affects controllability, and whether the ship has navigable water outside the marked channel. Whether the ship is large for the channel dimensions depends on more than the ratio of ship's beam to channel width. The turn angles, the turn dredging configuration, the length of straight segments, the frequency and size of oncoming traffic, the presence of crosscurrents, the frequency of low visibility, and the necessity of nighttime transits all help to determine what is large for a particular waterway.

This manual does not consider tug and barge combinations or large vessels assisted by tugs. At the present time any special aid needs of such users are left to the discretion of the designer or to historical practice in that waterway. No performance data is available for such operations.

3.2.5 View of Land

Aids to navigation only supplement natural and manmade landmarks. A waterway's proximity to land and the features that are visible determine how dependent the pilot must be on the aids. Where the waterway is close to land, features may function as aids of opportunity. Even where there are no especially well-placed or distinctive features that the pilot might select, the landmass provides cues for distance and for relative motion that open water or sparsely-placed aids do not generally provide. At night the lights of inhabited land may function as aids or may provide ambient lighting that makes both lighted and unlighted aids more visible. Cultural lights, or lights from other channels or other ships, may have a negative effect where they form a background that interferes with the pilot's identifying or attending to the aids. The system designer should understand -- by studying the chart, talking to the pilots, or riding with them -- where the landmass is helpful or harmful to the piloting process. This understanding will help him to decide how conservatively each region of the waterway must be marked.

The system designer should be aware that pilots do not always use an aid as it is intended or in the channel segment for which it it intended. For example, they may use a visible aid on or off the edge of a segment up ahead as a leading light or as part of a range while transiting an earlier segment. This may mean that the earlier segment is better "marked" than it appears at first analysis; or it may mean that the pilots are overly optimistic about the usefulness of aids, especially floating aids. Only discussions with the pilots will reveal these uses.

3.2.6 Consequences of Accident

Accidents in some waterways may have severe economic or political consequences. A busy harbor means high economic costs if shipping is interrupted or even delayed. A busy harbor or a dense population along the shores presents the potential for loss of life. Transported cargoes may be especially dangerous to the environment: for example, oil, LNG, or toxic chemicals. The environment may be especially sensitive because of fishing or recreational industries or conservational values. Or some combination of these possibilities may exist. Severe consequences mean a requirement for conservatism in applying the design and evaluation procedures in the manual.

3.2.7 Summary

The information suggested in this section is summarized in Worksheet 3-1, which can be copied and used to record collected information. Some is of a general nature needed for adaptation of design recommendations and interpretation of performance data. Some specific information is needed for the selection of performance data and for calculations in later sections. Information expressed as proportions is to be used in Section 9 for management procedures. Those listed are suggestions. The designer may identify others that are significant for his waterway.

3.3 REGIONS FOR REQUIRED MANEUVERS

The following sections of the manual are organized to treat the waterway as a series of regions based on the maneuver required in each: turn, recovery, and trackkeeping. The type of maneuver in a region determines the information that must be provided to the pilot by the aid system and the performance or risk that can be expected there. The designer should draw the regions for his waterway on the chart (or photocopy or sketch the relevant parts of the chart). The procedure is illustrated in Figure 3-1 and described below. It will also be helpful to indicate on the chart any local features identified in Section 3.2: for example, significant landmarks, currents, or banks.

3.3.1 Turn Regions

The turn region encloses the severest maneuver, with the necessity that the pilot make rapid, frequent judgments of the ship's alongtrack and crosstrack position, and velocities. For this reason, number and placement of aids in this region is most critical and measures of risk are the highest.

As a first step, each turn to be considered should be outlined as shown. Conservatively, it is suggested that the distance of the turn region (DT) be 0.5 nautical miles (nm) in each direction from the apex. This is a distance that will accommodate a variety of conditions. If the ships to be

SUMMARY OF WATERWAY CONDITIONS (SHEET 1 OF 3)

1. GENERAL INFORMATION

Waterway name and location ______

Local consultants ______

Chart number ______

Channel dimensions and characteristics ______

Environmental conditions ______

Operational practices ______

Ship sizes and types ______

View of land ______

Consequences of accidents ______

Worksheet 3-1

SUMMARY OF WATERWAY CONDITIONS (SHEET 2 OF 3)

Waterway name and location______________________________________

2. WATERWAY PARAMETERS

Channel Parameters (indicate on chart, copy of chart, or on worksheet)

A. Angle of turn (degrees)

DT1. DT2. DT3. DT4. DT5.

B. Navigable width 2000 feet beyond turn apex for cutoff turns (feet)

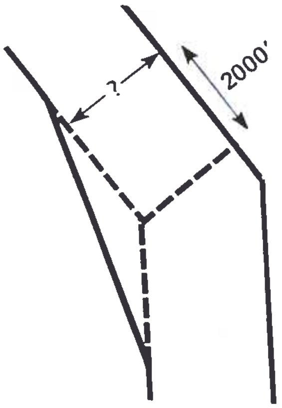
DT1. DT2. DT3. DT4. DT5.

C. Navigable channel width for design vessel per recovery region (feet)

DR1. DR2. DR3. DR4. DR5.

D. Navigable channel width (trackkeeping region)

DK1. DK2. DK3. DK4. DK5.



Environmental Parameters

A. Maximum crosstrack current (knots) by recovery region

DR1. DR2. DR3. DR4. DR5.

B. Maximum crosstrack current (knots) by trackkeeping region

DK1. DK2. DK3. DK4. DK5.

Worksheet 3-1 (Continued)

SUMMARY OF WATERWAY CONDITIONS (SHEET 3 OF 3)

Waterway name and location ______________________________

Design Vessel Parameters

Ship size (deadweight tons) __________

Length (feet) __________

Beam (feet) __________

Loaded draft (feet) __________

Typical transit speed (knots) __________

3. PROPORTIONAL OCCURRENCE OF VARIABLE CONDITIONS

Environmental Conditions

Proportion of design vessel transits experiencing maximum crosstrack current component:

Proportion of occurrence of day and night/dusk/dawn transits of design vessel:

Proportion of transits under each of following visibilities:

≥ distance long enough to detect both range structures (if present) _____

≥ 1-1/2 nm or long enough to detect the longest spaced aids _____

≥ 1/4 nm or the distance required to see all buoys in a turn or both buoys of a gated pair _____

< 1/4 nm or the distance required to see all buoys in a turn or both buoys of a gated pair _____

Operational Conditions

Proportion of transits of design vessel (or larger) versus transits of smaller vessels (over 1,000 dwt).

Proportion of transits of design vessel meeting traffic.

Worksheet 3-1 (Continued)

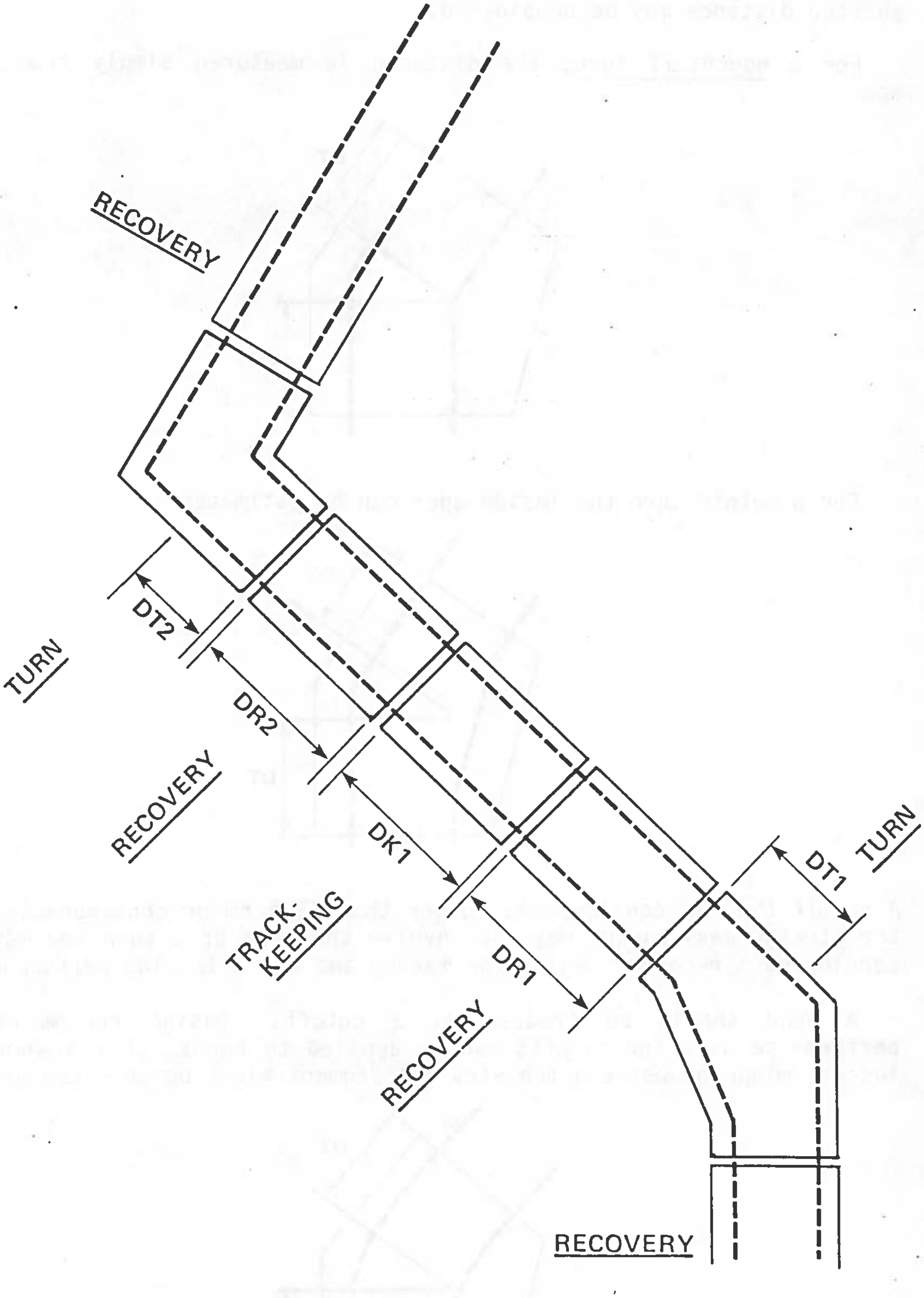
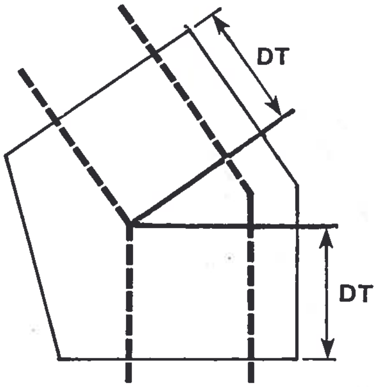


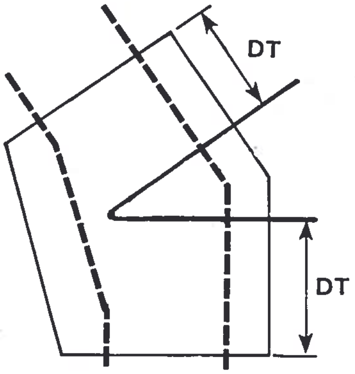
Figure 3-1. The Division of Waterway into Regions for Required Maneuvers

considered are small; the speeds, slow; or the turns, of small angle; a shorter distance may be considered.

For a noncutoff turn, the distance is measured simply from the inside apex.

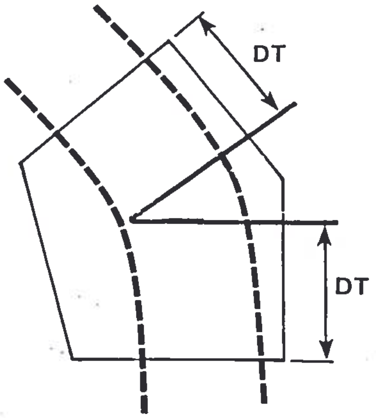


For a cutoff turn the inside apex can be estimated.



A cutoff that is considerably longer than ±0.5 nm or considerably wider than the straightaway widths may not involve the risk of a turn and may be better considered a recovery region for making and for selecting performance data.

A bend should be treated as a cutoff. Design recommendations and performance data for cutoffs can be applied to bends. For a short bend the inside, midpoint between the straight segment might be selected as the apex.



If there is a conspicuous aid on the inside, that might be the considered apex. A bend too long to be accommodated within the ±0.5 nm distance can be treated as a succession of cutoffs, possibly overlapping, or as a continuous turn.

Linked, S-shaped, or reversing bends or turns should be treated as successive bends or turns with the possibility that the ±0.5 nm distances may overlap. Where there are unique configurations of bends or turns, it will be helpful to have the pilots' reports on whether there are perceptible banks, whether they depend on such banks, and whether they negotiate the region as a continuous maneuver or a series of maneuvers.

3.3.2 Recovery Regions

The recovery region encloses the pilot's efforts to find the appropriate track in the new channel leg and to maneuver the ship to it. To do this, the pilot needs precise knowledge of the edges of the channel and of the ship's relationship to them. The region must be well-marked for this. For a two-way channel there are recovery regions above and below each turn region. The entrance to the waterway from sea may also be considered a recovery region. Presumably, the ship has room to turn into the waterway in safe water but then must recover from that turn in the restricted waterway.

The distance for the recovery (DR) depends first on the size and speed of the ship. Conservative recovery distances for ships transiting at a maneuvering speed the pilot considers prudent, generally 6 to 12 knots, are listed in Table 3-1.

TABLE 3-1. DISTANCE FOR THE RECOVERY REGION (DR) BY SHIP SIZE

Ship Size (1,000 deadweight tons)	DR (nautical miles)
30	0.67
50	0.97
70	1.29
90	1.60
110	1.90

NOTE:

DR for intermediate ship sizes can be calculated by the following equation:

$$CR_i = 0.67 + 0.0154\ (X_i - 30)$$

where:

DR_i = distance for recovery region (nautical miles)

X_i = ship size in 1,000 deadweight tons

3.3.3 Trackkeeping Regions

The trackkeeping region encloses the channel segment in which the pilot is satisfied with the ship's track in the channel and has no intention or need to leave that track. For this reason, he does not need precise knowledge of the channel edges. He needs only enough aids to give him a short-range destination up ahead.

The distance for each trackkeeping region (DK) is simply the remainder of the straight segments.

3.3.4 Summary

The waterway is divided into regions on the chart as follows.

The distance for the turn region (DT) is ±0.5 nm from the apex for each turn.

There is a recovery region above and below each turn and at the entrance from the sea. The distance (DR) is given in Table 3-1.

The trackkeeping region has as its length (DK) the remainders of the straight segments.

3.4 DESIGN AND EVALUATION OF AID SYSTEMS

The specification of waterway conditions is a necessary first step in the design and evaluation of aid systems. After it is complete, there are a number of possible paths through the remaining sections, depending on the designer's objectives.

The guidelines of Section 4 can be used as a nonquantitative design and/or evaluation procedure.

The sequence of steps in Table 3-2 is recommended to make maximum use of the quantitative procedures provided by the manual for aid system design. Each step is described in the section cited in the table.

Section 6 provides guidelines and performance data for special consideration of the meeting traffic situation.

Section 7 provides guidelines and performance data for special consideration of the reduced visibility situation.

If a radio aid system, such as Loran C, to be used independently of the SRA system, is of interest, the designer may go directly to Section 8 for performance data for a number of alternative displays. There are no data available for performance using racons.

TABLE 3-2. RECOMMENDED SEQUENCE FOR THE DESIGN AND EVALUATION OF AN AID SYSTEM

1. Complete Worksheet 3-1 (page 3-7), to produce a general picture of the waterway.

2. Compute the relative risk factors (RRFs) for regions with existing aids, using Section 5.

3. Record RRFs on Worksheet 5-7 (page 5-83), to organized the calculated values.

4. Record RRFs on Figure 9-1 (page 9-5), for a graphic representation of the calculated values.

5. Identify and redesign regions showing high risk. Redesign using Section 4.

6. Recompute RRFs for the affected regions.

7. Repeat steps 2 through 6 until RRFs cluster on Figure 9-1 as desired or until risk is identified as an operational matter.

SECTION 4. DESIGN GUIDELINES FOR AIDS TO NAVIGATION SYSTEMS

Section 4

DESIGN GUIDELINES FOR AIDS TO NAVIGATION SYSTEMS

4.1 INTRODUCTION

This section describes the general effects on performance caused by the many factors (channel characteristics, ship characteristics, environment, aids, etc.) investigated in the simulator experiments and in the trial applications of the manual. This discussion is an education into those effects to help the art of design and evaluation. The discussion is presented here in a systematic form to serve two objectives.

1. To design new aids to navigation systems. This section is planned primarily to guide the designer in generating new aid systems for the conditions in his waterway. The discussion here relates the waterway conditions that were catalogued in Section 3 to alternative aid arrangements that are appropriate for those conditions.

2. To provide a preliminary evaluation of existing or proposed aids to navigation systems. This section is also usable as a preliminary nonquantitative evaluation of existing or proposed aid systems. The recommendations for design in this section are not independent of the quantitative procedure in Section 5. The degree to which a proposed system meets the recommendations here predicts the measured performance in Section 5. Application of this design procedure to a waterway will help the designer understand why a proposed system is evaluated as high or low in performance in that section.

The following subsections include first a general discussion of the elements that make up a system, then a discussion of alternative arrangements of these elements to mark the turn, recovery, and trackkeeping regions. The demarcation of these regions is described in Section 3.3. As a first approximation to designing a system, possible arrangements for each region can be noted on the chart, a copy of the chart, or on worksheets provided at the end of this section. Also at the end of this section are instructions for selecting buoy locations to correspond to the noted arrangements. To use the procedure as a preliminary evaluation the existing or proposed aid arrangements can be characterized as high, moderate, or low in performance, according to the discussion in the text.

4.2 SYSTEM ELEMENTS

4.2.1 Natural and Man-made Landmarks

Land close to the waterway does not outline safe water as do aids, but can provide more general information on position. The best information on position comes when objects are close to the channel or when two objects form a natural range. Close objects or a range may indicate alongtrack position, providing the pilot the distance to a turn and when to start a turn maneuver; or provide him sufficient knowledge of crosstrack position to allow him to keep the ship in the channel. The presence of land, even without conspicuous features, helps the pilot perceive relative motion much better than does open water or sparsely-placed aids. When lights are present on the landmass, the same type of information is provided at night. Landmasses do not always make a positive contribution. At night, low-lying background lights may make it difficult for the pilot to identify and to attend to aids. In such cases, selecting conspicuous light characteristics is essential.

When the channel is close to land, there may be prominent banks at the channel edge that cause hydrodynamic forces to repel the approaching bow of the ship. The pilot, by observing the amount of rudder deflection toward the bank needed to maintain a parallel course, can often locate the edge and judge the ship's distance to it. When making a turn, an approach to the far bank in the next leg will take the ship around the turn with little or no use of the rudder. The pilot's "local knowledge" seems to be an important factor in the use of the banks. He should have experience with a particular waterway to know where bank effects exist, and how much rudder use to expect. General experience with banks is also a factor. Pilots experienced with banks consider them useful, even essential; pilots with no experience consider them treacherous and may avoid them. Although the avoidance of banks will not increase the risk of grounding, it means less usable channel is available for meeting traffic.

4.2.2 Aids: Floating or Fixed, On or Off the Channel Edge, Lighted or Unlighted

The Coast Guard aid system designer must consider factors like cost and physical location in choosing the types of aids to mark a waterway. The emphasis here is on the ways alternative types of aids can contribute to the effectiveness of the system in supporting the pilot. The following is a discussion of the relative contributions of these alternative types of aids: floating or fixed, on or off the channel edge, lighted or unlighted.

The lighted buoy on the channel edge is to the pilot on a large ship the "meat and potatoes" of aids. By outlining the safe water available, it provides positive information even for the most demanding maneuvers, negotiating a turn or meeting traffic. It does this day or night, visually or on radar.

An aid on the channel edge -- referred to as a "sidemark" in other Coast Guard contexts -- makes a similar contribution whether it is floating or fixed as long as it is in place. If a floating aid is off station, the pilot can often detect it by examining the whole channel in the radar for discrepancies from the familiar pattern. One advantage of regular patterns like gated buoys regularly spaced is that misplacement can be more easily detected, visually or on radar. A fixed aid on the channel edge provides the same information without the possibility that it is off station. For purposes of the design procedure in this section and for use of the performance data for evaluation in Section 5, it is assumed that aids on the channel edge are equivalent, whether floating or fixed.

If the aid is off the channel edge, it will not outline safe water but it will function as does a close landmark (see 4.2.1). In a given location, the designer may have to decide between a buoy on the channel edge and a fixed beacon some distance off. There is no performance data yet available for aids off the channel edge. Conservatively, it can be assumed the effectiveness of an aid falls off with increasing distance from channel edge. The distance and the effectiveness should be less of a problem for trackkeeping than for maneuvers that require a judgment of the space available, like making turns or meeting traffic.

A number of factors enter into the decision of whether to use lighted or unlighted aids. Unlighted aids are less costly to establish and maintain. This means they will permit a greater number or closer spacing of aids. Also, unlighted buoys tend to surface more reliably after being submerged by ice than do lighted buoys. They obviously benefit smaller vessels, if smaller vessels need to stay in the marked channel. The operator on a small vessel has a lower height of eye and will benefit from the closer spacing; he is less likely to have radar to see longer-spaced aids in restricted visibility; and he is likely to have the option of not moving at night, when unlighted aids are not visible.

Pilots on large ships are generally unenthusiastic about unlighted aids. In adequate visibilities for visual piloting, with the greater height of eye of the large ship, they don't need the closer spacing made possible by the use of additional aids. In restricted visibilities the additional unlighted aids on radar are helpful but not critical. "Helpful but not critical" means that pilots disagree as to whether they are needed for radar piloting. The available performance data suggest buoy spacing is a factor in radar piloting (see Section 7). Unlike other users, the pilot usually has no option to wait until day. Indeed, in northern ports he may make more nighttime than daytime transits in the course of a year. Unlighted aids do not provide the same information at night. Even if background lighting makes the unlighted aid visible at night, it is only visible when it is close aboard, limiting its usefulness for piloting a large ship with a long delay in response.

For large ships, unlighted aids are not an appropriate substitute for lighted aids. There is evidence from the ship tracks collected during the test implementation of the manual process that pilots at night do not use the space for turns and S-shaped maneuvers that is outlined by unseen unlighted aids, but make more severe maneuvers in a more constrained space. This performance in turns suggests that they may also constrain their ships' movements while meeting traffic at night in the vicinity of unlighted aids. While this would not increase the risk of grounding, it would increase the risk of collision. These data support the recommendation that large ships transiting at night have their needs met with lighted aids. Unlighted aids should be viewed as providing additional aids for other users or for reduced visibility. The design recommendations in this section and the evaluation procedure in Section 5 are based on the assumptions that lighted and unlighted aids are equivalent in the daytime and that unlighted aids make no contribution at night. (Section 4.3.4 contains recommendations for light rhythms for the critical turn region.)

4.2.3 Ranges: Visibility, Sensitivity, Turns and Straightaways

Ranges are dependent on adequate visibility or detection distance for their use. The selection of range lights or structures for the detection distance wanted is considered in the Aids to Navigation Manual - Technical (COMDTINST M16550.3). This manual assumes both structures are detectable when the range is to be used. If the waterway is to be used when the structures are not detectable, then other aids (sidemarks) must be sufficient without the range.

The performance of a range varies with its "sensitivity". That is, the geometry of the range in relation to the eyepoint of the user determines how readily he will detect crosstrack error from the axis of the range. The sensitivity of the range is extensively discussed in Aids to Navigation Manual - Range Design (COMDTINST M16500.4). For the purposes of this manual, the following calculation will provide a measure of sensitivity, K:

$$K = [WR]/[D(H-h)] \tag{4-1}$$

where:
K = lateral sensitivity
W = channel width (feet)
R = distance between range structures (nautical miles)
D = distance from front structure to the observer, usually at the extreme ends of the recovery region (nautical miles)
H = height of rear structure (feet)
h = height of front structure (feet)

In Section 5, instructions for the selection of performance data make the following assumptions:

- If K is equal to or greater than 3, it is a high-sensitivity range.
- If K is calculated as less than 3, it is a low-sensitivity range.

For purposes of this section, the high-sensitivity range provides better performance for all uses than does a low-sensitivity range.

It seems likely that both general experience in the use of ranges and local knowledge of a particular range are factors in performance. There is evidence taken on the simulator that naive observers are just as likely as pilots to detect misalignment of the range structures. However, it seems from discussions with pilots and from observing their use of ranges that they learn to interpret misalignment in terms of crosstrack position in the channel and to correct the judgment of crosstrack position for alongtrack distance down the channel from the range structures. If this is true, it means that the present recommendations and the performance data in Section 5, based on simulator runs with ranges new to the pilots are conservative. This is a specific instance of the generality in Section 2 that performance in general purpose simulated waterways measures performance conservatively because of a lack of local knowledge.

The recommendations and performance data are for forward ranges. Without data, the conservative assumption is that back ranges would show inferior performance. This inferiority is not because it becomes more difficult to detect misalignment on a back range, but because it becomes more difficult to interpret the misalignment in terms of crosstrack distance and to maneuver the ship in response. Again, experience and local knowledge may be helpful.

Ranges alone perform poorly in turns, because they do not outline the available safe water. This is especially true with ranges of low sensitivity (K 3). Turns do exist at sea marked only by ranges in the contiguous straight legs. It may be that the channel is wide for ship size or that the turn area is widened to accommodate an imprecise turn maneuver. Performance may be helped by other information sources, such as nearby landmarks, bank effects, and pilots' local knowledge. Local knowledge in such a situation may consist of expectations about the appearance of the range from various positions or of a well-rehearsed series of rudder applications that is not very dependent on the aids. When these factors apply, there is no reserve for severe conditions or unexpected events. The conservative conclusion is that turns are not well marked by ranges.

A range is the ideal aid for recovery from a turn or other maneuver and for trackkeeping on the axis of that range. Even if a range is available, a pullout buoy may be necessary to define the outboard channel edge when recovering from a turn. A range should be considered where visibilities are usually adequate and where there is a need to keep a large ship at the center of a narrow channel. A high-sensitivity range allows the pilot to keep the ship on the axis even under adverse conditions of crosswind and current. A range of low sensitivity will not perform as well in such a situation and may perform less well than buoys (sidemarks). Section 5 presents quantitative data to guide this decision. Ranges do not perform as well when the pilot is required to judge his position off the axis of the range: for example, only a high-sensitivity range used by experienced pilots should be considered feasible in meeting traffic situations. Another possibility for frequent meeting traffic is a system of quarterline ranges, ranges with the axis one quarter of the distance from the channel edge, that would allow ships to meet traffic on the axis of a range. Buoys or aids (sidemarks) on the channel edge are best marking for meeting traffic.

4.2.4 Short-Range Aids and Radar

The manual is organized with certain assumptions about short-range aids (SRA) and radar. Visual piloting is the basic process of navigation in restricted waterways. Pilots use radar to examine large portions of the waterway for misplaced buoys and for traffic; or to reassure themselves of their progress at night and in reduced visibility. But they prefer to keep moment-to-moment control of the ship using visual information as long as the visibility allows. They prefer not to pilot completely by radar unless it is absolutely necessary. To serve their needs, the manual assumes the SRA system is designed for visual piloting. It also assumes the aids are equipped with passive reflectors and are detectable on radar. If reduced visibility is frequent in a waterway, the design for visual piloting should be conservative. Such a design will probably be the best SRA design for radar. Section 7 contains guidance for re-examining the SRA system to ensure that it is.

4.2.5 Summary

The discussion of the performance of system elements is summarized in Table 4-1.

TABLE 4-1. PERFORMANCE OF SYSTEM ELEMENTS

	System Elements	Performance for Narrow Channels
4.2.1	landmarks	- are most useful when close or form a range - provide relative motion cues - do not outline safe water
	bank forces	- outline safe water when ship is close
4.2.2	fixed aids	- reliable and effective
	floating aids	- less reliable and equally effective
	aids on channel edge (sidemarks)	- outline safe water
	aids off channel edge	- act as landmarks
	lighted aids	- perform day and night
	unlighted aids	- allow close spacing for day or reduced visibility - equivalent to lighted aids during daytime
4.2.3	ranges	- perform relatively poorly in turns - perform best in recovery and trackkeeping
4.2.4	SRA with passive reflectors	- provide secondary system for reduced visibility

4.3 MARKING FOR THE TURN REGIONS

The turn maneuver is the most demanding, so aids in this region are most critical. The best turn maneuver for large ships is one that allows the most gradual change in heading or the largest turn radius. Pilots respond to both dredging and aid configurations in choosing a track which allows the largest turn radius. The best aid configuration is one which allows the safest use of most available dredged space.

In narrow channels in U.S. ports, noncutoff turns, cutoff turns, and bends occur with roughly equal frequency. The first two configurations are illustrated in Figure 4-1. The discussion here emphasizes the noncutoff turns that require the shortest turn radius and, thus, carry the highest risk. Cutoff turns and bends allow longer radius turns and, therefore, are lower risk.

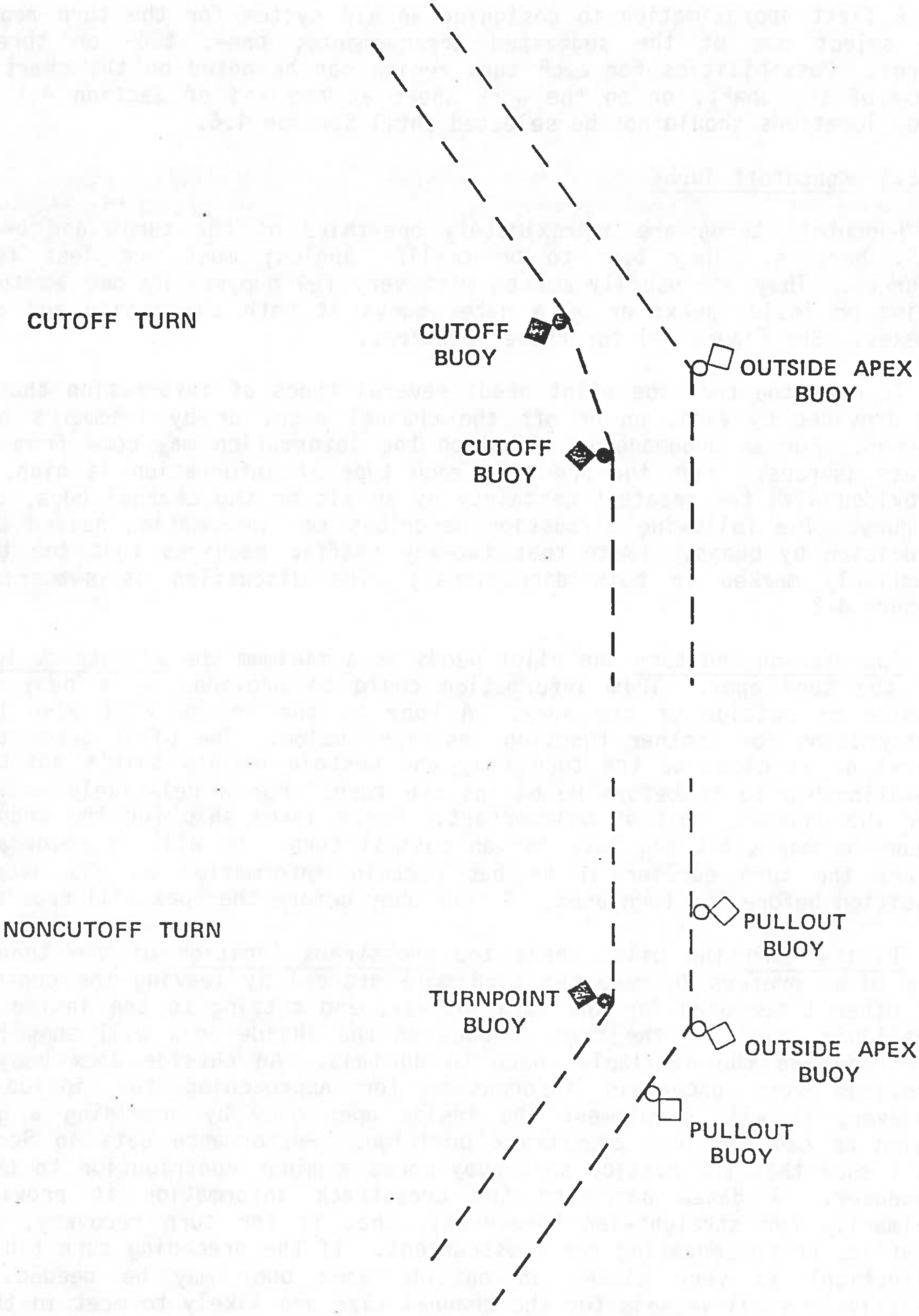


Figure 4-1. Turn Configurations and Possible Buoy Placements

A first approximation to designing an aid system for the turn region is to select one of the suggested arrangements; one-, two- or three-buoy turns. Possibilities for each turn region can be noted on the chart, on a copy of the chart, or on the work sheet at the end of Section 4. Actual buoy locations should not be selected until Section 4.6.

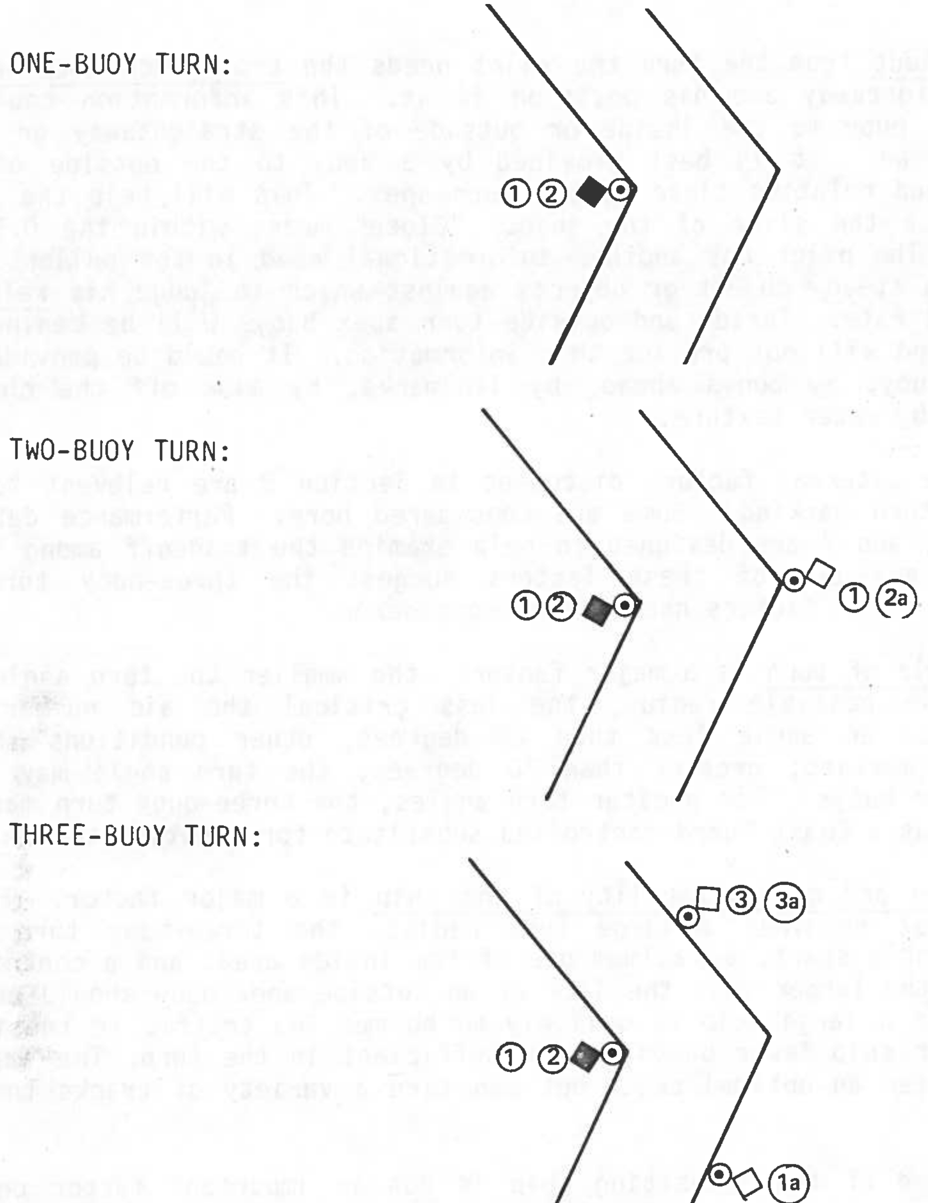
4.3.1 Noncutoff Turns

Noncutoff turns are approximately one-third of the turns and bends in U.S. harbors. They tend to be smaller angles; most are less than 20 degrees. They are usually marked with very few buoys: by one at the turn point or inside apex; or by a gate, buoys at both the inside and outside apexes. See Figure 4-1 for these locations.

To make the turn the pilot needs several types of information that could be provided by aids, on or off the channel edge, or by landmarks or bank forces. For an undemanding situation the information may come from any of these sources. When the need for each type of information is high, it is provided with the greatest certainty by an aid on the channel edge, usually a buoy. The following discussion describes the information needed and its provision by buoys. (Note that two-way traffic requires that the turn be similarly marked in both directions.) The discussion is summarized in Figure 4-2.

Approaching the turn the pilot needs as a minimum the alongtrack location of the turn apex. This information could be provided by a buoy to the inside or outside of the apex. A buoy to the inside will also provide information for another function described below. The pilot tends to wait until he is close to the turn buoy and certain of his ship's position in relationship to it before he begins the turn. For a relatively small ship for the channel, this is unimportant. For a large ship for the channel it means he may start too late for an optimal turn. He will be encouraged to start the turn earlier if he has certain information on his alongtrack position before the turn apex. A turn buoy before the apex will provide it.

In the turn the pilot needs the crosstrack location of the turn apex. The pilot prefers to make the turn more gradual by leaving the centerline, or other track used for the straightaway, and cutting to the inside of the available space for the turn. A buoy on the inside apex will show him its location and the available space to do this. An outside apex buoy alone provides very uncertain information for approaching the inside apex. However, it will supplement the inside apex buoy by providing a gate in which he can find his crosstrack position. Performance data in Section 5 will show that the outside apex buoy makes a minor contribution to the turn maneuver. A gated pair and the crosstrack information it provides is primarily for straight-leg maneuvers: that is for turn recovery, meeting traffic, or compensating for crosscurrent. If the preceding turn (in either direction) is very close, an outside apex buoy may be needed. Only relatively small vessels for the channel size are likely to meet in the turn and need the gate for that reason. Pilots on large ships try to avoid meeting in or near the turn. Performance data in Section 6 supports this reluctance. If there is crosscurrent (or wind) in the turn region, the gated pair may be needed.



Notes:

The numbers identify the information needs met by each buoy as follows:

Approaching the turn (upbound)
1. Alongtrack location of turn apex as a minimum
1a. Alongtrack position before turn apex

In the turn:
2. Crosstrack location of inside apex for turn maneuver
2a. Crosstrack position, a cross channel for non-turn maneuvers

Pullout:
3. Crosstrack location of next straightaway
3a. Relative motion during turn maneuver

Figure 4-2. Alternative Buoy Arrangements for Noncutoff Turns

In the pullout from the turn the pilot needs the crosstrack location of the next straightaway and his position in it. This information could be provided by a buoy to the inside or outside of the straightaway or by a gated pair ahead. It is best provided by a buoy to the outside of the straightaway and relative close to the turn apex. This will help the pilot detect and stop the slide of the ship. "Close" means within the 0.50 nm turn region. The pilot has another informational need in the pullout. He needs to see a steady object or objects against which to judge his relative motion or turn rate. Inside and outside turn apex buoys will be behind the swinging bow and will not provide this information. It could be provided by the pullout buoy, by buoys ahead, by landmarks, by aids off the channel edge, or even by water texture.

Many of the waterway factors discussed in Section 3 are relevant to the selection of turn marking. Some are considered here. Performance data in Sections 5, 6, and 7 are designed to help examine the tradeoff among these factors. If any one of these factors suggest the three-buoy turn is necessary, the other factors need not be considered.

1. The angle of turn is a major factor: the smaller the turn angle and the larger the possible radius, the less critical the aid number and placement. For an angle less than 20 degrees, other conditions should determine the marking; greater than 20 degrees, the turn angle may be a reason for more buoys. For greater turn angles, the three-buoy turn marking may be viewed as a Coast Guard-controlled substitute for a cutoff turn.

2. The size and maneuverability of the ship is a major factor. For a large ship that requires a large turn radius, the three-buoy turn will encourage an early start, a maximum use of the inside area, and a controlled pullout. For the larger ship the lack of an outside apex buoy should not be a problem since a large ship is unlikely to be meeting traffic in the turn. For the smaller ship fewer buoys may be sufficient in the turn. The smaller ship doesn't need an optimal track but can take a variety of tracks through the turn.

3. The speed of the transiting ship is not an important factor on its own over the range of speeds likely in a narrow channel. Differences in performance due to changes in ship maneuverability with speed are minor compared to differences due to ship size and buoy number and arrangement. The combination of larger ship size, higher speed, and low buoy number may be a problem. The recommendation is that the turn be marked for ship size and that the pilot be responsible for selecting an appropriate speed (as he is now).

4. Channel width is a major factor in the turn. The channel width in relation to ship size determines the criticalness of the ship's track and, therefore, the criticalness of the marking. For a wide channel width relative to the ship, fewer aids may be needed.

5. If there is considerable difference between information available to the pilot in the day and night, there will be a considerable difference in performance. In the worse case the view of land, water, and aid structures will be gone and the aids will be reduced to flashing lights. At night

pilots are reluctant to approach the channel edge, and, therefore, make less than optimal use of the available space. They tend to stay on the centerline longer and start the turn later presumably because they are less sure of the apex location. With a smaller ship they are able to start to turn later, to make a smaller radius turn, and pullout close to the centerline. They tend to pull out closer to the centerline at night than in the daytime; presumably, because they are less sure of the edges. With a larger ship the smaller turn radius is not possible and the ship tends to exit the turn further to the outside of the next straightaway than in the daytime. If large ships, for the channel width, are making frequent nighttime transits heavily dependent on the aids, the three-buoy turn will be more helpful at night than in the daytime, encouraging maximum use of the space.

6. The likelihood of meeting traffic and the likely ship size together are a consideration for turn marking. The operators of small vessels willing to meet in the turns are served by the two-buoy turn for this purpose. The project findings, discussed in Section 6, are that larger ships are better served by a three-buoy turn if they must meet close to the turn. When given their preference, pilots on large ships plan to meet far from the turn, in which case the turnmarking is less important. The designer is advised to consider the frequency of various ship sizes and the probability they will meet, and also to discuss with the pilots their customs in meeting traffic.

7. Visibility is a factor in turnmarking. To the extent that the turn maneuver is dependent on landmarks or aids at a distance from the turn, performance will be degraded when visibility is too low to use them. In such a case, the three-buoy turn will support visual piloting at shorter visibilities than the one- or two-buoy turns. (Section 7 discusses the possibility of reduced visibility piloting using SRA with passive reflectors and conventional radar.)

4.3.2 Cutoff Turns

Cutoff turns, turns widened by dredging away the inside apex, make up about one-third of the turns and bends in U.S. harbors. They tend to be of larger angles, 20 to 40 degrees. The marking of cutoff turns varies widely with buoy number ranging from one to more than four and with no consistency to their placement. Cutoff turns appear to be marked with the assumption that the extra space ensures safety. A broader conclusion is that, with the extra margin provided by cutoff, system designers have allowed themselves to be influenced by mitigating, surrounding conditions. The suggestions here are conservative in that they provide aids that can support piloting when the surroundings are not helpful. It is up to the designer to decide whether this is necessary. See Figure 4-1 for the outline of a cutoff turn and the buoy locations suggested here. (The aid system designer may decide that a cutoff area is too short or too narrow to allow a shortening of the turn radius and elect to consider the turn a noncutoff in marking it. There are many turns at sea where this decision was apparently made.)

The cutoff area allows a longer turn radius through the turn. The suggestions here are made with the assumption that the best marking is one that outlines the cutoff area so the pilot can take advantage of it. The information given by the suggested buoy locations is summarized in Figure 4-3. An irregularly-shaped cutoff may require a different number and placement of aids but the principles will be the same.

Approaching the turn, a buoy on the outside apex or anywhere on the inside edge will give the pilot the general alongtrack location of the turn area. But only a buoy on the beginning of the diagonal will allow him to make the earliest possible turn off the straight leg into the available space.

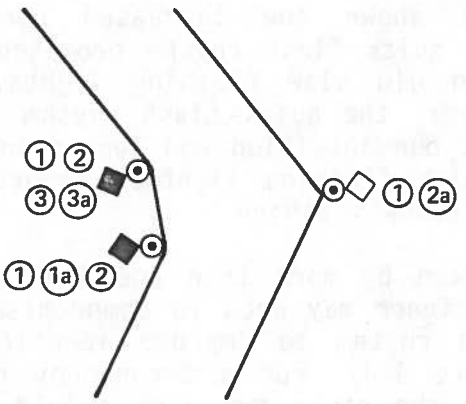
In the turn only the buoys on the ends of the diagonal edge will allow the pilot to make maximum use of available space. Other possibilities for the cutoff area are that there be only one buoy on the diagonal, either along the edge or set in to where the straight channel apex would have been; that only the outside apex be marked; or that the inside of the turn be marked by an aid off the channel edge. When the extent of the cutoff is not marked, pilots may avoid using it, treating it like a noncutoff turn. The outside apex buoy probably contributes little to the turn maneuver. While it is generally true that pilots prefer to avoid meeting in the turn, if the cutoff area is considerably wider than the straightaway and of reasonable length, it may become a preferred meeting place, in which case the outside apex buoy is essential. A particularly large cutoff may require more than three buoys to allow the pilots to make maximum use of the space for meeting and overtaking traffic.

In the turn pullout the last buoy on the diagonal edge will provide the crosstrack location of the inside edge of the next straightaway. It may be appropriately positioned sufficiently late in the turn maneuver to provide a fixed point against which to judge the relative motion or turn rate of the ship. Because the ship is making a longer radius turn, the hydrodynamic forces pushing him to the outside are not as great as was the case in the noncutoff turn and it is less critical that there be a buoy marking the location of the outside edge of the next leg immediately after the turn. However, that edge should be marked early in the recovery region.

The waterway factors that directly affect performance and the subsequent need for aids are reviewed for noncutoff turn in Section 4.3.1. Those factors have similar effects and require similar consideration for cutoff turns. Performance data in Section 5 provides separate quantification for cutoff and noncutoff turns.

4.3.3 Bends

Slightly less than one-third of the course changes in major U.S. ports are bends. They tend to be of long length and large angle averaging 49 degrees in course change from one straight segment to the next. Bends are marked with equal frequency with one buoy marking the inside, with two buoys marking the inside, or with buoys to both sides. When bends occur because of adjacent landmasses, the view of land and the bank forces present are a major consideration.



NOTES:

The numbers identify the information needs met by each buoy as follows:

Approaching the turn (upbound):

1. General alongtrack location of turn apex
1a. Extent of space available to start turn

In the turn:
2. Extent of space available for turn maneuver
2a. Extent of space available for non-turn maneuvers

Pullout:
3. Crosstrack location of next straightaway
3a. Relative motion during turn maneuver

Figure 4-3. Buoys Outlining a Cutoff Turn

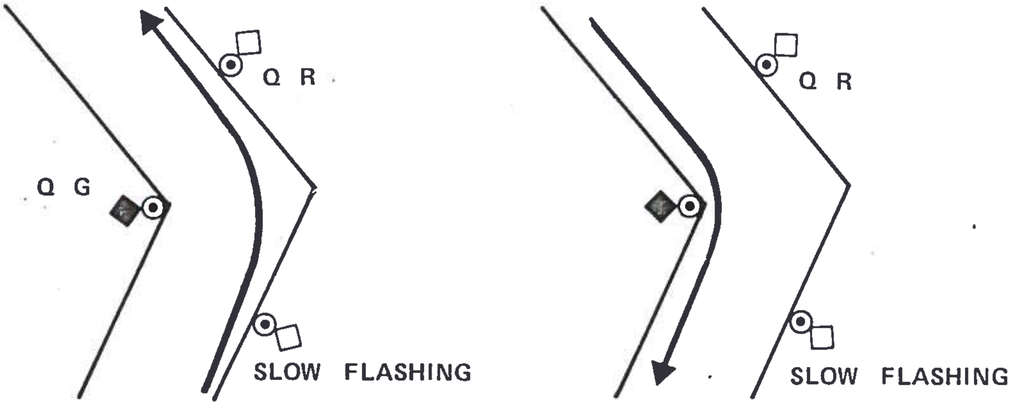
To the extent that aids are needed, the principles involved in marking cutoff turns can be generalized to bends. Aids (buoys or fixed structures) to the inside tell the pilot where the turn begins and the extent of available space for moving to the inside of the bend. This function may be unimportant if the bottom contours are such that the pilots prefer to keep the ship close to the outside edge in the bend and depend on the bank forces to keep the ship in safe water. In either case the pilot needs an aid or aids in the next straight segment to mark its location and width.

Section 5 contains some suggestions for adapting measured performance for bends.

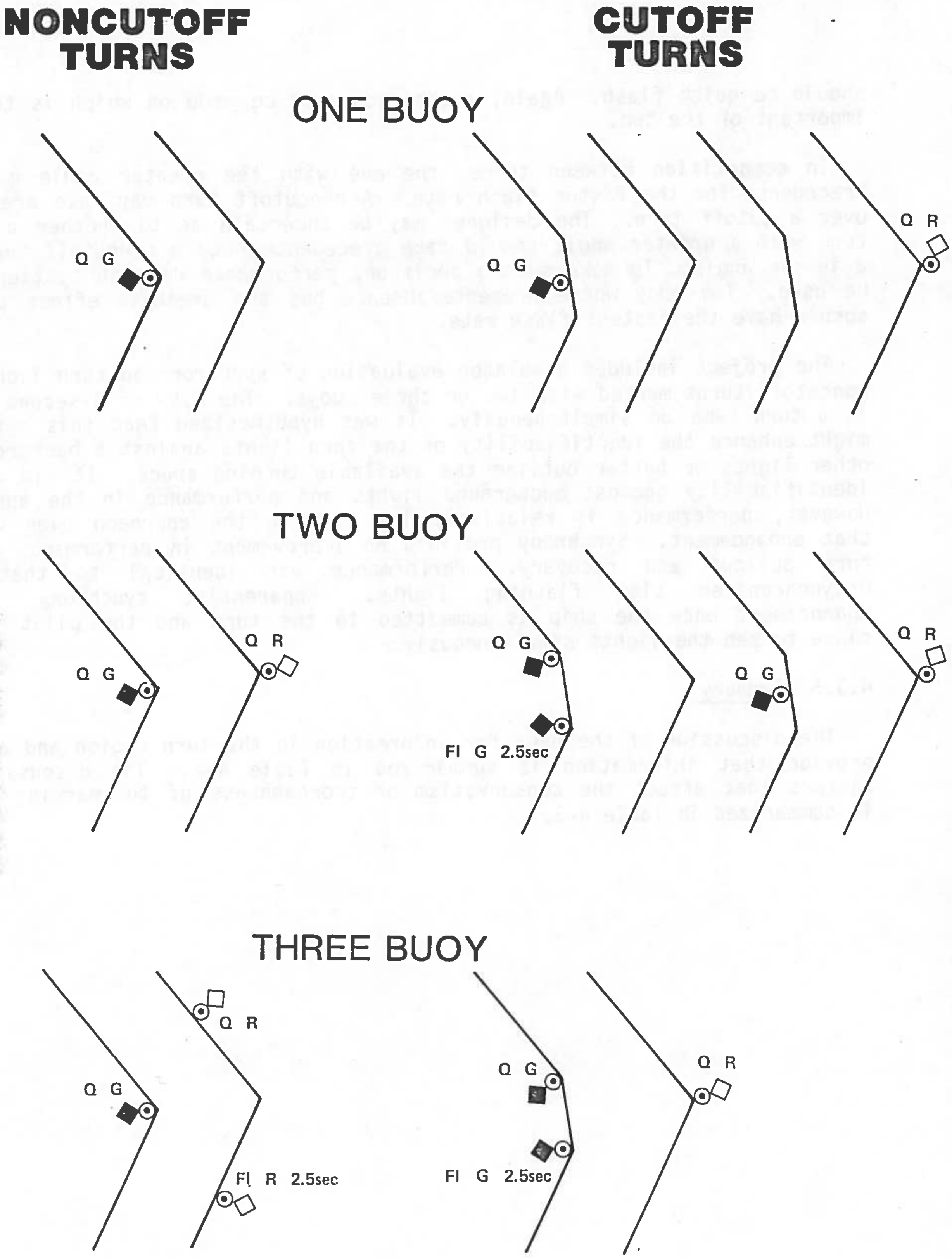
4.3.4 Turn Light Rhythms

Research has shown the increased conspicuity and information rate provided by the quick flash rhythm prompted significantly better nighttime performance than did slow flashing lights. Since the turn is the most demanding maneuver, the quick flash rhythm is most appropriate there. This finding supports our intuition and long-standing policy of marking turns and hazards with quick flashing lights. Generally speaking, lighted buoys in turns should be quick flashing.

In turns marked by more than one lighted aid on the same side of the channel, the designer may need to compromise some of the signal quality of the quick flash rhythm to improve identification. Possible arrangements appears in Figure 4-4. For a three-buoy noncutoff turn, the inside apex buoy and one of the other two aids should be quick flash, with the third having a slow flashing rhythm. The pullout buoy is more critical than the setup buoy and should be quick flash for the direction of transit that needs it most. Possibly, ships have a deeper draft while transiting in one direction than the other, or the background lights are more helpful or more confusing in one direction than the other. It could also be assumed that, for a ship transiting slightly to the right of the centerline of the channel, a left-hand turn will need a quick flash light for pullout more than would a right-hand turn.



For three-buoy cutoff turns the convention is to mark the outside apex light quick flash, making the turn apex identifiable in both directions. However, the ship does not turn around this light. One of the inside lights



NOTE:

1. IN SECTION 5, INSTRUCTIONS ARE GIVEN FOR THE APPLICATION OF PERFORMANCE DATA TO THESE DIFFERING ARRANGEMENTS.

Figure 4-4. Suggested Turn Light Rhythms should be quick flash. Again, a decision must be made on which is the most important of the two.

In competition between turns, the one with the greater angle may take precedence for the faster flash rate. A noncutoff turn may take precedence over a cutoff turn. The designer may be uncertain as to whether a cutoff turn with a greater angle should take precedence over a noncutoff turn with a lesser angle. To make such a decision, performance data in Section 5 can be used. The buoy whose presence/absence has the greatest effect on risk should have the fastest flash rate.

The project included simulator evaluation of synchronized turn lights for noncutoff turns marked with two or three buoys. The 2.5- or 4-second lights in a turn came on simultaneously. It was hypothesized that this synchrony might enhance the identifiability of the turn lights against a background of other lights or better outline the available turning space. It did enhance identifiability against background lights and performance in the approach. However, performance is relatively low risk in the approach even without that enhancement. Synchrony provided no improvement in performance in the turn pullout and recovery. Performance was identical to that with unsynchronized slow flashing lights. Apparently, synchrony is no enhancement once the ship is committed to the turn and the pilot is too close to see the lights simultaneously.

4.3.5 Summary

The discussion of the need for information in the turn region and aids to provide that information is summarized in Table 4-2. The discussion of factors that affect the conservatism or thoroughness of turnmarking needed is summarized in Table 4-3.

TABLE 4-2. NEED FOR INFORMATION IN THE TURN REGION AND THE AIDS THAT PROVIDE IT

	NEED FOR INFORMATION	AIDS
4.3.1	NONCUTOFF TURNS	
	Approaching the turn	
	1. alongtrack location of turn apex	inside apex buoy
	1a. alongtrack position before turn	set up buoy
	In the turn	
	2. crosstrack location of inside apex	inside apex buoy
	2a. crosstrack position in channel	outside apex buoy
	Pullout	
	3. crosstrack location of next leg	pullout buoy
	3a. relative motion during turn	pullout buoy
4.3.2	CUTOFF TURNS	
	Approaching the turns	
	1. general location of turn apex	anywhere on diagonal
	1a. extent of space available	at start of diagonal
	In the turn	
	2. extent of space for turn	at ends of diagonal
	2a. extent of space for a nonturn maneuver (traffic)	at outside apex
	Pullout	
	3. crosstrack location of next leg	at far end of diagonal
	3a. relative motion during turn	at far end of diagonal
4.3.3	BENDS	
	Supplement landmass	see CUTOFF TURNS
4.3.4	FLASH PATTERNS FOR LIGHTED AIDS	
	identifiability	different from nearby lights
	information rate	fastest flash

TABLE 4-3. FACTORS AFFECTING THE CONSERVATISM NEEDED IN TURN MARKING

FACTOR	EFFECT
Greater angle of turn	increases the need for the three-buoy turn
Larger ship size	increases the need for the three-buoy turn
Larger channel width	decreases the need for additional aids in turn
Nighttime	increases dependence on aids in turn
Meeting traffic	and ship size together affect the need for aids in turn
Reduced visibility	increases dependence on aids in turn

4.4 MARKING FOR THE RECOVERY REGIONS

In the recovery region, the pilot must counter the effects of the turn maneuver and choose and acquire a new track in the straightaway. This is dependent on the marking of the straightaway. An appropriate marking is one that allows him to do this with a precision sufficient for the conditions. The principles involved in designing the aid system are similar whenever the pilot needs to choose a new track and maneuver the ship to it. Such situations include recovery from a turn, maneuvering in crosstrack current or wind, and meeting or overtaking traffic. A system that is designed for one of these purposes is likely to be appropriate for the others.

Narrow channels in U.S. ports are generally marked by combinations of beacons, buoys, and ranges. For discussion here, the distinction between fixed beacons and floating buoys is not relevant. Aids off the channel edge were considered in Section 4.2.2 and will not be considered again. The discussion here is about "buoys", by which is meant any aid or sidemark on the channel edge. These are considered conservatively as acting alone. Ranges alone are also considered conservatively later in this section.

In U.S. ports the straight segments catalogued had a mean length of 1.90 nm, a mean width of 600 feet, and a mean depth of 37 feet. There was a relationship between the dimensions of a straightaway and the way it was marked. Each buoy arrangement is discussed below in the context of the channel dimensions in which it is likely to be found. While the data is not available, the relationship between channel dimensions and buoy arrangement suggest there is also a relationship between ship size and buoy arrangement.

Buoys on the channel edge appear at sea in three different arrangements. These are illustrated in Figure 4-5 and are as follows.

1. A <u>gated</u> arrangement where the buoys are opposite each other on a line perpendicular to the channel axis.

2. A <u>staggered</u> arrangement where the buoys appear alternately on opposite edges of the channel. ("Staggered" can be interpreted as representing any irregular arrangements.)

3. A <u>one-side</u> arrangement where the buoys are placed on only one edge of the channel.

At sea the mean distance over all arrangements between consecutive buoys on either side of the channel was 0.75 nautical miles (nm). For purposes of this manual two spacings were selected to bracket this distance. <u>Long spacing is 1.25 nm and short spacing is 0.625 nm</u>. Notice that the arrangements and spacings in Figure 4-5 differ in a systematic way in the alongtrack distance between a buoy on either side during a transit, in alongtrack distance between buoys on a single side, and in buoy density or the number of buoys needed to mark a nautical mile.

A first approximation to designing an aid system for the recovery region is the selection of one of the three arrangements; gated, staggered, or one side; in one of two spacings; long or short. Possibilities for each

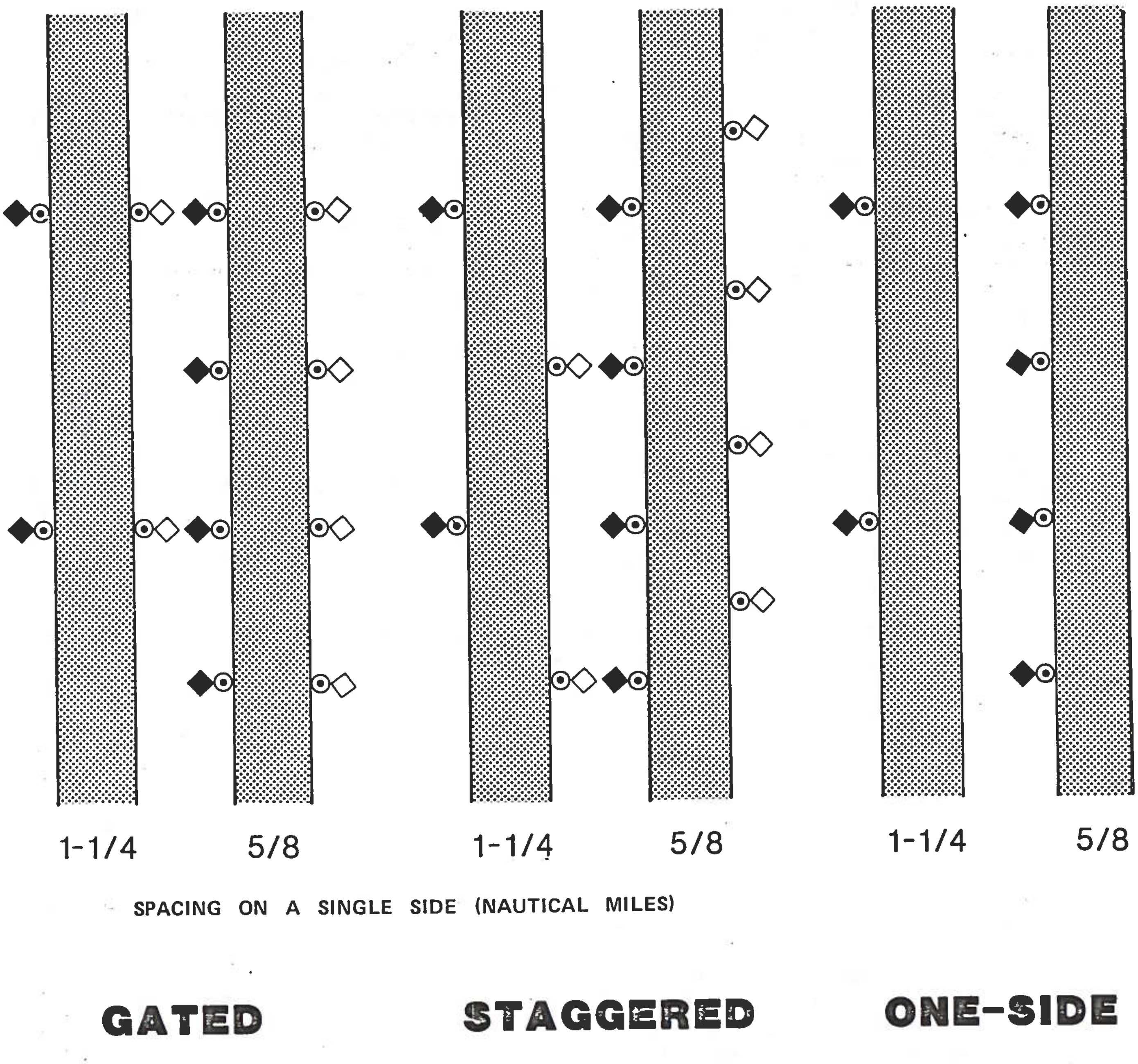


Figure 4-5. Alternative Buoy Arrangements for Straightaways

recovery region can be noted on the chart, on a copy of the chart, or on the worksheets at the end of Section 4. Actual buoy locations or spacings should not be selected until Section 4.6.

4.4.1 Gated Arrangements

Of the narrow channels examined that are marked by buoys (or aids on the channel edge) 38 percent of the total mileage was marked by gated arrangements. Channels marked by this arrangement tended to be the longest with a mean of 3.1 nm, and the widest, with a mean of 667 feet. While the data is not available, the use of a gated arrangement is probably associated with larger ships. The mean distance between gates was approximately 0.90 nautical miles (nm). This distance between consecutive aids during a transit was longer than that found with the other arrangements but gated arrangements were still associated with a somewhat greater buoy density (the number of buoys per nautical mile). Apparently, in designing aid systems there is both a tendency to try to extend the spacing of gates and a tendency to accept their cost when a need is perceived. The findings of the project provide support for both these tendencies: gates provide superior performance under a variety of conditions and this superior performance is relatively resistant to increases in spacing.

Gated buoys show superior performance because they help the pilot to find both the edges and the centerline of the channel. They mark the edge of the channel when he needs to maneuver close to it, but so do staggered buoys. Because they are opposite each other across the channel, gated buoys allow the pilot to "split the gates;" that is, to maneuver the ship so the jackstaff is centered in the gate(s) up ahead and to use that center as a short-term destination. As the ship nears the center of a gate, the pilot can compare his ship's distance to the buoy on either side and correct the track, if necessary. The pilot can make the comparative judgments of his jackstaff's position between the two buoys ahead, or of the ship's distance to the two buoys to either side, with much greater accuracy than he can judge the absolute distance off one buoy. Performance with this technique is resistant to increases in spacing.

The following are the factors to consider in deciding how conservative marking in the recovery region needs to be. Here, "conservative" means gates and, possibly, short-spaced gates. If the designer decides that any factor is so unfavorable as to require short-spaced gates, it is not necessary to consider other factors. Performance data in Section 5 will help in examining trade-offs among the factors.

1. The presence of current across the intended track of the ship is a major consideration in the marking requirement. (The manual assumes that following or head currents are not a problem for consideration.) In Section 5 the instruction for selecting performance data distinguish between a crosscurrent less and greater than the current requiring a crab angle of 2 degrees to compensate. That is, if the ship must steer a heading of more than 2 degrees off the channel bearing to maintain a track parallel to that bearing, there is a need for high buoy density to help in the recovery region for two reasons, First, crosscurrent is a shiphandling problem requiring adjustments to the ship's heading. Second, it prevents the

parallel orientation to the channel bearing that allows the pilot to make optimal use of the symmetry of the gates. The required crab angle for a channel can be calculated as:

$$CA = \tan^{-1}\left(\frac{\text{maximum crosscurrent component in knots}}{\text{expected transit speed in knots}}\right) \qquad (4\text{-}2)$$

Approximations to this calculation appear in Table 4-4.

For the purposes of this manual the following rules apply:

- If CA is calculated as 0 to 2 degrees, the crosscurrent is minimal and need not be considered.
- If CA is calculated as 2 to 5 degrees, the crosscurrent requires conservative marking and conservative selection of performance data.
- If CA is calculated as greater than 5 degrees, the crosscurrent is substantial and the performance data in Section 5 may not apply.

If sufficient information on current is not available to calculate the crab angle with any certainty, the judgment of the pilots as to whether they consider crosscurrent a problem is the most appropriate substitute.

2. The speed of the transit is a factor in a crosscurrent situation. Pilots may prefer to increase the speed to decrease the effect of the crosscurrent. If they do this, they may decrease the crab angle; but at a higher speed they are more dependent on the aids for timely information during recovery. The selection of an appropriate speed for conditions should be the responsibility of the pilot. The responsibility of the aid system designer is to provide appropriate aids for the crosscurrent and the ship size.

3. Wind across the track may be a shiphandling problem. It will set and twist a ship depending on the size and shape of its sail area; and when gusting, it will add unpredictability to the behavior of the ship. When winds across the track are frequent or strong, marking should be conservative.

4. The effect of nighttime is not as great or as consistent in the recovery region as it is in the turn region. However, if there are other negative factors present, nighttime increases the overall difficulty. Frequent nighttime transits under unfavorable conditions suggest a need for conservative marking.

5. Ship size as a factor has already been considered in Section 3.3.2 in specifying the length of the recovery region. The length of the recovery region for a large ship from turns at either end of the straightaway may mean that a whole straightaway is a recovery region. This designation alone suggests a relative conservatism in design and in the selection of performance data. Within the recovery region the larger ship is best served by the short-term destination which gates ahead provide. The larger ship

TABLE 4-4. CRAB ANGLE AS A FUNCTION OF MAXIMUM CROSSCURRENT COMPONENT (KNOTS) AND EXPECTED TRANSIT SPEED (KNOTS)

TRANSIT SPEED KNOTS	Maximum Crosscurrent Component (Knots)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
6	≤2	≤2	2-5	2-5	2-5	≥5	≥5	≥5	≥5	≥5
7	≤2	≤2	2-5	2-5	2-5	2-5	≥5	≥5	≥5	≥5
8	≤2	≤2	2-5	2-5	2-5	2-5	≥5	≥5	≥5	≥5
9	≤2	≤2	≤2	2-5	2-5	2-5	2-5	≥5	≥5	≥5
10	≤2	≤2	≤2	2-5	2-5	2-5	2-5	2-5	≥5	≥5
11	≤2	≤2	≤2	2-5	2-5	2-5	2-5	2-5	2-5	≥5
12	≤2	≤2	≤2	≤2	2-5	2-5	2-5	2-5	2-5	2-5
15	≤2	≤2	≤2	≤2	≤2	2-5	2-5	2-5	2-5	2-5

Note:

$$\text{Crab angle} = \tan^{-1}\left(\frac{\text{maximum crosscurrent component (knots)}}{\text{expected transit speed (knots)}}\right)$$

takes longer to respond, which requires the pilot to initiate heading changes sooner to achieve the same track. Earlier initiation requires earlier judgment of the ship's position and velocities. Earlier judgment requires shorter buoy spacing. The pilot on the larger ship with its higher height of eye may be able to see multiple gates ahead but this does not substitute for passing the buoys close aboard. The larger the ship size, the greater a need for shorter spacing in the recovery region.

6. Channel width is a major determiner of what constitutes a large ship. If the channel is wide for the ship size, the pilot can safely take longer to detect and correct crosstrack error and the requirement for passing buoys is reduced.

7. Meeting traffic may be a consideration in the recovery region. While pilots on large ships prefer to meet after they have recovered from a turn, for a large ship in a short straightaway that wait may not be possible. For such cases the straightaway should be marked for the best possible recovery with relative short spacing coming out of the turns.

8. Visibility is a factor in the marking of the recovery region. First, when visibility is reduced, landmarks and aids off the channel edge do not contribute and the pilot is forced to depend on the closer buoys. Second, the visibility expected is obviously a factor in the spacing of buoys. The selection of buoys of sufficient size and contrast to be detected for visibility conditions is considered in Aids to Navigation Manual - Technical (COMDTINST M16500.3). Coast Guard standards for detection appear in Aids to Navigation Manual - Administration (COMDTINST M16500.7). This manual assumes that for visual piloting the spacing between gates is shorter than the detection distance 100 percent of the time. If reduced visibility is frequent, preference should be given to the shorter of alternative spacings considered. Generally, a system designed conservatively for visual piloting will be appropriate for reduced visibility requiring radar piloting. Section 7 provides assurance for this.

4.4.2 Staggered Arrangements

In U.S. harbors staggered arrangements marked 12 percent of narrow channel mileage. Channels so marked tended to be shorter, narrower, and shallower than channels marked by gated arrangements. The mean spacing for staggered arrangements was 0.69 nm between consecutive aids to either side or 1.38 nm between aids on a single edge of the channel. Compared to the 0.90 nm spacing of gates, staggered buoys required a lower buoy density, or number of buoys per nautical mile. The smaller number of buoys was probably the intent in using this arrangement. If the smaller channels meant that staggered arrangements were associated with smaller ships, this may be appropriate.

The analysis of performance for staggered arrangements was done using the same channel and ship size as the gated arrangements so that direct comparisons could be made. With staggered arrangements performance is generally more sensitive to spacing. With short spacing (0.62 nm on a single side), pilots try to approximate the techniques they use with gates. They direct the ship to the centerline of the channel up ahead as they perceive it between the asymmetrically-placed buoys, and they adjust the ship's track as they pass a buoy abeam to the extent that they can recall the distance to the last opposite-side buoy. With undemanding conditions this performance can approximate that of gated buoys. However, with short spacing there is no savings in buoys over gates (see Figure 4-5) and, under more demanding conditions like crosstrack wind and current, even long-spaced gates are superior to any staggered arrangement.

With long-spaced staggered buoys the pilots cannot and do not try to approximate the techniques they use with gated buoys. Instead, they use one buoy at a time, or "buoy-hop". They choose a heading that puts the jackstaff just inside the buoy up ahead and maintain that heading until they are close to the buoy. Then they change the heading to put the jackstaff just inside the next buoy. They keep the ship in the channel with no attempt to find the channel edge or centerline. Given this technique, performance is sensitive to unfavorable circumstances. (Visual piloting is so preferred by pilots that they use this technique rather than switch to radar to compensate for low buoy density.)

The only condition where a staggered arrangement is superior to gated is when visibility or detection distance is less than gate spacing with radar not available. This would not be the case with a large ship. The analysis of existing arrangements at sea and the simulator performance data converge in suggesting that staggered arrangements are for small vessels.

Staggered arrangements should be considered for large ships only when conditions are not demanding and when a savings over a gated arrangement is possible. See the discussion in Section 4.4.1 on gated arrangements for the factors that make conditions in the recovery region demanding.

4.4.3 One-Side Arrangements

In U.S. harbors 17 percent of straight channel mileage was marked by buoys along one side. The percentages of occurrence of arrangements discussed do not total 100 percent. The remaining mileage was marked by combinations or had no buoys (or fixed aids) on the channel edge. The channels marked on one side tended to be wide and short. The mean length of such channels was 1.7 nm and the mean spacing was 0.75 nm. The last two statistics imply that the one side arrangement frequently occurred as a single buoy between turns, not as a row of single buoys over a long distance. For a short, wide straightaway with the turn buoys visible, the one buoy may be appropriate.

The analysis of performance or one-side arrangements was done using the same channel and ship size as the other arrangements so that direct comparisons are possible. For one-side arrangements the pilot has only one technique available: that is, to choose a distance off a buoy and try to maintain it. This technique is not sensitive to spacing but is very sensitive to crosscurrent and wind. This means that it is not a general purpose arrangement and it is probably not appropriate for meeting traffic.

One-side arrangements should be considered only when conditions are undemanding and when a savings over other arrangements is possible. See the discussion in Section 4.4.1 on gated arrangements for the factors that make conditions in the recovery region demanding. The analysis of existing markings at sea suggests it should be used only where turnmarking on the other side of the channel is visible most of the time.

4.4.4 Ranges

In U.S. ports, straight channel mileage was marked by ranges alone only 1 percent of the time and by ranges with buoys, beacons, or both, 48 percent of the time. These statistics mean that the superior performance of a range was provided for recovery in about half of the cases, but that other aids were available when visibility was too short to make use of the range.

The use of a range is discussed in some detail in Section 4.2.3 under "System Elements" and will not be repeated here. Note that ranges are not always higher performers than buoys. There is overlap between higher-performing buoy systems and lower-sensitivity ranges. Performance data in Section 5 illustrates this overlap.

Because of the dependence of ranges on visibility, the aid system designer should consider the aids in each recovery region separately as a range system and as a buoy system. Section 5 presents separate performance data for ranges and for buoys.

4.4.5 Summary

The alternative arrangements for marking a recovery region with buoys that were considered are summarized in Figure 4-5. Ranges are another possibility and should be considered separately.

A number of factors were considered that determine the need for conservative marking in the recovery region. "Conservative" here means gated buoys, possibly short-spaced gated buoys, or ranges. The factors are summarized in Table 4-5.

4.5 MARKING FOR THE TRACKKEEPING REGIONS

The trackkeeping region encloses the channel segment in which the pilot is satisfied with the ship's track in the channel and does not need to leave that track. It is the least demanding of all maneuvers. For this reason, he does not need precise knowledge of the channel edges. He needs only enough aids to give him a short-range destination up ahead.

The possibilities for marking a trackkeeping region are the same as those suggested for marking a recovery region: that is; gated, staggered, or one-side buoys; with long or short spacing. These possibilities are illustrated in Figure 4-5. Ranges are again a possibility. Because the need for information from aids is less, less conservative or lower-performing alternatives may be selected. For example, longer-spaced gates, staggered arrangements, or low-sensitivity ranges may be sufficient. Performance data in Section 5 may be used to examine the trade-off between the lower risk region and the lower performing aid arrangements.

TABLE 4-5. FACTORS AFFECTING THE CONSERVATISM NEEDED IN MARKING THE RECOVERY REGION

FACTOR EFFECT

Crosstrack current has a major effect because it requires a crab angle.

Speed should be selected by the pilot for conditions.

Wind across the track is a factor if frequent or strong.

A nighttime transit is more difficult when other negative factors are present.

Ship size has a major effect on recovery length and difficulty.

Increased channel width relative to ship size decreases the need for aid density.

Meeting traffic during recovery has a major effect.

Visibility has a major effect on spacing needed.

A first approximation to designing an aid system for the trackkeeping region is the selection of one of the three arrangements; gated, staggered, or one-side; in one of two spacings; long or short. Possibilities for each trackkeeping region can be noted on the chart, on a copy of the chart, or on the worksheets at the end of Section 4. Actual buoy locations or spacing should not be selected until Section 4.6.

The factors discussed in Section 4.4.1 and summarized in Table 4-5 are relevant in the trackkeeping region as well. Three are of special interest.

1. If crosstrack wind or current are changing or unpredictable, the ship is not trackkeeping; the region should be marked for recovery.

2. Meeting traffic means that the pilot will have to maneuver to a new track. This maneuver is less of a problem during trackkeeping than during recovery but still requires more information on crosstrack position (ranges or gated buoys) or channel edge (buoys of at least moderate spacing).

3. Visibility is always a factor in possible aid spacing. Spacing should not be longer than the limits set in the Aids to Navigation Manual - Administrative (COMDTINST M16500.7), Chapter 4, for trackkeeping.

4.6 MARKING THE WATERWAY

For a first approximation to aid system design, one or more alternative arrangements were selected for each region and noted on the chart or a copy of the chart. When this selection is completed for an entire waterway, the next step is to select buoy locations for those arrangements. This can only be done on a chart or a copy of a chart. The designer may want to do more than one design for a waterway. For example, one design might be conservative for each region; while a second design is less conservative in each region. Some selections for regions may have effects on other regions. For example, a one- or two-buoy turn marking leaves more of the channel for straightaway marking than does a three-buoy turn. Different trade-offs are possible between buoys and ranges in waterways where visibility is not a problem or where ice makes buoys unworkable.

In marking the waterway, the TURN REGIONS should be marked first.

1. For noncutoff turns the alternatives are discussed in Section 4.3.1 and summarized in Figure 4-2. Locations for buoys in one- and two-buoy turns are obvious. For three-buoy turns, the setup and pullout buoys should be between 2000 feet and the 0.50 nm limit of the turn region. The more difficult the turn, the closer they should be to 2000 feet. The factors determining difficulty are discussed in Section 4.3.1 and are summarized in Table 4-3.

2. For cutoff turns the alternatives are discussed in Section 4.3.2 and summarized in Figure 4-3. If the dredged area is to be outlined, the locations are determined. Any other placement is left to the discretion of the designer.

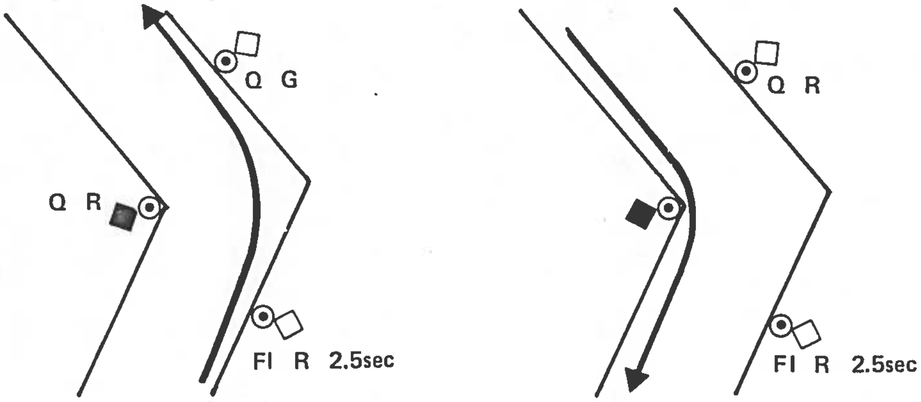
3. For bends the possibilities are discussed in Section 4.3.3. Both the number and location of aids must be left to the discretion of the designer.

The RECOVERY REGIONS should be marked next. Consideration must be given to the marking in the adjacent turn region(s), to the presence or absence of a trackkeeping region, and to the overall length of the straightaway. To ensure continuity of marking, spacing for recovery region buoys should be measured from the last buoy in the turn region. Sparse marking in the turn region may suggest that the recovery buoys need to be closer. For a one-buoy turn, the first recovery buoy(s) has a pullout function. For a cutoff turn, even if it is marked with three buoys, the recovery buoys will serve the pullout function. If a turn marked with an odd number of buoys, 1 or 3, is to be followed by staggered or one-side buoys, the first recovery buoy should be on the opposite side of the channel from the last turn buoy.

In a straightaway that does not have a trackkeeping region the distance between turn buoys should be divided into equal spacings for gates (or for staggered or one-side buoys). This division may suggest an adjustment of a setup or pullout buoy location in preceding or following turn regions. The design of marking for a straightaway may reduce to a decision as to whether or divide it by one, two, or three gates. The factors to consider in the decision are discussed in Section 4.4.1 and were summarized in Table 4-5.

If a straightaway has a TRACKKEEPING REGION, it may be possible to increase the spacing or decrease the buoy density from that in the recovery region. The longer spacing might be twice the shorter spacing, or might go to some larger division or multiple of a nautical mile. Any selection of longer spacing for the trackkeeping regions should be considered carefully in terms of strong or unpredictable crosstrack wind or current, meeting traffic, or reduced visibility.

As a next step, the waterway system should be examined for its effectiveness in both directions. The need for aids may not be the same for both directions. Possibly features on land are more helpful or more confusing in one direction than the other. Bank effects may be more helpful in one direction. Wind or current may be more of a problem. Large ships may be consistently more heavily-loaded in one direction: that is, commerce in a port may involve bringing oil or bulk cargoes in or out. When there is a likelihood of meeting traffic close to a turn, turns may be made differently in one direction than the other. For a right-hand turn, the pilot will prefer to keep the ship to the inside both to minimize the turn radius and to prepare for meeting traffic. For a left-hand turn the pilot cannot cross to the inside to minimize the turn radius if he expects to meet traffic very soon out of the turn. In this case he is more dependent on a pullout buoy.



If the designer decides that the need is the same in both directions, he should assure himself that the aid system is equally effective in both directions. For example, aid spacing in a straightaway should be appropriate for recovery from both adjacent turns. Ranges are conservatively assumed to be less effective as back ranges.

As a final step, flash rhythms should be selected for any new lighted buoys. Guidelines for the selection appear in Section 4.3.4 with a summary in Figure 4-4. The flash rhythms should promote identification in both directions.

The procedure in this section was prepared for DESIGN, or the generation of new aid systems for a waterway. If the system designer's intention was design and if one clearly preferred system resulted, the design is complete. If there is not one clearly preferred system, the quantitative performance data in Section 5 will be helpful in choosing among alternatives. If meeting traffic or reduced visibility are particular problems in a waterway, Sections 6 or 7, respectively, may be helpful in choosing among alternatives.

If this section was used for a preliminary EVALUATION, the designer, should go on to Section 5 to assign quantitative performance data to each region as marked. The assignment of a relative risk factor value to each region is a necessary preparation for the management procedures in Section 9.

SECTION 5. EVALUATION PROCEDURE FOR AIDS TO NAVIGATION SYSTEMS PERFORMANCE

Section 5
EVALUATION PROCEDURE FOR AIDS TO NAVIGATION SYSTEMS PERFORMANCE

5.1 INTRODUCTION

The primary purpose of this section is evaluation. This section provides a quantitative measure of quality of an aids to navigation system. This measure can be used to serve a number of objectives.

1. To establish priorities in the waterway. Evaluating all the regions in a waterway will reveal those that have conspicuously higher or lower risk. Those that have higher risk can be assigned priority for additional resources. Those that have conspicuously lower risk can be considered for reduction in service.

2. To supplement the qualitative design guidelines. If the qualitative design guidelines of Section 4 resulted in competing alternative arrangements, a measure of quality for each assists in selecting among them. If only some regions of the waterway are in doubt, it is possible to calculate measures only for the competitors in those regions rather than for the whole channel.

3. To prepare for management procedures described in Section 9. The management procedures described in Section 9 require quantitative measures for the waterway under a number of conditions. Evaluation of the quality of the system as marked is basic to all the management procedures.

Some preparation is necessary in order to apply the procedures in this section. The background material on the performance data and performance measures in Section 2 is recommended but not essential. The specification of local waterway conditions and the division of the waterway into regions by the instructions in Section 3 is essential to the use of this section. The qualitative discussion of how conditions affect performance presented in Section 4 is recommended but not essential. The present section contains instructions for the selection of performance data for conditions with little discussion of the material in the earlier sections.

This section is organized to parallel Section 4. It is divided for the turn, recovery, and trackkeeping regions. For each region, there are instructions and tables for calculating a measure of quality, the relative risk factor, RRF. There are instructions for selecting baseline data expressed as crosstrack means and standard deviations, for correcting the data for the ship size and channel width of interest, for adjusting for the ship's crab angle in the channel, for calculating the number of standard deviations that will fit between the extreme points of the ship and the channel edge to either side, and, finally, for converting those last measures to probabilities. During this procedure, the system designer is offered options for either adjusting the calculations to the exact parameters of this situation or accepting standardized values to save steps. The designer must decide how important precision is to his purpose.

The present section contains data for evaluating an aids to navigation system under several different conditions. The manual follows Chapter 4 of the Aids to Navigation Manual - Administration (COMDTINST M16500.7) in calling those conditions, which affect the availability of the aids to the mariner, "subsystems". The subsystems considered in this section are the following.

1. visibility sufficiently long to detect both range structures (if present)

2. daytime with visibility of 1-1/2 nautical miles or just long enough to detect the longest spaced aids

3. nighttime with visibility of 1-1/2 nautical miles or just long enough to detect the longest spaced aids

Evaluating each subsystem will point out the strengths and weaknesses of the aid system and show the system designer where his efforts should be directed. The separate evaluations are also a preparation for the management procedures of Section 9. The system designer may use the performance data for radar in Section 7 or radio aids in Section 8 to evaluate the aid system under conditions of reduced visibility.

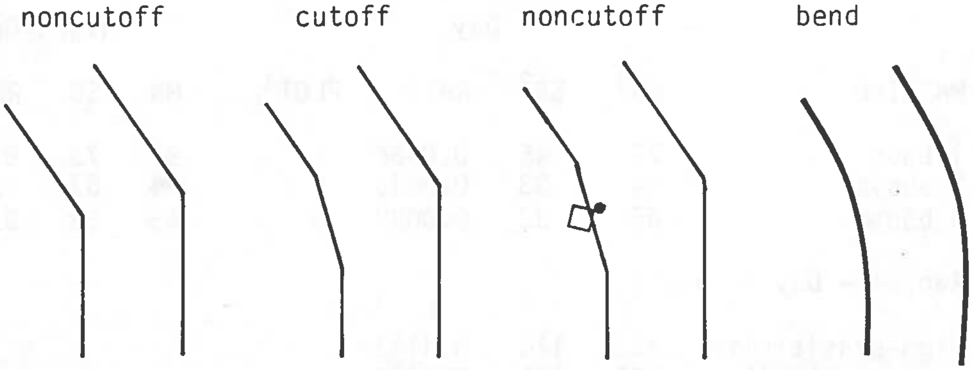
5.2 EVALUATION OF PERFORMANCE IN THE TURN REGIONS

This section contains instructions and data tables for calculating a relative risk factor (RRF) value for each turn region. Instructions for specifying the turn regions appear in Section 3.3.1. The performance data given here to represent the turn region was taken several thousand feet beyond the apex where the ship is slipping towards the outside of the turn and is at its maximum risk of grounding.

5.2.1 Selection of Baseline Data

The method of calculating the RRF uses "baseline" performance data for a 30,000 dwt ship in a 500-foot channel and "corrects" it for other ship sizes and channel widths. This subsection contains instructions for the selection of baseline data from Table 5-1 for each turn region. The steps are summarized in Worksheet 5-1 which can be copied for each turn region and design alternative. The experienced designer may prefer not to use this worksheet but to enter baseline data on Worksheet 5-2.

1. Turn Configuration.* Performance data are presented in Table 5-1 for both noncutoff and cutoff turns. These configurations are discussed in Section 4.3 and are illustrated here. Select the appropriate configuration for each turn region.



- A noncutoff turn is one that allows only the width of the straight channel segments for the turn.

- A cutoff turn is one that has been widened by dredging, generally at the inside apex of the turn. If a turn is dredged as a cutoff, but has a buoy set into the cutoff area, it should be considered a noncutoff turn.

- A bend may be considered a cutoff for the purpose of selecting performance data. The data will overestimate risk to the extent that the turn radius is longer than any allowed by a cutoff (continued on page 5-8)

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*Risk in Table 5-1 is consistent within a dredging configuration but not necessarily between configurations. The noncutoff >20 degree turns were run on a different simulator and with a different pilot group than the others. Unexpectedly high risk in cutoff turns relative to noncutoff turns reflects a shift in the pilots' standard of caution with turn configuration.

TABLE 5-1. BASELINE PERFORMANCE DATA FOR TURN REGION

NONCUTOFF TURNS 0-20 degrees

	Day				Night/Dusk/Dawn			
MARKING	MN[1]	SD[2]	RRF[3]	PLOT[4]	MN	SD	RRF	PLOT
1 buoy	8	50	0.0003	1	28	99	0.0760	2
2 buoys	8	50	0.0003	1	28	99	0.0760	2
3 buoys	8	50	0.0003	1	27	63	0.0070	3
Ranges - Day or Night								
High-sensitivity	22	94	0.0582					
Low-sensitivity	34	139	0.2107					

NONCUTOFF TURNS 20 degrees

	Day				Night/Dusk/Dawn			
MARKING	MN[1]	SD[2]	RRF[3]	PLOT[4]	MN	SD	RRF	PLOT
1 buoy	72	45	0.0068	4	94	73	0.1113	5
2 buoys	94	33	0.0035	6	94	67	0.0918	7
3 buoys	65	33	0.0002	8	65	56	0.0174	9
Ranges - Day or Night								
High-sensitivity	132	170	0.4143					
Low-sensitivity	207	251	0.5965					

---

1. Means (MN) are expressed as feet from channel centerline with positive values to the outside of the turn.

2. Standard deviations (SD) are in feet.

3. The relative risk factor (RRF) was calculated using the instructions in Section 5.2.3 and the standard conditions in Table 5-2.

4. Plot numbers refer to RRF plots in Section 5.2.2

TABLE 5-1. BASELINE PERFORMANCE DATA FOR TURN REGION (CONTINUED)

CUTOFF TURNS 0-20 degrees

	Day				Night/Dusk/Dawn			
MARKING	MN	SD	RRF	PLOT	MN	SD	RRF	PLOT
1 buoy	-58	86	0.0243	NA	-95	83	0.0489	NA
2 buoys	-5	36	0.0000	NA	2	76	0.0097	NA
3 buoys	-5	36	0.0000	NA	2	76	0.0097	NA
Ranges - Day or Night								
High-sensitivity	22	94	0.0582					
Low-sensitivity	34	139	0.2107					

CUTOFF TURNS 20 degrees

	Day				Night/Dusk/Dawn			
MARKING	MN	SD	RRF	PLOT	MN	SD	RRF	PLOT
1 buoy	-88	93	0.0612	10	-61	148	0.1725	11
2 buoys	-6	41	0.0000	12	-14	76	0.0068	13
3 buoys	-6	41	0.0000	12	-14	76	0.0068	13
Ranges - Day or Night								
High-sensitivity	132	170	0.4143					
Low-sensitivity	207	251	0.5965					

1. Means (MN) are expressed as feet from channel centerline with positive values to the outside of the turn.

2. Standard deviations (SD) are in feet.

3. The relative risk factor (RRF) was calculated using the instructions in Section 5.2.3 and the standard conditions in Table 5-2.

4. Plot numbers refer to RRF plots in Section 5.2.2

WORKSHEET FOR EVALUATION OF THE TURN REGION: SELECTION OF BASELINE DATA (SHEET 1 OF 2)

Instructions in Section 5.2.1.

Copy for each design/evaluation objective and turn region.

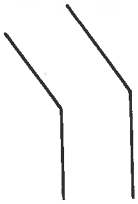
Design/Evaluation Objective:____

____

Turn Identification:____

1. Turn Configuration: (check one)

Noncutoff



Cutoff

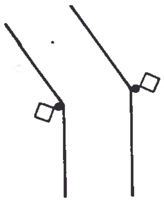
Bend

2. Angle of Turn: (check one) 0-20 degrees >20 degrees

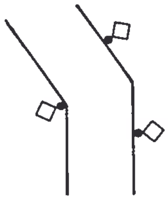
3. Aid Arrangement: (check one)

Noncutoff

one-buoy

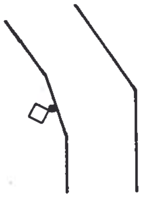


two-buoy

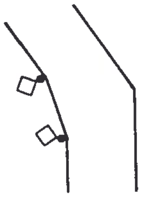


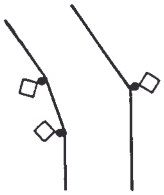
three-buoy

Cutoff



one-buoy





two- or three-buoy

4. Range Sensitivity, K: (check one) high (K>3) low (K<3)

[WxR]/[D(H-h)] = K

[x]/[(-) = ( )

reminder:
K: sensitivity
W: width (ft)
R: between structures (nm)
D: to front structure (nm)
H: rear structure (ft)
h: front structure (ft)

Worksheet 5-1

WORKSHEET FOR EVALUATION OF THE TURN REGION: SELECTION OF BASELINE DATA (SHEET 2 OF 2)

5. SELECT BASELINE DATA:

	MN	SD	RRF
Day	____	____	____
Night/dusk/dawn	____	____	____
Range	____	____	____

For cutoff turn only, MN for corresponding noncutoff turn (see instructions in Section 5.2.1):

Day ____

Night/dusk/dawn ____

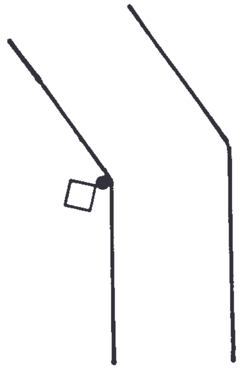
Worksheet 5-1 (Continued)

turn, to the extent that the pilot can see close land, and to the extent that he can use bank effects to guide the ship. The system designer should note on the worksheet that risk is overestimated when selecting cutoff turn data to represent performance in a bend.

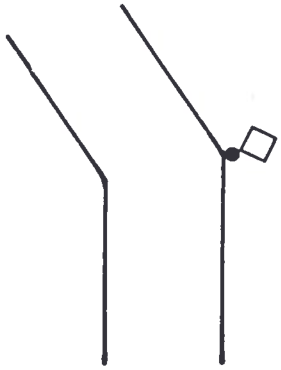
2. Angle of turn*. For each turn configuration, data is presented for turns 0-20 degrees and greater than 20 degrees. Select one of these alternatives for each turn region. For a bend the angle of turn is the change in course from one straight segment to the next.

3. Aid arrangement. Performance data for each turn configuration and angle of turn is further divided for the number of buoys in the turn. Buoy location as well as number is important. The following rules for selection of data follow from the discussion in Sections 4.3.1 and 4.3.2. If the turnmarking includes unlighted buoys, select day and night performance data separately. For day consider both lighted and unlighted buoys; for night consider only the lighted buoys.

- For a noncutoff turn with one buoy to the inside apex, use the one-buoy data.



- For a noncutoff turn with one buoy on the outside apex or anywhere else in the turn region, use the one-buoy data with a note that risk is underestimated.



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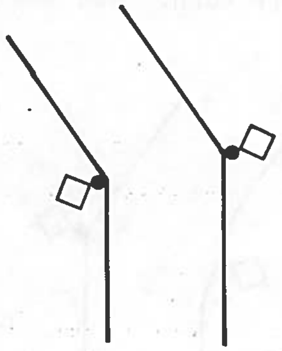
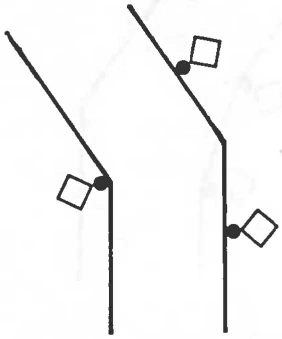
*Angle of turn is treated in Table 5-1 as a two-part variable. The system designer whc has a particular need to evaluate turn angle can use the data here to represent the 15- and 35-degree turns and do a linear interpolation on the means and standard deviation to find performance data for the turn angle in which he is interested.

- For a noncutoff turn with two buoys arranged as a gate on the inside and outside apex, use the two-buoy data.



- For a noncutoff turn with two buoys in the turn region but in other locations than at the inside and outside apex, read Section 4.3.1 and decide whether it is best represented by the one- or two-buoy turn and whether risk is under- or overestimated by the data chosen.

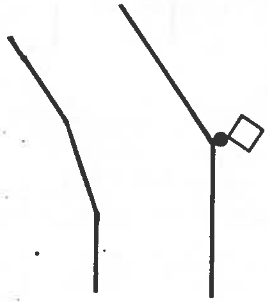
- For a noncutoff three-buoy turn with buoys arranged as illustrated with the distance of the two outside buoys between 2000 feet and 0.50 nautical miles (nm) from the outside apex, use the three-buoy data.



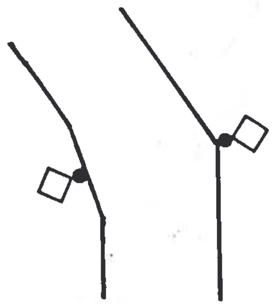
- For a noncutoff three-buoy with the buoys arranged in some other way than illustrated, read Section 4.3.1 and decide whether it is best represented by a one-, two-, or three-buoy turn and whether risk is under- or overestimated by the data chosen.

- For a cutoff turn with one buoy anywhere <u>on</u> the diagonal, use the one-buoy data. (If the one buoy is set inside the diagonal, consider it a noncutoff turn.)

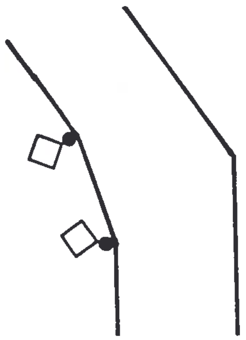
- For a cutoff turn with one buoy on the outside apex use the one-buoy data with a note that risk is underestimated.



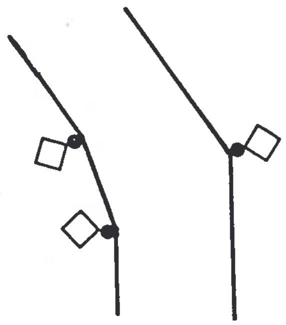
- For a cutoff turn with two buoys arranged with one on the diagonal and one at the outside apex, use the one-buoy data. Note on the worksheet that risk is overestimated. (If the inside buoy is set inside the diagonal, consider it a noncutoff turn. Use two buoy data.)



- For a cutoff turn with buoys placed on the ends of the diagonal, use the two-buoy data. Note that risk may be underestimated.



- For a cutoff turn with three buoys, two outlining the cutoff area and one on the outside apex, use the three-buoy data.



- For a cutoff turn with three buoys arranged in some other way, read Section 4.3.2 and decide if it is a one-, two-, or three-buoy turn and if risk is over- or underestimated by the data chosen.

- For bends read Section 4.3.2 and 4.3.3 and use the most appropriate cutoff data with a note that risk is probably overestimated.

4. Ranges as turn marking. Calculate range sensitivity as follows:

$$K = [WR]/[D(H-h)] \tag{5-1}$$

where:
K = lateral sensitivity
W = channel width (feet)
R = distance between structures (nautical miles)
D = distance from front structure to center of turn
H = height of rear structure (feet)
h = height of front structure (feet)

- If K is equal to or greater than 3, use high-sensitivity range data.
- If K is less than 3, use low-sensitivity range data.

Use range data tabled for either noncutoff turns or cutoff turns.

5. SELECT BASELINE DATA: Select baseline data for the following conditions and enter on worksheet.

	Mean	Standard Deviation	Relative Risk Factor
Day	____	____	____
Night/Dusk/Dawn	____	____	____
Ranges (Sufficient Visibility)	____	____	____

If the designer intends to calculate the relative risk factor value for his specific condition rather than using precalculated values, and he is considering cutoff turns, he will need additional data. He will also need the baseline mean for the noncutoff turn chosen to correspond to the cutoff turn by the following rules. The use of this data is described later.

- For a cutoff turn with one buoy to the inside or the outside or one buoy to each side, use the mean for a noncutoff turn of the same angle, the same day or night condition, and one buoy.

- For a cutoff turn with two buoys marking the inside diagonal or three buoys outlining the cutoff area, use the mean for a noncutoff turn of the same angle, the same day or night condition, and three buoys.

5.2.2 Use of Precalculated Relative Risk Factor (RRF) Values

Several options are available for arriving at a relative risk factor (RRF) value. The simplest option is to use the RRF values in the baseline data tables in Section 5.2.1. Another possibility is to take a value from the plots presented in this subsection. The most precise and most time-consuming option is to calculate a value by the instructions given in Section 5.2.3. Caution must be exercised in comparing values obtained in different ways. The discussion of each option includes the comparisons that are appropriate.

The RRF values in the baseline data Table 5-1 were calculated for a 30,000 dwt ship in a 500-foot channel. The values of the mean and standard deviation of each condition considered are given in that table. The parameters of the ship and channel used in the calculations in Table 5-1 appear in Table 5-2, along with a sample calculation for the first entry.

The baseline RRF values can be used in a number of situations.

- The baseline RRF values are obviously appropriate when the standard ship and channel parameters match the waterway parameters.
- If the objective is to compare among aid alternative or subsystems within a single region, the baseline RRF values may be used. Within a single region, if the standard ship and channel parameters do not match the waterway parameters, they will have a constant difference from the true values for all the alternatives being compared.
- The baseline RRF values may be used for preliminary comparisons between regions of a waterway or between waterways if the baseline values maintain a constant difference from true values for all the conditions being compared. For example, if the waterway is a consistent 600 feet wide and transited by a 50,000 dwt design vessel, the baseline values may be used. However, if the widths of the waterway regions vary or if the ship size varies between waterways, such comparisons are not appropriate. For example, the baseline values should not be used to compare 500- and 600-foot wide segments or transits by 30,000 and 50,000 dwt ships. The baseline values would not be equally good approximations for all conditions.

To simplify calculations for the system designer, some conditions represented by baseline data in Table 5-1 are also represented by plots extrapolating the baseline data over ship size and channel width. To maximize the usefulness of the relatively fewer plots, they were prepared either for conditions that appear at sea with a high frequency or for conditions that are of high risk and, therefore, are expected to receive attention. For the turn regions the plots appear as Plots 5-1 to 5-13. Note that on each plot, the value for a 30,000 dwt ship in a 500-foot channel corresponds to a baseline value in Table 5-1. In that table the baseline values that correspond to a plot are indicated by the number of the plot.

In order to precalculate the RRF values, parameter values for the ship and channel were standardized. The parameters for ship size used appear in

TABLE 5-2. PARAMETERS OF SHIP AND CHANNEL USED FOR BASELINE RELATIVE RISK FACTOR (RRF) VALUES IN THE TURN REGION AND A SAMPLE CALCULATION

SHIP PARAMETERS

Ship size	30,000 deadweight tons (dwt)
Ship length	590 feet
Ship beam	85 feet
Crosstrack current to representation forces	0.50 knots
Transit speed	6 knots
B' (feet)	67 feet

CHANNEL PARAMETERS

Channel width	500 feet
Direction of turn	left*
Extra width for cutoff	50 feet to inside of turn

SAMPLE CALCULATION OF RRF: Noncutoff, 20 degrees, day, 1 buoy

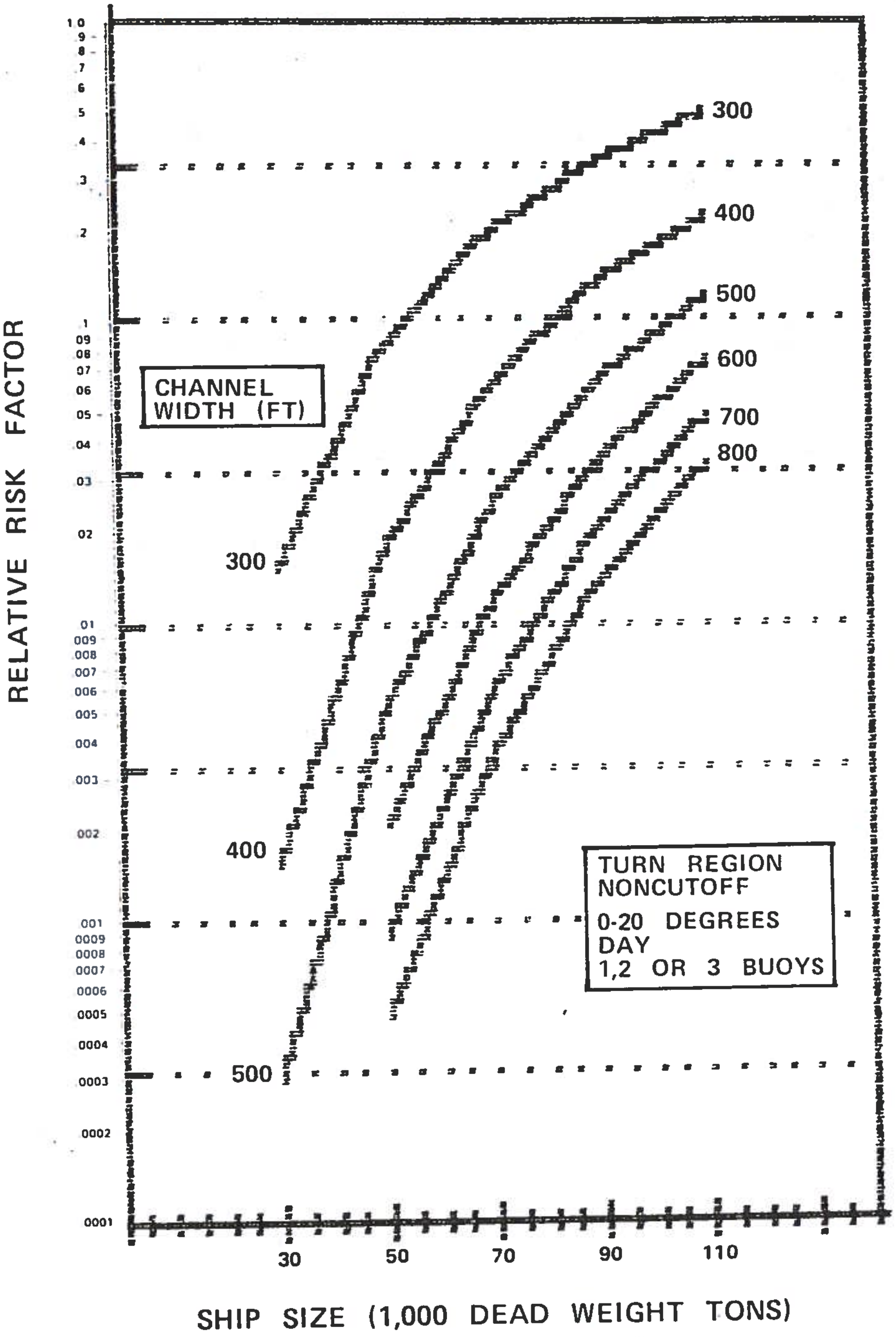
[(W/2) - (MN) - (B')]/(SD) = (NS)
[(500/2) - (8) - (67)]/(50) = (3.5)

[(W/2) + (MN) - (B')]/(SD) = (NP)
[(500/2) + (8) - (67)]/(50) = (3.82)

PS + PP = RRF
(0.0002) + (0.0001) = (0.0003)

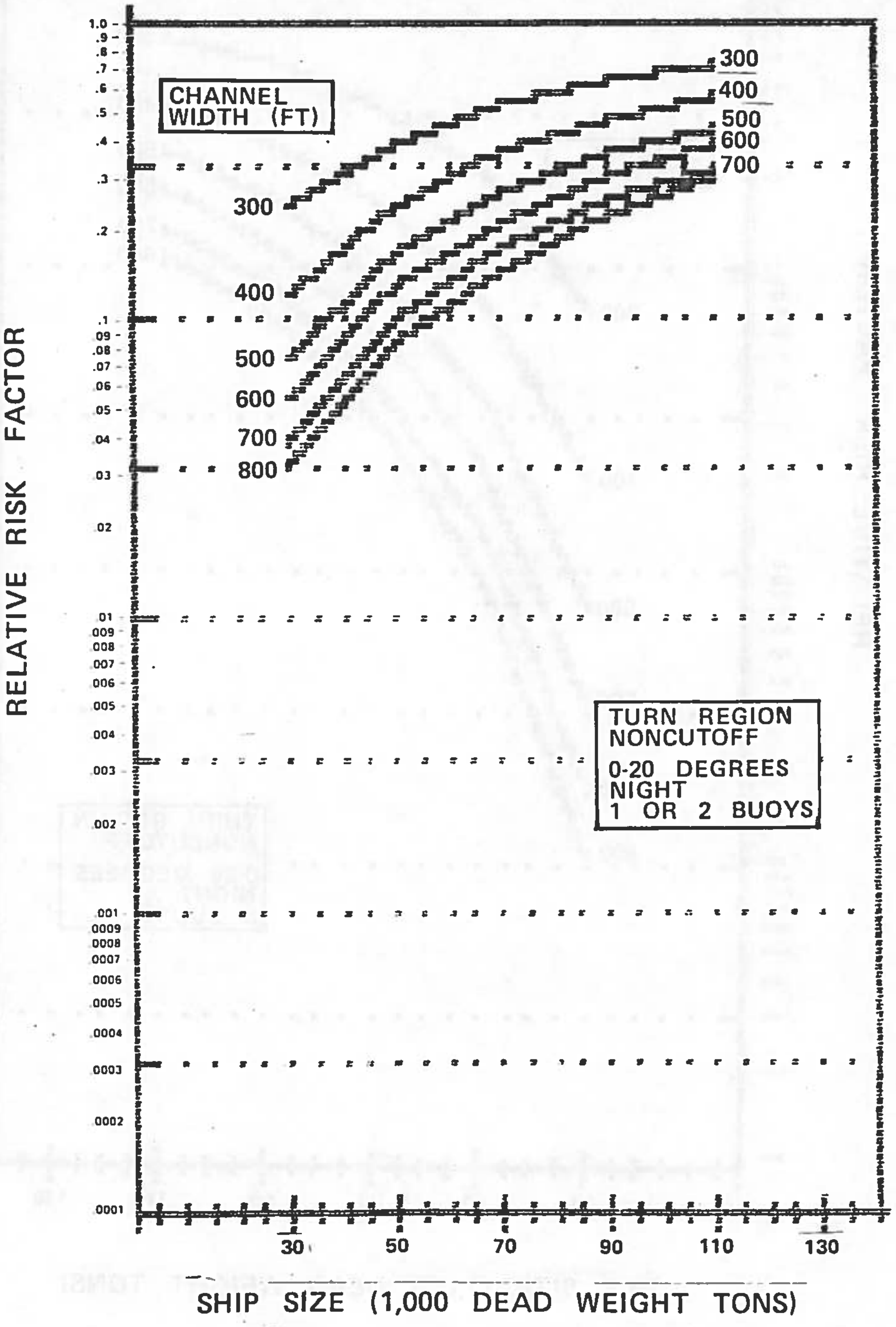
Reminder:
W: channel width
MN: mean
B' = adjusted beam/2
SD: standard deviation
NS: SDs to starboard
NP: SDs to port
PS: prob to starboard
PP: prob to port
RRF: relative risk factor

*Note that when the RRF is calculated by adding together the probability of grounding to each side, the direction of turn doesn't matter.

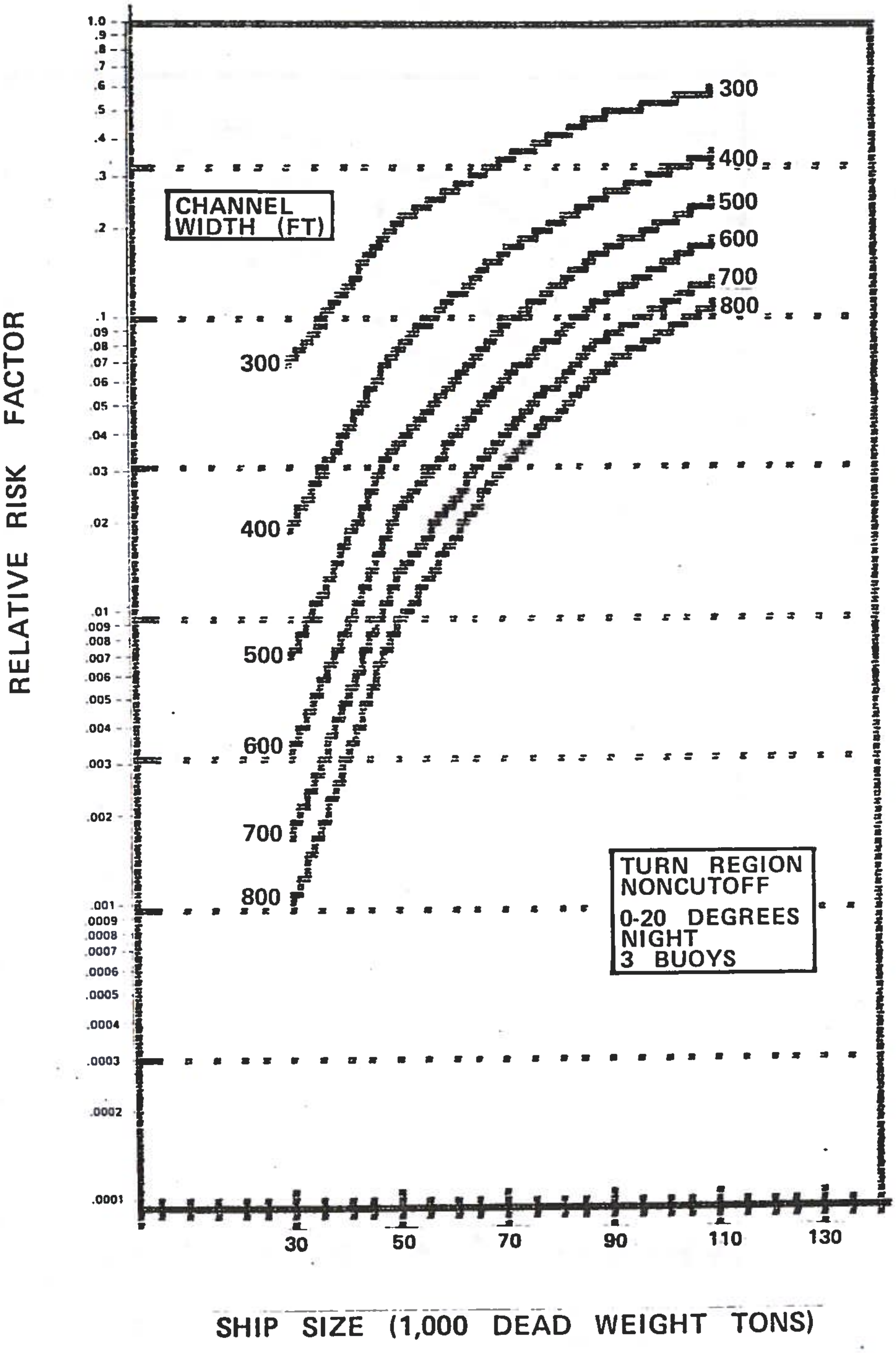


Note that the curves for the wider channel widths do not show values for the smaller ship sizes. The missing values are less than 0.0000.

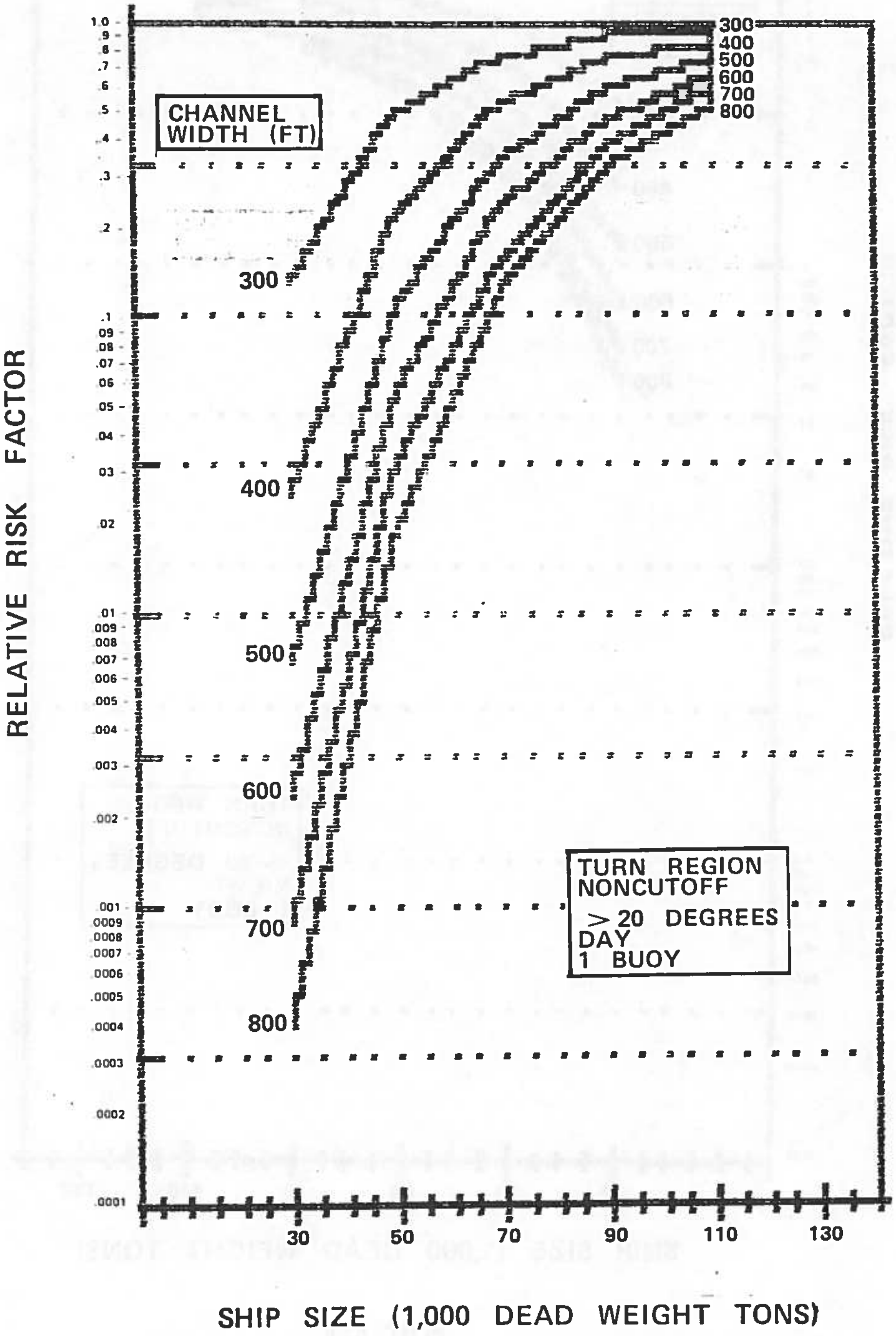
PLOT 5-1


RELATIVE RISK FACTOR
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
CHANNEL WIDTH (FT)
300
400
500
600
700
800
300
400
500
600
700
TURN REGION
NONCUTOFF
0-20 DEGREES
NIGHT
1 OR 2 BUOYS
30
50
70
90
110
130
SHIP SIZE (1,000 DEAD WEIGHT TONS)

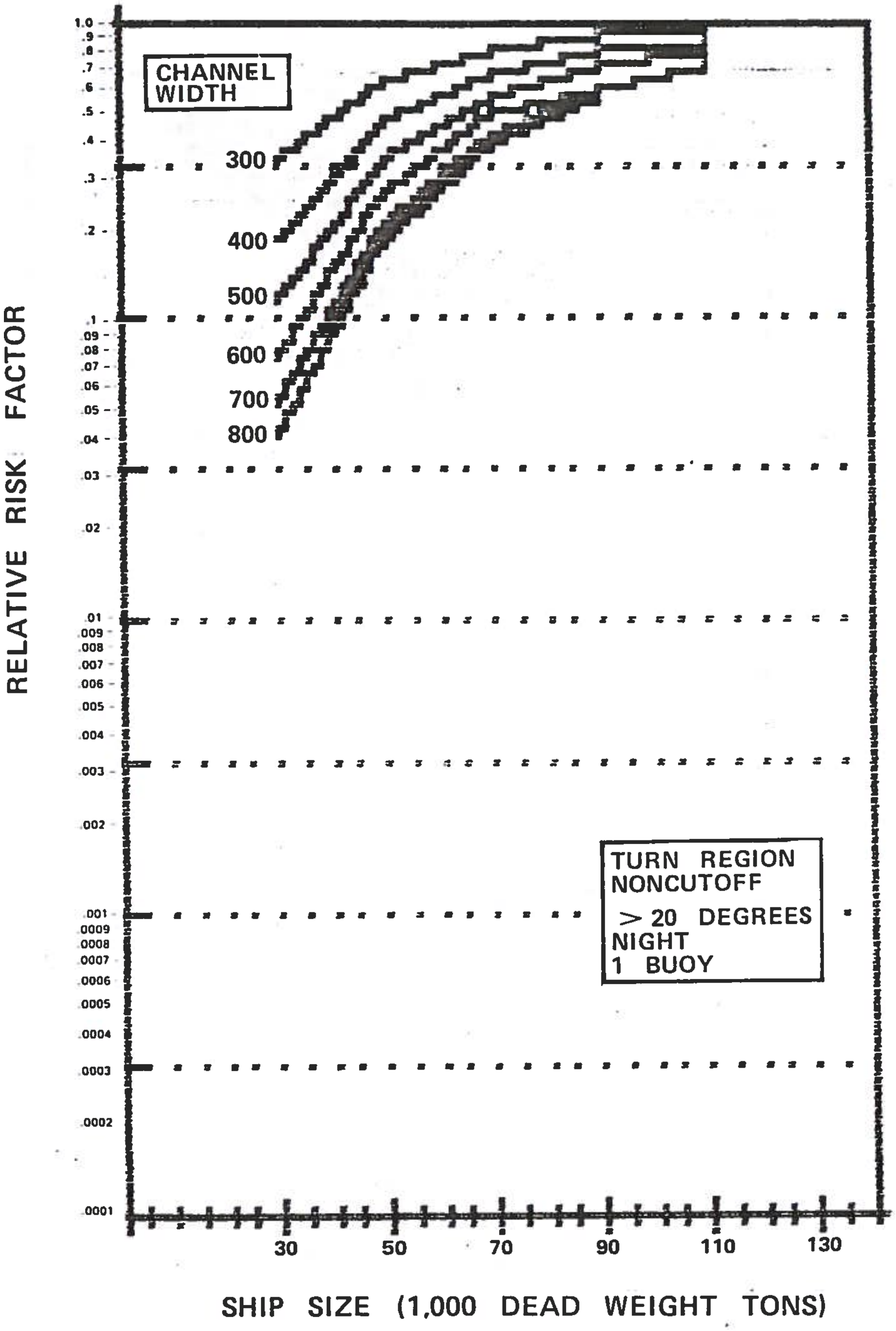
PLOT 5-2


RELATIVE RISK FACTOR
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
CHANNEL WIDTH (FT)
300
400
500
600
700
800
300
400
500
600
700
800
TURN REGION
NONCUTOFF
0-20 DEGREES
NIGHT
3 BUOYS
30
50
70
90
110
130
SHIP SIZE (1,000 DEAD WEIGHT TONS)

PLOT 5-3

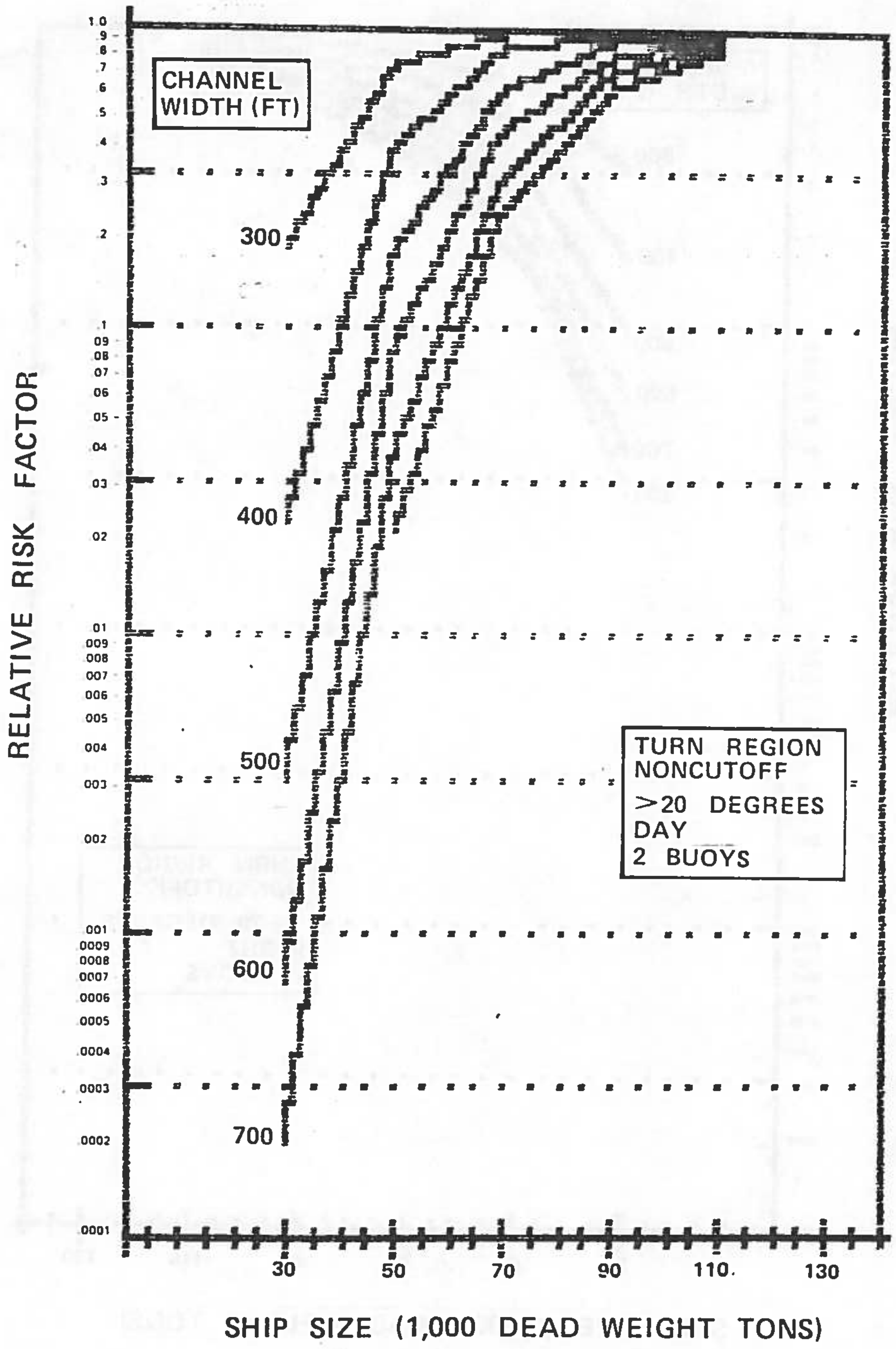

RELATIVE RISK FACTOR
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
CHANNEL WIDTH (FT)
300
400
500
600
700
800
300
400
500
600
700
800
TURN REGION
NONCUTOFF
> 20 DEGREES
DAY
1 BUOY
30
50
70
90
110
130
SHIP SIZE (1,000 DEAD WEIGHT TONS)

PLOT 5-4



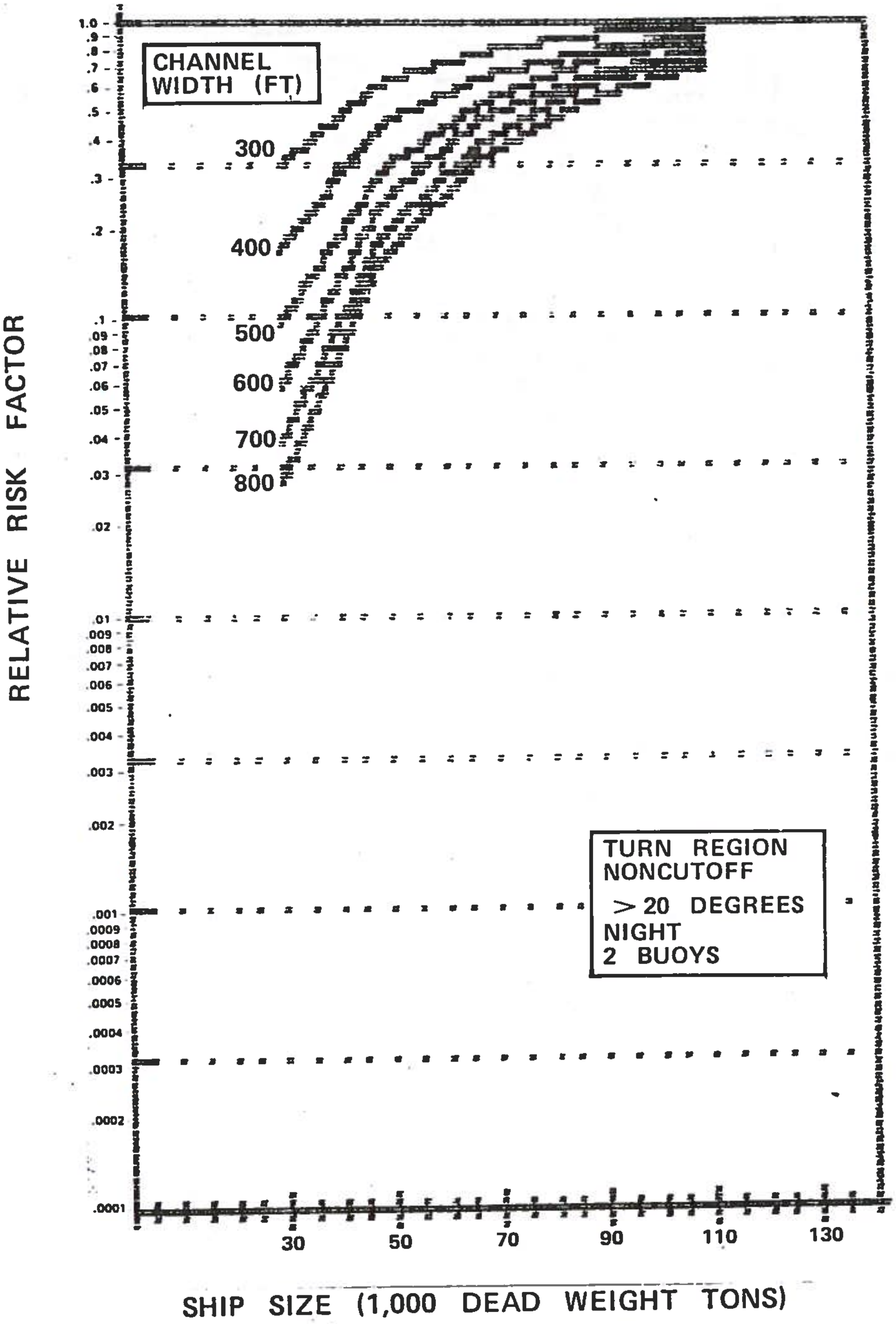
RELATIVE RISK FACTOR
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
CHANNEL WIDTH
300
400
500
600
700
800
TURN REGION
NONCUTOFF
> 20 DEGREES
NIGHT
1 BUOY
30
50
70
90
110
130
SHIP SIZE (1,000 DEAD WEIGHT TONS)

PLOT 5-5

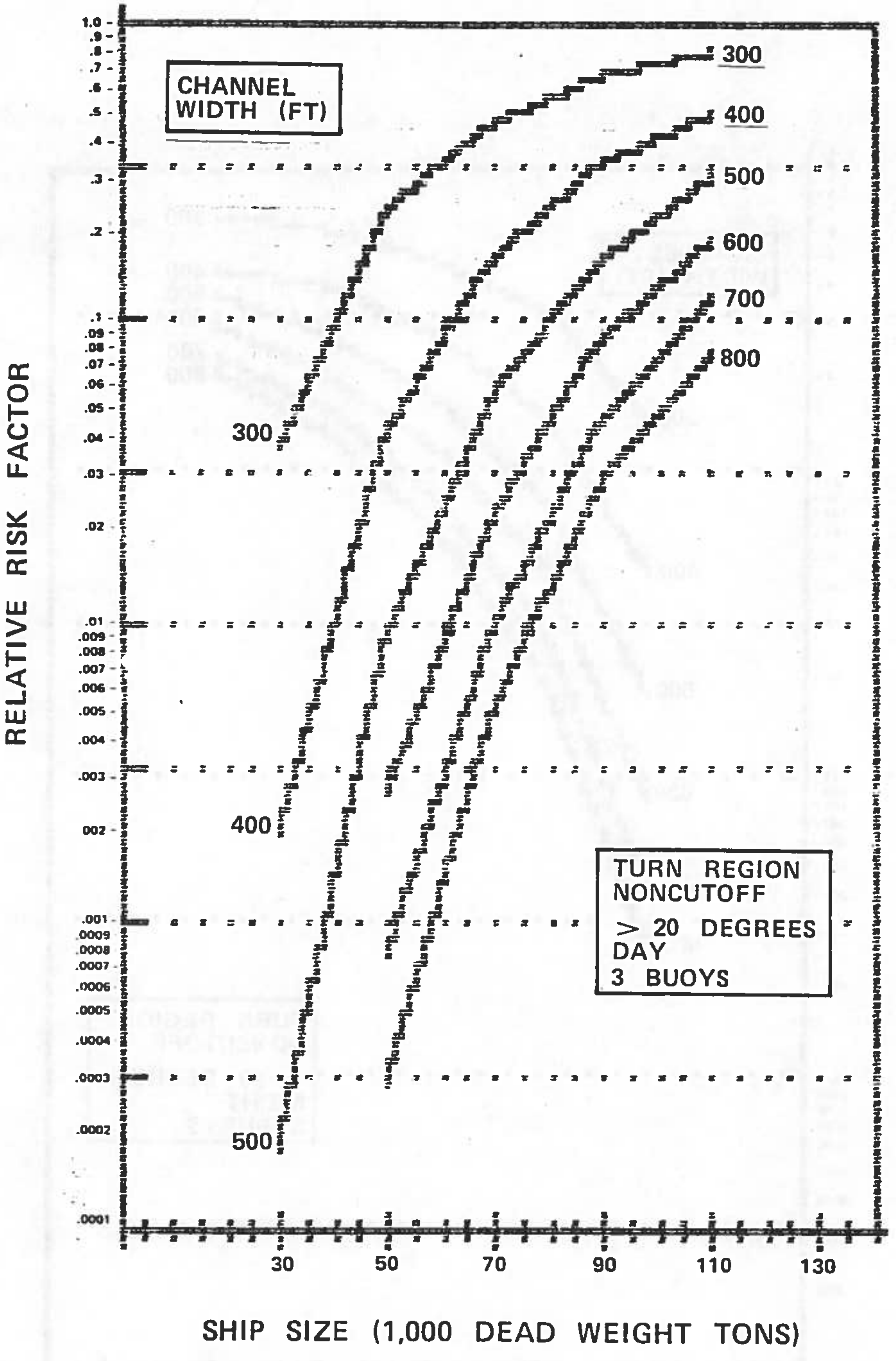


Note that the curves for the wider channel widths do not show values for the smaller ship sizes. The missing values are less than 0.0000.

PLOT 5-6

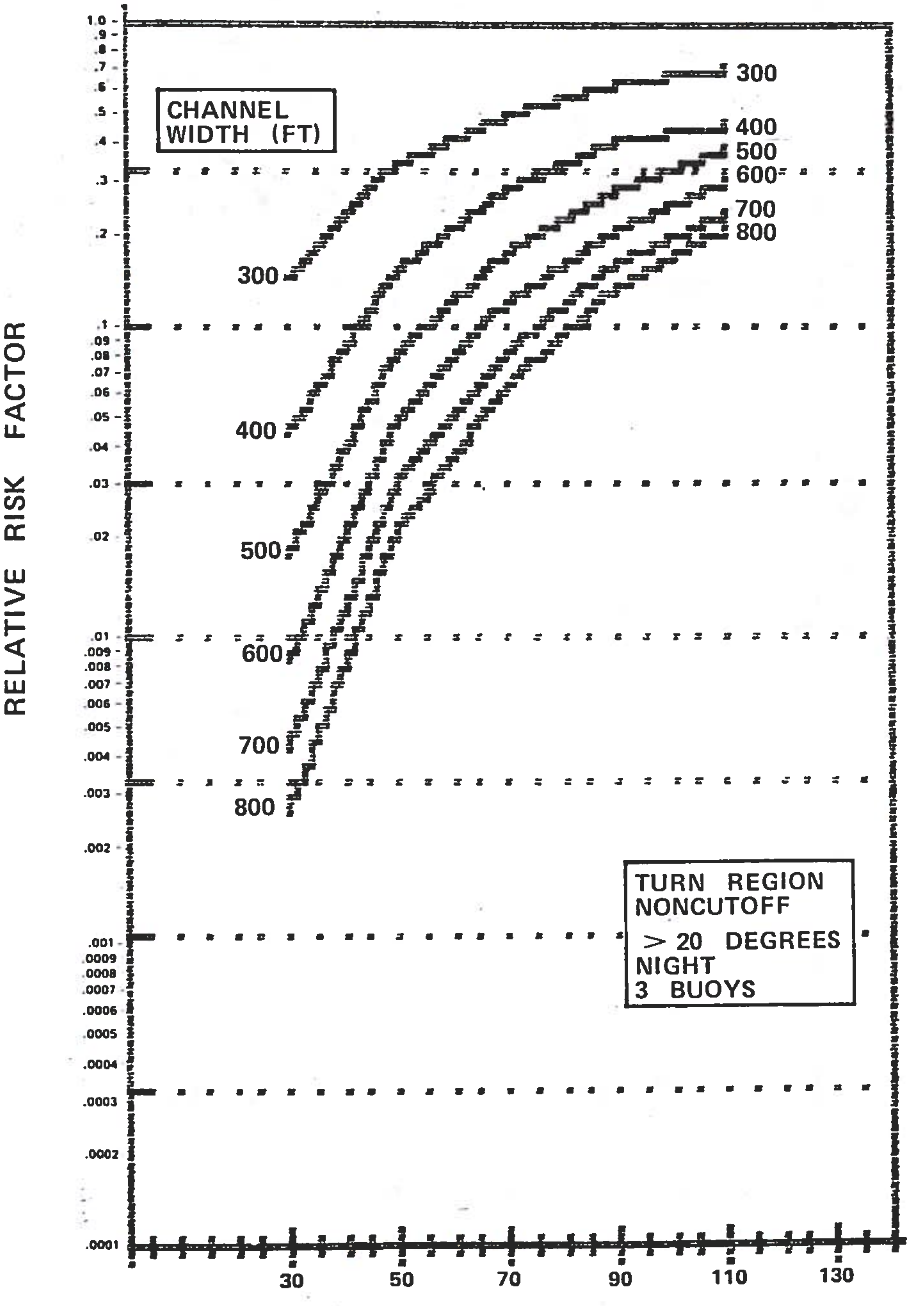

CHANNEL WIDTH (FT)
300
400
500
600
700
800
TURN REGION NONCUTOFF
> 20 DEGREES
NIGHT
2 BUOYS
RELATIVE RISK FACTOR
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
30
50
70
90
110
130
SHIP SIZE (1,000 DEAD WEIGHT TONS)

PLOT 5-7



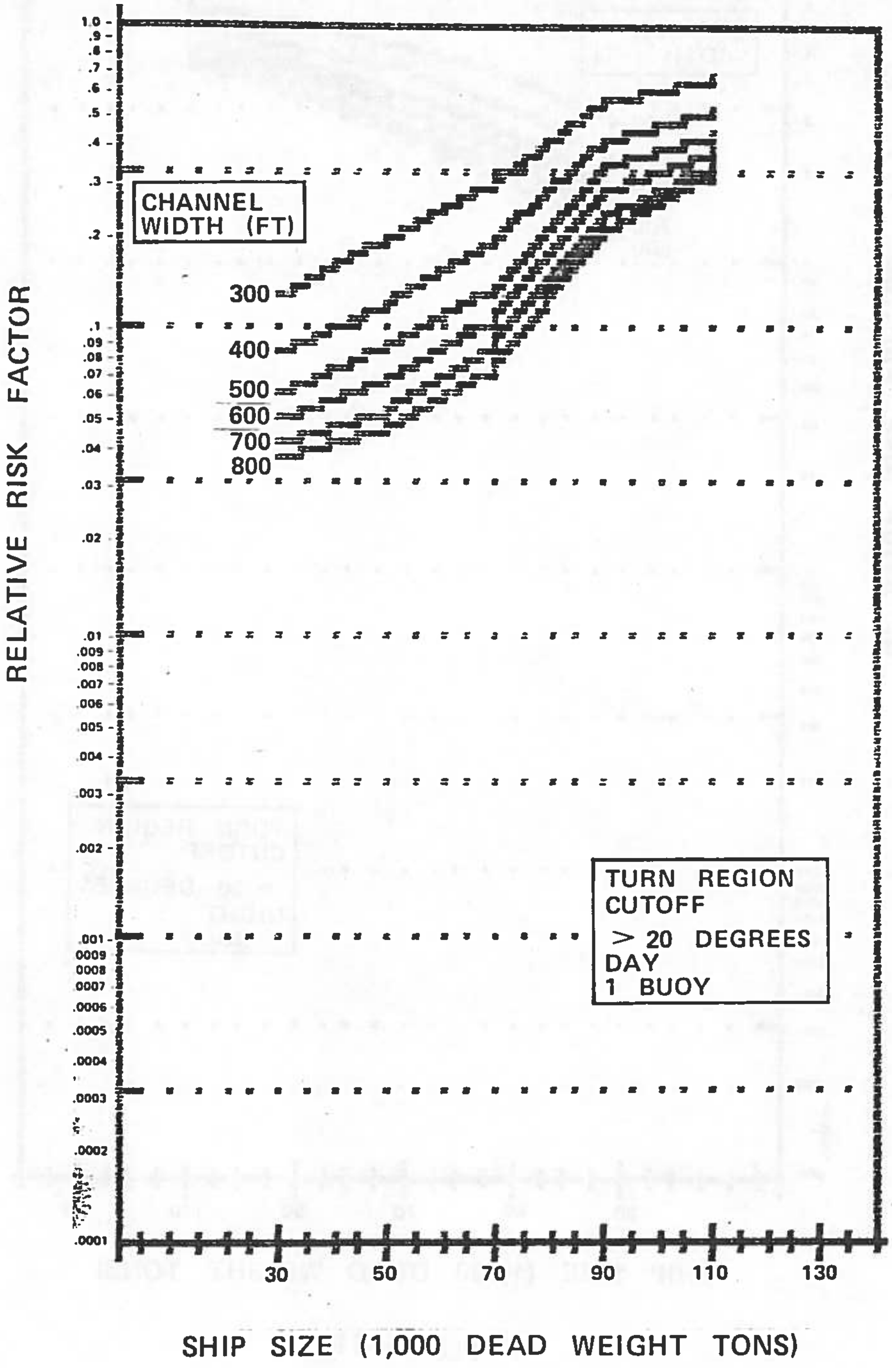
NOTE: MISSING VALUES ARE < 0.0000

PLOT 5-8

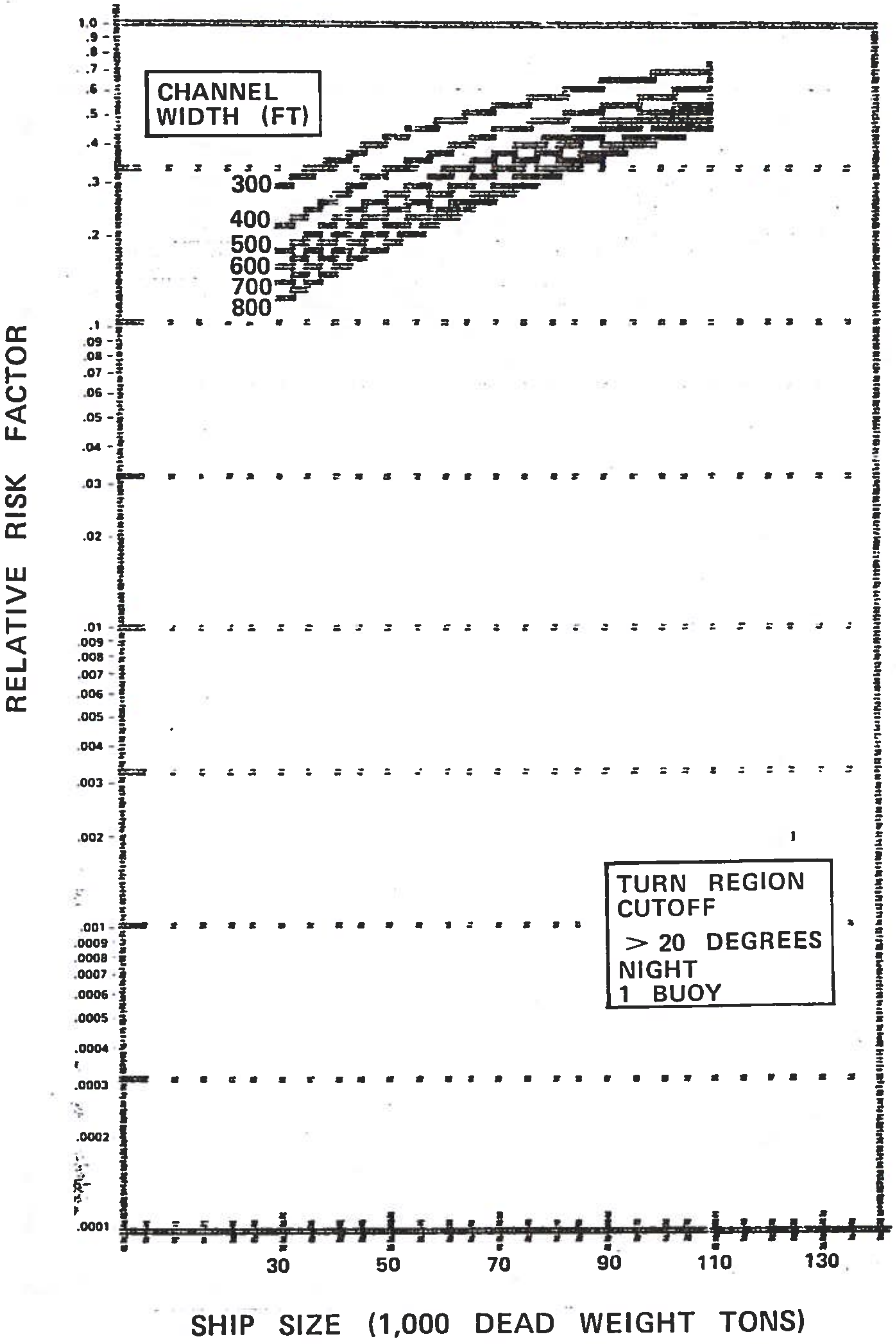


RELATIVE RISK FACTOR
SHIP SIZE (1,000 DEAD WEIGHT TONS)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
30
50
70
90
110
130
CHANNEL WIDTH (FT)
300
400
500
600
700
800
TURN REGION
NONCUTOFF
> 20 DEGREES
NIGHT
3 BUOYS

PLOT 5-9

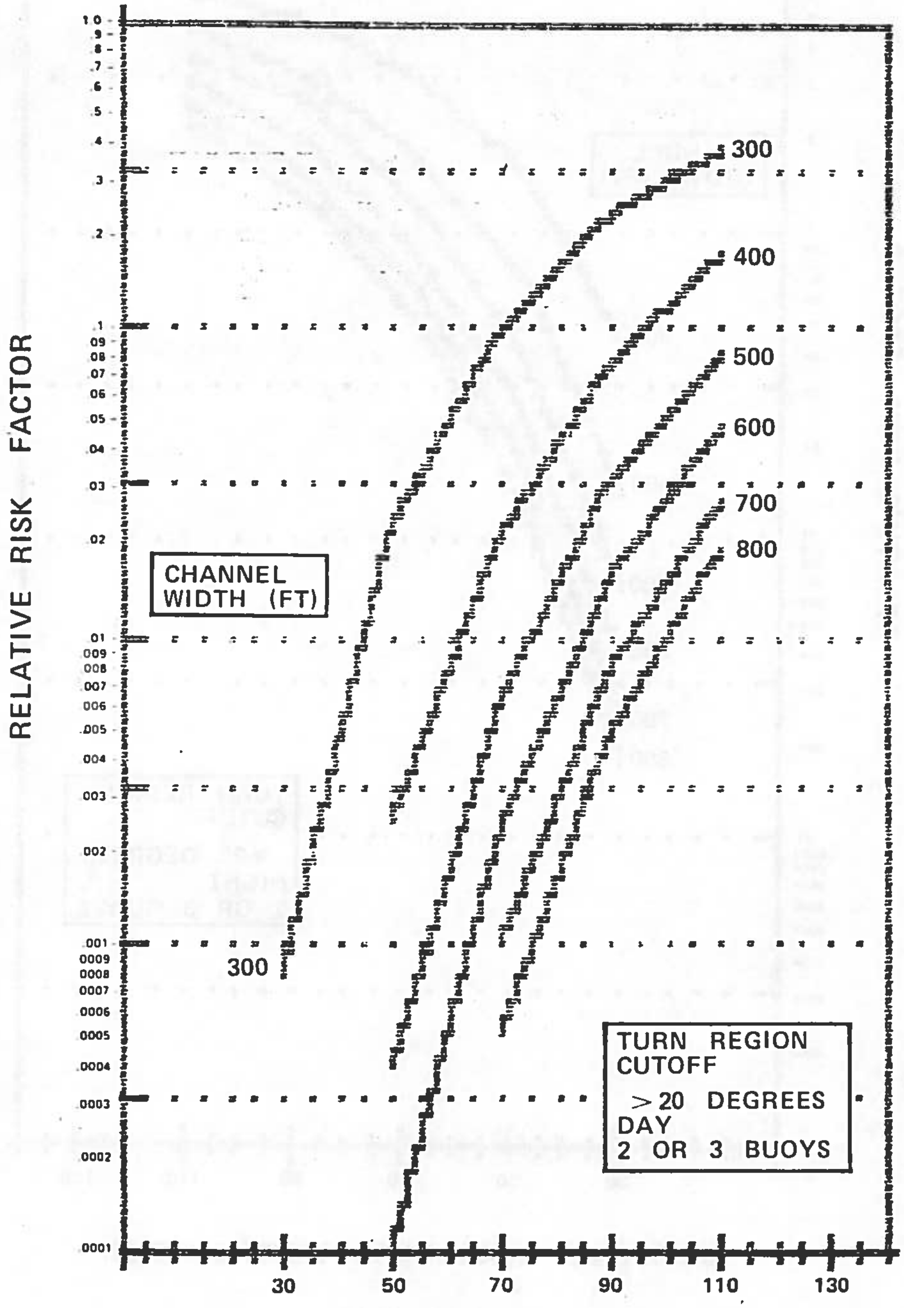

RELATIVE RISK FACTOR
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
CHANNEL WIDTH (FT)
300
400
500
600
700
800
TURN REGION CUTOFF
> 20 DEGREES
DAY
1 BUOY
30
50
70
90
110
130
SHIP SIZE (1,000 DEAD WEIGHT TONS)

PLOT 5-10



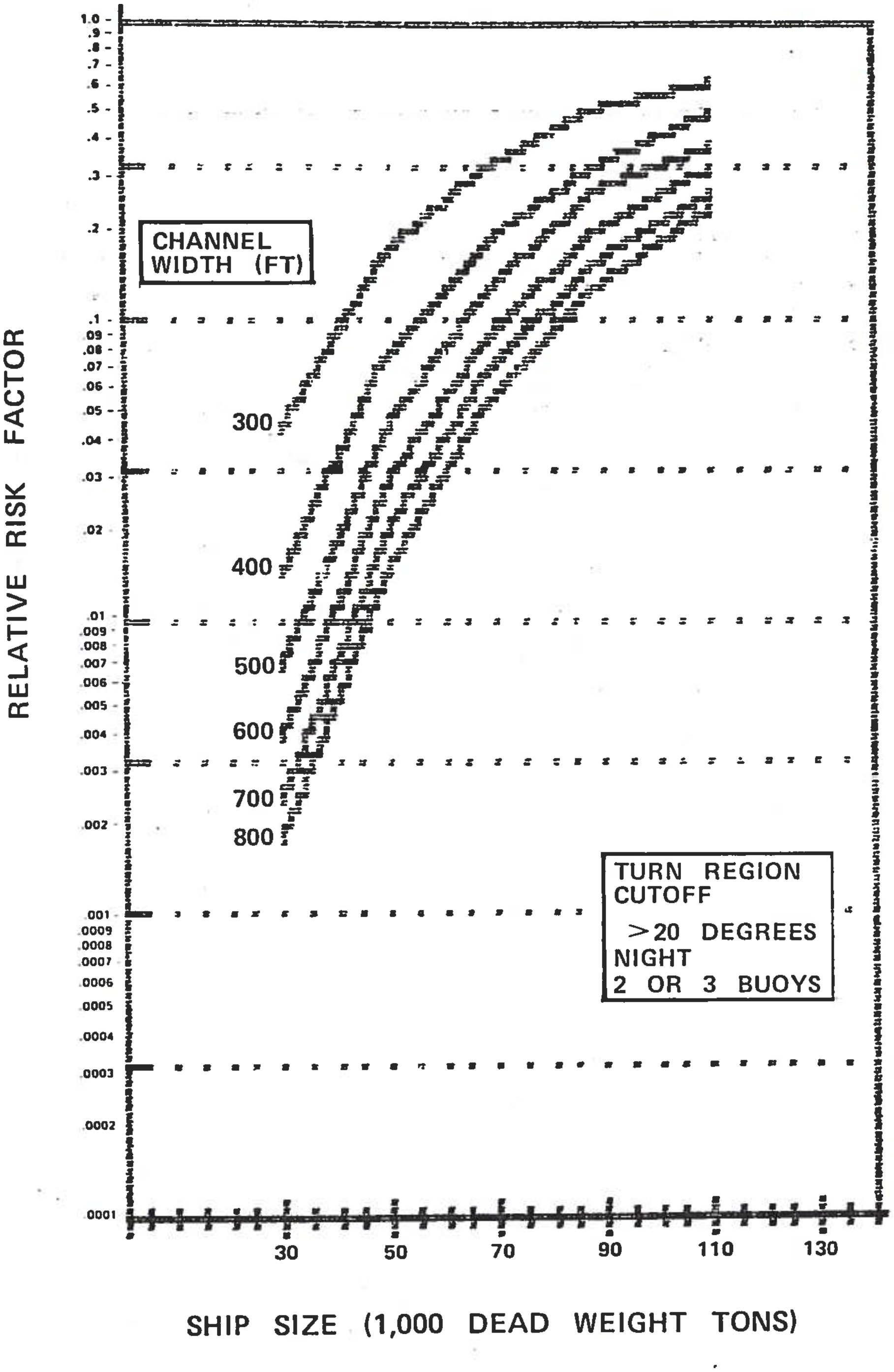
CHANNEL WIDTH (FT)
300
400
500
600
700
800
TURN REGION CUTOFF
> 20 DEGREES
NIGHT
1 BUOY
RELATIVE RISK FACTOR
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
30
50
70
90
110
130
SHIP SIZE (1,000 DEAD WEIGHT TONS)

PLOT 5-11



Note that the curves for the wider channel widths do not show values for the smaller ship sizes. The missing values are less than 0.0000.

PLOT 5-12


RELATIVE RISK FACTOR
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
CHANNEL WIDTH (FT)
300
400
500
600
700
800
TURN REGION CUTOFF
>20 DEGREES
NIGHT
2 OR 3 BUOYS
30
50
70
90
110
130
SHIP SIZE (1,000 DEAD WEIGHT TONS)

PLOT 5-13

Table 5-3. Five ship sizes were selected and each associated with a length and beam. The forces in the turn were assumed to be equivalent to a crosstrack current component of 0.50 knots, and for transit speed a conservatively slow 6 knots was selected. The resulting adjusted beam divided by two that was used in calculating the RRF also appears in the table. The last two columns are values for the recovery and trackkeeping regions that are discussed in Section 5.3 and 5.4. Six channel widths were selected: they are the original 500 feet and 300, 400, 600, 700, and 800 feet. For the cutoff turns, it was assumed that an extra 50 feet was available to the inside of the turn for all channel widths. The correction factors for ship size and channel width were applied according to the table and instructions in the following subsection for calculating specific RRF values.

The instructions given earlier in this subsection for selecting baseline data are equally appropriate for selecting a plot. Note that there are plots for noncutoff turns of angles greater than and less than 20 degrees. For cutoff turns there are only plots for angles greater than 20 degrees. The small angle cutoff turns were omitted because they are both of low frequency at sea and of low risk. The system designer interested in such a turn has two choices. He can either use the plots for the larger angle cutoff turns with a notation that risk may be overestimated or he can calculate the specific RRF value he needs by the instruction that follow. Once the appropriate plot is selected, the designer can find a value for the ship size and channel width of interest. These were indicated on the Worksheet 3-1, summary of waterway conditions. He can interpolate on the plot to find intermediate values. If he has a need for more precise values, he can calculate them. Extrapolating to values outside those plotted is not recommended.*

RRF values taken from the plots can be compared to RRF values taken from the baseline Table 5-1 for a 30,000 dwt ship in a 500-foot channel. Values taken from the plots may also be compared to RRF values for specific conditions calculated according to the instructions that follow.

5.2.3 Relative Risk Factor (RRF) Calculations for Specific Conditions

If the intention in applying the manual is the design and evaluation of aid arrangements, minimize calculations by using as many values from the baseline tables and the plots as possible and by only filling in missing values. Precalculated and individually calculated values, can be mixed if the instructions are followed precisely, and the same ship and environmental parameters are used. Use the conservative 6-knot speed and the 0.50-knot crosstrack current to represent turn forces in calculating the adjusted beam and divide the adjusted beam by half. If the standardized ship dimensions in Table 5-3 are acceptable; the adjusted beam, halved (B') can be taken directly from the table.

---

*Note that the multicycle logarithmic scale on the ordinate of the plots preserves the order of the RRF values but not the intervals between them. The resolution is high for the lower RRF values but decreases for the higher values. The values from 0.1 to 1 are compressed into the top quarter of the scale.

TABLE 5-3. STANDARD SHIP DIMENSIONS USED IN CALCULATION OF RELATIVE RISK FACTOR (RRF) FOR PLOTS

Ship Size 1,000 deadweight tons	Length[1] (feet)	Beam[2] (feet)	B' (feet) Turn[3] Pullout	B' (feet) With[4] Crosscurrent	B' (feet) Without[5] Crosscurrent
30	590	85	67.00	54.79	42.50
50	683	102	79.45	65.23	51.00
70	745	116	89.04	73.52	58.00
90	777	133	98.87	82.69	66.50
110	794	148	107.80	90.54	74.00

NOTES:

1. Length as a function of 1,000 deadweight tons is not linear but a linear interpolation between adjacent values will yield a usable number.

2. Beam as a function of 1,000 deadweight tons is a linear function. The beam for any ship size can be found by:

$$\text{beam}_i = 85 + 0.7875\ (\text{dwt}_i - 30)$$

3. B' (feet) was calculated for the turn pullout by:

(length/2) x (crosstrack current/transit speed) + (beam/2) = B'

where
crosstrack current = 0.50 knots
transit speed = 6 knots

4. B' (feet) was calculated for recovery or trackkeeping with crosscurrent as in 3. above but with a crosstrack current = 0.25 knots.

5. B' (feet) was calculated for recovery and trackkeeping without crosscurrent by dividing the beam by 2.

If the intention is to compare transits with different ship sizes in the same waterway or between waterways, precalculated and individually calculated values can still be mixed. Use true ship parameters with a 6-knot transit speed, a 0.50-knot crosstrack current, and use the B' formula in Table 5-3.

If the designer prefers to use true transit speed, to assume a different crosstrack current, or to divide the beam at the ship's center of gravity; all the RRF values used should be calculated in the same way. No precalculated values should be used.

The RRF factor should not be used to evaluate the effect of the same ship transiting at different speeds. The adjusted beam can vary appropriately with speed. But because there is no speed correction factor for the performance data, the performance data will not vary.

RRF values can be calculated by the system designer for all baseline conditions in Table 5-1 and for a variety of ship sizes and channel widths. The instructions for calculating the RRF are summarized in Worksheet 5-2, which can be copied for each turn region and alternative aid arrangement. Note that Worksheet 5-2 begins where Worksheet 5-1 for selecting baseline data, finishes. The instructions below elaborate on the items in Worksheet 5-2.

1. Baseline Data from Worksheet 5-1 (or Table 5-1). If appropriate baseline data has not already been selected according to the instructions given in Section 5.2.1, it must be done now. The baseline RRF value is a predictor of what can be expected. If the ship being considered is larger than 30,000 dwt or the channel being considered is narrower than 500 feet, the risk will be higher. If the channel is wider, the risk will be lower. Select baseline and enter them in Item 1 of Worksheet 5-2. (For cutoff turns special instructions for additional baseline data appears in the discussion for Item 5.)

2. Channel Parameters from Worksheet 3-1. Channel parameters needed in the calculations were entered in Worksheet 3-1, the worksheet on waterway conditions. Either copy them from there or measure them now on the chart. For a noncutoff turn, the navigable width for the design vessel in the straight leg following the turn should be entered in Item 2. For a cutoff turn the navigable width 2000 feet beyond the estimated inside apex should be entered. Enter in Item 2.

3. Environmental parameters from Worksheet 3-1. If crosstrack current is apparent within the turn region, enter the value of the maximum crosstrack current component. Consider it positive whatever its direction. If there are no meaningful crosstrack currents or they are unknown, use 0.50 knots toward the outside of the turn to represent the turn forces. Enter in Item 3.

4. Design Vessel Parameters from Worksheet 3-1. A design vessel was chosen and its parameters entered in Worksheet 3-1. If the parameters were not established then, it should be done now. Ship size (deadweight tons) is needed to correct the performance data. The ship's length (feet between

WORKSHEET FOR EVALUATION OF THE TURN REGION: CALCULATION OF THE RELATIVE RISK FACTOR (RRF) FOR SPECIFIC CONDITIONS

(SHEET 1 OF 5)

Instructions in Section 5.2.3.

Copy for every design/evaluation objective and turn region.

Design/Evaluation Objective:______________________________

____

Turn Identification:______________________________

1. Baseline Data from Worksheet 5-1 (or Table 5-1)

	MN	SD	RRF
Day	____	____	____
Night/dusk/dawn	____	____	____
Range	____	____	____

For cutoff turn only, MN for corresponding noncutoff turn (see instructions in Section 5.2.3):

Day	____
Night/dusk/dawn	____

2. Channel Parameters from Worksheet 3-1

For noncutoff turn, navigable width (feet)______________________________(W)

For cutoff turn, navigable width 2000 feet beyond apex (feet)__________(W)

3. Environmental Parameters from Worksheet 3-1

Crosstrack current (knots) +______________

or assume turn forces equivalent to 0.50 knots toward outside of turn.

Worksheet 5-2

WORKSHEET FOR EVALUATION OF THE TURN REGION:
CALCULATION OF THE RELATIVE RISK FACTOR (RRF) FOR SPECIFIC CONDITIONS
(SHEET 2 OF 5)

4. Design Vessel Parameters from Worksheet 3-1

Ship size (deadweight tons) ______________________________

Length (feet) ______________________________

Beam (feet) ______________________________

Transit speed (knots) ______________________________

B':

[(length/2) x (crosstrack current/transit speed)] + (beam/2) = (B')

[(/2) x (/)] + (/2) = (feet)

5. Correct Mean (MN) and Standard Deviation (SD)

See Table 5-4 for correction factors.

	day, 3 buoys		other conditions		
MCSHP	_____	or	_____	MCWID	_____
SCSHP	_____	or	_____	SCWID	_____

Calculation for noncutoff turns:

DAY

(MN) x (MCSHP) x (MCWID) = (MN')
( ) x ( ) x ( ) = ( )

(SD) x (SCSHP) x (SCWID) = (SD')
( ) x ( ) x ( ) = ( )

NIGHT

(MN) x (MCSHP) x (MCWID) = (MN')
( ) x ( ) x ( ) = ( )

(SD) x (SCSHP) x (SCWID) = (SD')
( ) x ( ) x ( ) = ( )

RANGE

(MN) x (MCSHP) x (MCWID) = (MN')
( ) x ( ) x ( ) = ( )

(SD) x (SCSHP) x (SCWID) = (SD')
( ) x ( ) x ( ) = ( )

Worksheet 5-2 (Continued)

WORKSHEET FOR EVALUATION OF THE TURN REGION:
CALCULATION OF THE RELATIVE RISK FACTOR (RRF) FOR SPECIFIC CONDITIONS
(SHEET 3 OF 5)

Calculation for Cutoff Turns:

DAY

a. Corresponding noncutoff baseline MN ________________________

b. (noncutoff baseline MN) x (MCSHP) = (product)
( ) x ( ) = ( )

c. (product) - (noncutoff baseline MN) = (difference)
( ) - ( ) = ( )

d. (cutoff baseline MN) + (difference) = (cutoff MN corrected for ship size)
( ) + ( ) = ( )

(cutoff MN corrected for ship size) x (MCWID) = (MN')
( ) x ( ) = ( )

(SD) x (SCSHP) x (SCWIP) = (SD')
( ) x ( ) x ( ) = ( )

NIGHT/DUSK/DAWN

a. Corresponding noncutoff baseline MN ________________________

b. (noncutoff baseline MN) x (MCSHP) = (product)
( ) x ( ) = ( )

c. (product) - (noncutoff baseline MN) = (difference)
( ) - ( ) = ( )

d. (cutoff baseline MN) + (difference) = (cutoff MN corrected for ship size)
( ) + ( ) = ( )

(cutoff MN corrected for ship size) x (MCWID) = (MN')
( ) x ( ) = ( )

(SD) x (SCSHP) x (SCWIP) = (SD')
( ) x ( ) x ( ) = ( )

Reminder:
MCSHP: mean correction factor for ship size
MCWID: mean correction factor for channel width
SCSHP: standard deviation correction for ship size
SCWIP: standard deviation correction for channel width

Worksheet 5-2 (Continued)

WORKSHEET FOR EVALUATION OF THE TURN REGION: CALCULATION OF THE RELATIVE RISK FACTOR (RRF) FOR SPECIFIC CONDITIONS

(SHEET 4 OF 5)

RANGE

Note that baseline means for cutoff and noncutoff turns marked by ranges are the same.

(MN) x (MCSHP) x (MCWIP) = (MN')
(   ) x (   ) x (   ) = (   )

(SD) x (SCSHP) x (SCWIP) = (SD')
(   ) x (   ) x (   ) = (   )

Worksheet 5-2 (Continued)

WORKSHEET FOR EVALUATION OF THE TURN REGION:
CALCULATION OF THE RELATIVE RISK FACTOR (RRF) FOR SPECIFIC CONDITIONS
(SHEET 5 OF 5)

6. CALCULATE RELATIVE RISK FACTOR (RRF)

See Table 5-5 for PS and PP.

DAY

[(W/2) - (MN') - (B')]/(SD') = (NS)
[/2) - ( ) - ( )]/( ) = ( )

[(W/2)* + (MN') - (B')]/(SD') = (NP)
[(/2)* + ( ) - ( )]/( ) = ( )

(PS) + (PP) = (RRF)
( ) + ( ) = ( )

NIGHT/DUSK/DAWN

[(W/2) - (MN') - (B')]/(SD') = (NS)
[/2) - ( ) - ( )]/( ) = ( )

[(W/2)* + (MN') - (B')]/(SD') = (NP)
[(/2)* + ( ) - ( )]/( ) = ( )

(PS) + (PP) = (RRF)
( ) + ( ) = ( )

RANGE

[(W/2) - (MN') - (B')]/(SD') = (NS)
[/2) - ( ) - ( )]/( ) = ( )

[(W/2)* + (MN') - (B')]/(SD') = (NP)
[(/2)* + ( ) - ( )]/( ) = ( )

(PS) + (PP) = (RRF)
( ) + ( ) = ( )

*For a cutoff turn the extra width should be added to the port side only as follows:

(W/2) + (extra width) = (width to port)
(/2) + ( ) = ( )

The starboard side should be treated like a noncutoff turn.

reminder:
W: channel width from #2
MN': corrected MN from #5
B': adj. beam/2 from #4
SD': corrected SD from #5
NS: SDs to starboard
NP: SDs to port
PS: prob. to starboard
PP: prob. to port
RRF: relative risk factor

Worksheet 5-2 (Continued)

perpendiculars), its beam (feet), and its expected transit speed (knots) are needed to calculate the halved adjusted beam (B'). Enter the needed values in Item 4 and complete the calculations. Note that the B' for a turn remains the same if the baseline data is changed for day, night/dusk/dawn, ranges, and different aid arrangements. Unless different crosstrack currents are assumed in different turns, it is even the same for different turn regions.

5. Correct Mean (MN) and Standard Deviation (SD). Correction factors to correct the baseline MN and SD for the ship size and channel width appear in Table 5-4.

For ship size, if the baseline data to which it will be applied is for a three-buoy turn under daytime conditions, choose from the first set of values. For any other baseline data, use the second set of values. They provide a more conservative correction.

To correct the baseline data for channel width use the width that is marked by the aids 2000 feet beyond the turn. If this width is not the same as the navigable width for the design vessel draft, the resulting RRF will be affected.*

If the value for ship size or channel width needed is not in the table, interpolate using formulas given.

Select correction factors for the ship size mean (MCSHP), standard deviation (SCSHP), channel width mean (MCWID) and standard deviation (SCWID). Enter these in Item 5. Complete calculations as instructed below.

For a noncutoff turn the calculations for correcting the MN and SD are straightforward as shown in Item 5. The correction must be done for as many baseline conditions as are of interest: daytime, night/dusk/dawn, ranges, alternative aid arrangements, turn regions.

---

*The baseline data is corrected for the channel width marked by the aids on the assumption that the baseline data represents the piloted performance of the vessel and that the pilots adjust that performance to the width of the marked channel. If the aids are set back from the edge of the navigable channel for the design vessel, this assumption results in a higher RRF. It is undoubtedly conservative in that the pilots know that the channel is less than that marked, even though they cannot accurately estimate its exact width. If the bottom is very soft, the designer may want to note that risk is overestimated. If the aids are set inside the edge of the navigable channel for the design vessel, the RRF will be lower. The risk of hitting the aid itself is not considered.

TABLE 5-4. CORRECTION FACTORS FOR THE TURN REGION

FOR THREE-BUOY TURN, DAY ONLY

SHIP SIZE 1,000 dwt	30	50	70	90	110
MCSHP[1]	1	1.18	1.35	1.53	1.71

Slope = 0.0089

SHIP SIZE 1,000 dwt	30	50	70	90	110
SCSHP[2]	1	1.21	1.41	1.62	1.82

Slope = 0.0103

FOR ALL OTHER CONDITIONS

SHIP SIZE 1,000 dwt	30	50	70	90	110
MCSHP	1	1.44	1.88	2.33	2.77

Slope = 0.0221

SHIP SIZE 1,000 dwt	30	50	70	90	110
SCSHP	1	1.18	1.35	1.53	1.71

Slope = 0.0089

CHANNEL WIDTH (marked by aids, in feet)

	300	400	500	600	700	800
MCWID[3]	0.67	0.83	1	1.17	1.33	1.5
SCWID[4]	0.67	0.83	1	1.17	1.33	1.5

NOTES:

1. MCSHP: mean correction factor for ship size. These values are to be applied directly only to baseline data for the noncutoff turns. See special instructions in text for correcting data for the cutoff turns.

   To interpolate for MCSHP, use

$$MCSHP_i = 1 + \text{slope}\,(X_i - 30)$$

   where:
   $MCSHP_i$ = correction factor for any ship size in 1,000 dwt
   X_i = ship size in 1,000 dwt
   slope = value given in table above

TABLE 5-4. CORRECTION FACTORS FOR THE TURN REGION (CONTINUED)

2. SCSHP: standard deviation correction for ship size.

   Interpolate as in Note. 1.

3. MCWID: mean correction factor for channel width

   To interpolate for MCWID, use:

$$MCWID_i = 1 + 0.5\ (W_i - 500)/300$$

   where

   $MCWID_i$ = correction factor for any channel width

   W_i = channel width

4. SCWID: standard deviation correction factor for channel width.

   Interpolate as in note 3.

For a cutoff turn, the ship size correction factor cannot be applied directly to the baseline MN but requires some special calculations.*

a. Find the corresponding noncutoff baseline MN in Table 5-1 by the following rules:

- For a cutoff turn with one buoy to the inside or outside or one buoy to each side, use the mean for a noncutoff turn of the same angle, same day or night condition, and with one buoy.
- For a cutoff turn with two buoys on the inside diagonal or three buoys outlining the cutoff area, use the mean for a noncutoff turn of the same angle, the same day or night condition and three buoys.

b. Find the appropriate ship size correction factor (MCSHP) in Table 5-4 and multiply noncutoff baseline MN by it.

c. Subtract noncutoff baseline MN from corrected noncutoff MN, the product of b.

d. Add the difference from c. to the cutoff baseline MN.

The final number in d. is the cutoff MN corrected for ship size. A sample calculation follows.

To correct the baseline MN for a cutoff turn of 35 degrees with one buoy for daytime conditions to represent a 50,000 dwt ship:

a. From Table 5-1 the noncutoff, >20 degrees, 1 buoy, day baseline MN is 72.

b. From Table 5-4 the "other conditions," 50,000 dwt ship size correction factor (MCSHP) is 1.44.

$$72 \times 1.44 = 103.68$$

c. The noncutoff corrected MN minus the noncutoff baseline MN is:

$$103.68 - 72 = 31.68$$

d. From Table 5-1 the cutoff, >20 degrees, 1 buoy day baseline MN is -88. The difference above added to it is:

$$-88 + 31.68 = -56.32$$

---

*Note in Table 5-1 that some of the baseline MNs for the cutoff turn are minus values, indicating a track through the cutoff area. Multiplying these minus values by the ship size correction factor, developed using noncutoff turn data, would give a paradoxical result. The larger the ship, the shorter the radius of its track through a constant turn configuration. The method of calculation used instead ensures that the radius of the track through the turn and, therefore, the RRF increases with ship size.

To correct the cutoff MN for channel width, multiply the MN corrected for ship size by the channel width correction factor (MCWID) as instructed for the noncutoff turns.

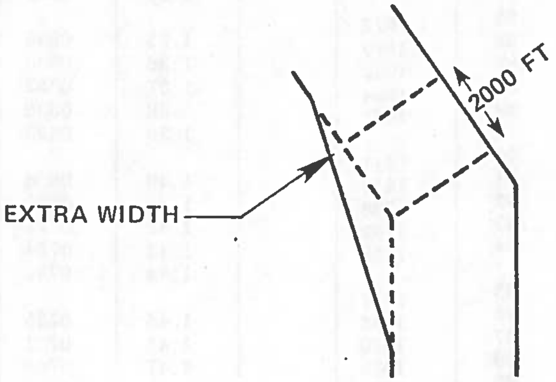
The SD for the cutoff turns are corrected for both ship size and channel width as instructed for the noncutoff turns.

No distinction is made between noncutoff and cutoff turns marked by ranges. Use the instructions for noncutoff turns for correcting baseline range data whatever the turn configuration.

6. CALCULATE THE RELATIVE RISK FACTOR (RRF). For simplicity the instructions here and in Worksheet 5-2 assume all turns are left-hand turns. As long as the RRF is found by dividing the adjusted beam by two and by adding the probabilities of exceeding either edge together, true direction of a turn is irrelevant. The designer who has a need to calculate the risk of grounding to either side separately may concern himself with the direction of the turn.

For a noncutoff turn to calculate the RRF, first calculate the number of SDs (NS) that will fit between the extreme starboard point of the ship and the edge of the channel. Start with the navigable channel width (W) and divide it by two. Subtract the corrected MN crosstrack displacement of the set of tracks (MN') and one-half the adjusted beam of the ship (B'). The distance remaining between the extreme starboard point and the edge of the channel is then divided by the corrected crosstrack SD (SD'). The result is labeled NS in Worksheet 5-2. NS may be negative. For the port side start with the useful channel width (W) and divide it by two. Add the additional space allowed by the displacement of the MN' to starboard. Subtract (B'). The distance remaining between the extreme port point and the edge of the channel is then divided by SD'. The result is labeled NP in Worksheet 5-2. NP may be negative.

For the (left-hand) cutoff turn add the extra width allowed by dredging 2000 feet beyond the estimated apex to the port side of the channel:



(W/2) + (extra width) = width to port side

Proceed as for a noncutoff turn.

To find RRF as a probability enter Table 5-5 with NS to find PS, the probability of exceeding the starboard edge. Then use NP to find PP, the

TABLE 5-5. NORMAL DISTRIBUTION VALUES FOR THE CUMULATIVE PROBABILITIES, PS OR PP, OF A POINT FALLING BEYOND NS OR NP (SEE NOTE)

N	P(N)	N	P(N)	N	P(N)	N	P(N)
.00	.5000	.50	.3085	1.00	.1587	1.50	.0668
.01	.4960	.51	.3050	1.01	.1562	1.51	.0655
.02	.4920	.52	.3015	1.02	.1539	1.52	.0643
.03	.4880	.53	.2981	1.03	.1515	1.53	.0630
.04	.4840	.54	.2946	1.04	.1492	1.54	.0618
.05	.4801	.55	.2912	1.05	.1469	1.55	.0606
.06	.4761	.56	.2877	1.06	.1446	1.56	.0594
.07	.4721	.57	.2843	1.07	.1423	1.57	.0582
.08	.4681	.58	.2810	1.08	.1401	1.58	.0571
.09	.4641	.59	.2776	1.09	.1379	1.59	.0559
.10	.4602	.60	.2743	1.10	.1357	1.60	.0548
.11	.4562	.61	.2709	1.11	.1335	1.61	.0537
.12	.4522	.62	.2676	1.12	.1314	1.62	.0526
.13	.4483	.63	.2643	1.13	.1292	1.63	.0516
.14	.4443	.64	.2611	1.14	.1271	1.64	.0505
.15	.4404	.65	.2578	1.15	.1251	1.65	.0495
.16	.4364	.66	.2546	1.16	.1230	1.66	.0485
.17	.4325	.67	.2514	1.17	.1210	1.67	.0475
.18	.4286	.68	.2483	1.18	.1190	1.68	.0465
.19	.4247	.69	.2451	1.19	.1170	1.69	.0455
.20	.4207	.70	.2420	1.20	.1151	1.70	.0446
.21	.4168	.71	.2389	1.21	.1131	1.71	.0436
.22	.4129	.72	.2358	1.22	.1112	1.72	.0427
.23	.4090	.73	.2327	1.23	.1093	1.73	.0418
.24	.4052	.74	.2296	1.24	.1075	1.74	.0409
.25	.4013	.75	.2266	1.25	.1056	1.75	.0401
.26	.3974	.76	.2236	1.26	.1038	1.76	.0392
.27	.3936	.77	.2206	1.27	.1020	1.77	.0384
.28	.3897	.78	.2177	1.28	.1003	1.78	.0375
.29	.3859	.79	.2148	1.29	.0985	1.79	.0367
.30	.3821	.80	.2119	1.30	.0968	1.80	.0359
.31	.3783	.81	.2090	1.31	.0951	1.81	.0351
.32	.3745	.82	.2061	1.32	.0934	1.82	.0344
.33	.3707	.83	.2033	1.33	.0918	1.83	.0336
.34	.3669	.84	.2005	1.34	.0901	1.84	.0329
.35	.3632	.85	.1977	1.35	.0885	1.85	.0322
.36	.3594	.86	.1949	1.36	.0869	1.86	.0314
.37	.3557	.87	.1922	1.37	.0853	1.87	.0307
.38	.3520	.88	.1894	1.38	.0838	1.88	.0301
.39	.3483	.89	.1867	1.39	.0823	1.89	.0294
.40	.3446	.90	.1841	1.40	.0808	1.90	.0287
.41	.3409	.91	.1814	1.41	.0793	1.91	.0281
.42	.3372	.92	.1788	1.42	.0778	1.92	.0274
.43	.3336	.93	.1762	1.43	.0764	1.93	.0268
.44	.3300	.94	.1736	1.44	.0749	1.94	.0262
.45	.3264	.95	.1711	1.45	.0735	1.95	.0256
.46	.3228	.96	.1685	1.46	.0721	1.96	.0250
.47	.3192	.97	.1660	1.47	.0708	1.97	.0244
.48	.3156	.98	.1635	1.48	.0694	1.98	.0239
.49	.3121	.99	.1611	1.49	.0681	1.99	.0233
.50	.3085	1.00	.1587	1.50	.0668	2.00	.0228

NOTE: IF N IS NEGATIVE P(-N) = 1 - P(N)

TABLE 5-5. NORMAL DISTRIBUTION VALUES FOR THE CUMULATIVE PROBABILITIES, PS OR PP, OF A POINT FALLING BEYOND NS OR NP (SEE NOTE) (CONTINUED)

N	P(N)
2.00	.0227
2.01	.0222
2.02	.0217
2.03	.0212
2.04	.0207
2.05	.0202
2.06	.0197
2.07	.0192
2.08	.0188
2.09	.0183
2.10	.0179
2.11	.0174
2.12	.0170
2.13	.0166
2.14	.0162
2.15	.0158
2.16	.0154
2.17	.0150
2.18	.0146
2.19	.0143
2.20	.0139
2.21	.0136
2.22	.0132
2.23	.0129
2.24	.0125
2.25	.0122
2.26	.0119
2.27	.0116
2.28	.0113
2.29	.0110
2.30	.0107
2.31	.0104
2.32	.0102
2.33	.0099
2.34	.0096
2.35	.0094
2.36	.0091
2.37	.0089
2.38	.0087
2.39	.0084
2.40	.0082
2.41	.0080
2.42	.0078
2.43	.0075
2.44	.0073
2.45	.0071
2.46	.0069
2.47	.0068
2.48	.0066
2.49	.0064
2.50	.0062
2.50	.0062
2.51	.0060
2.52	.0059
2.53	.0057
2.54	.0055
2.55	.0054
2.56	.0052
2.57	.0051
2.58	.0049
2.59	.0048
2.60	.0047
2.61	.0045
2.62	.0044
2.63	.0043
2.64	.0041
2.65	.0040
2.66	.0039
2.67	.0038
2.68	.0037
2.69	.0036
2.70	.0035
2.71	.0034
2.72	.0033
2.73	.0032
2.74	.0031
2.75	.0030
2.76	.0029
2.77	.0028
2.78	.0027
2.79	.0026
2.80	.0026
2.81	.0025
2.82	.0024
2.83	.0023
2.84	.0023
2.85	.0022
2.86	.0021
2.87	.0021
2.88	.0020
2.89	.0019
2.90	.0019
2.91	.0018
2.92	.0018
2.93	.0017
2.94	.0016
2.95	.0016
2.96	.0015
2.97	.0015
2.98	.0014
2.99	.0014
3.00	.0013
3.00	.0013
3.01	.0013
3.02	.0013
3.03	.0012
3.04	.0012
3.05	.0011
3.06	.0011
3.07	.0011
3.08	.0010
3.09	.0010
3.10	.0010
3.11	.0009
3.12	.0009
3.13	.0009
3.14	.0008
3.15	.0008
3.16	.0008
3.17	.0008
3.18	.0007
3.19	.0007
3.20	.0007
3.21	.0007
3.22	.0006
3.23	.0006
3.24	.0006
3.25	.0006
3.26	.0006
3.27	.0005
3.28	.0005
3.29	.0005
3.30	.0005
3.31	.0005
3.32	.0005
3.33	.0004
3.34	.0004
3.35	.0004
3.36	.0004
3.37	.0004
3.38	.0004
3.39	.0003
3.40	.0003
3.41	.0003
3.42	.0003
3.43	.0003
3.44	.0003
3.45	.0003
3.46	.0003
3.47	.0003
3.48	.0003
3.49	.0002
3.50	.0002
3.50	.0002
3.51	.0002
3.52	.0002
3.53	.0002
3.54	.0002
3.55	.0002
3.56	.0002
3.57	.0002
3.58	.0002
3.59	.0002
3.60	.0002
3.61	.0002
3.62	.0001
3.63	.0001
3.64	.0001
3.65	.0001
3.66	.0001
3.67	.0001
3.68	.0001
3.69	.0001
3.70	.0001
3.71	.0001
3.72	.0001
3.73	.0001
3.74	.0001
3.75	.0001
3.76	.0001
3.77	.0001
3.78	.0001
3.79	.0001
3.80	.0001
3.81	.0001
3.82	.0001
3.83	.0001
3.84	.0001
3.85	.0001
3.86	.0001
3.87	.0001
3.88	.0001
3.89	.0000
3.90	.0000
3.91	.0000
3.92	.0000
3.93	.0000
3.94	.0000
3.95	.0000
3.96	.0000
3.97	.0000
3.98	.0000
3.99	.0000
4.00	.0000

NOTE: IF N IS NEGATIVE P(-N) = 1 - P(N)

probability of exceeding the port edge. The two probabilities added together are the RRF.*

Calculate the RRF for all aid alternatives and for all turn regions of interest. A worksheet for summarizing the RRFs calculated appear at the end of Section 5.

---

*If both NS and NP are 4 or greater, RRF found in this way will be 0.000 or an indeterminate amount less. The measure calculated in this way does not differentiate among low risk conditions. The designer comparing several such low risk conditions has a number of choices. He can decide that differences among low RRFs do not matter and make decisions on some other basis. He can calculate PS and PP on his own. He can assume a slower speed and/or a greater crosstrack current in calculation, possibly bringing one or more RRF values above threshold. Or he can use (NS+NP) as a measure. (NS+NP) is a measure of the order of risk but not the magnitude.

5.3 EVALUATION OF PERFORMANCE IN THE RECOVERY REGIONS

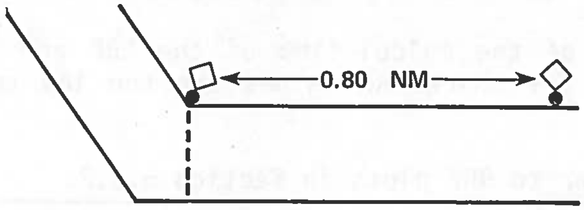
This section contains instructions and data tables for the provision of a relative risk factor (RRF) value for each recovery region. Instructions for specifying the recovery regions appear in Section 3.3.2. The performance data presented in this section to represent the recovery region were taken during a maneuver to the centerline at a point where both the crosstrack displacement (the mean, MN) and the crosstrack dispersion (the standard deviation, SD) of the set of transits were at their highest and contributed to a high RRF for the region.

5.3.1 Selection of Baseline Data

The method of calculating the RRF uses "baseline" performance data for a 30,000 dwt ship in a 500-foot channel and "corrects" it for other ship sizes and channel widths. This subsection contains instructions for the selection of baseline data from Table 5-6 for each recovery region. The steps are summarized in Worksheet 5-3 which can be copied for each recovery region.and design alternative. The system designer may prefer not to use this worksheet but to enter baseline data on another worksheet in Section 5.3.3.

1. Aid Arrangement. Performance data are presented in Table 5-6 for a number of aid arrangements. Gated, staggered, and one-side arrangements were discussed in Section 4.4. To summarize that discussion Figure 4-5 is repeated here. Ranges are discussed in Section 4.2.3. The calculations necessary to determine their sensitivity are repeated here. Select the appropriate arrangement by the following rules for each recovery region and each design alternative to be evaluated.

   - For a gated arrangement, if the alongtrack distance from the last aid in the turn to the first gate is 0.80 nautical miles (nm), any of the data for gated aids can be used. For a larger ship, this spacing should be repeated for the entire length of the recovery region to justify this choice of data. A sample arrangement is illustrated.



   - For a staggered arrangement, if the alongtrack distance from the last aid in the turn to the first straight channel aid is ≤0.31 nm and it is on the opposite side of the channel from the last aid in the turn and the general distance along one edge between staggered aids is ≤0.62 nm, the data for short-spaced staggered

TABLE 5-6. BASELINE PERFORMANCE DATA FOR RECOVERY REGION

CRAB ANGLE, 0-2 degrees

MARKING	MN[1]	SD[2]	RRF[3]	NP+NS[4]
gated aids, day or night	7	39	0.0000	10.6
short-spaced, staggered aids	16	29	0.0000	14.3
long-spaced, staggered aids	5	65	0.0018	6.37
one-side channel marking	15	44	0.0000	9.44
high-sensitivity range	15	25	0.0000	16.64
low-sensitivity range	50	35	0.0000	11.88

CRAB ANGLE, 2-5 degrees

MARKING	MN[1]	SD[2]	RRF[3]	PLOT[5]
gated aids, day	97	34	0.0019	14
gated aids, night/dusk/dawn	97	48	0.0202	15
short-spaced, staggered aids	100	51	0.0307	
long-spaced, staggered aids	94	70	0.0735	16
one-side channel marking	116	86	0.1789	
high-sensitivity range	56	42	0.0005	17
low-sensitivity range	41	117	0.1151	18

NOTES:

1. Means (MN) are expressed as feet from channel centerline.
2. Standard deviations (SD) are in feet.
3. The relative risk factor (RRF) was calculated using the instructions in Section 5.3.3 and the standard conditions described in Table 5-7.
4. NP+NS comes out of the calculation of the RRF and is included only for those situations for which RRF values are too low to differentiate among alternatives.
5. Plot numbers refer to RRF plots in Section 5.3.2.

WORKSHEET FOR EVALUATION OF THE RECOVERY REGION: SELECTION OF BASELINE DATA (SHEET 1 OF 3)

Instructions in Section 5.3.1.

Copy for each design/evaluation objective and recovery region.

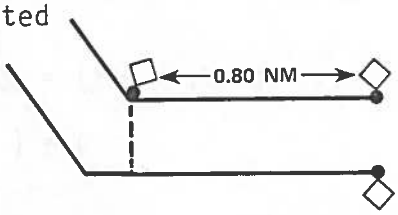
Design/Evaluation Objective: ____

____

Region Identification: ____

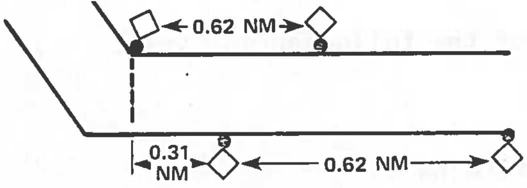
1. Aid Arrangement: (check one)

a. gated



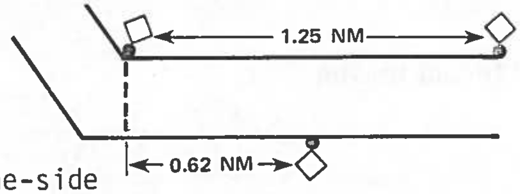
b. gated,
longer spacing

c. staggered, short-spaced



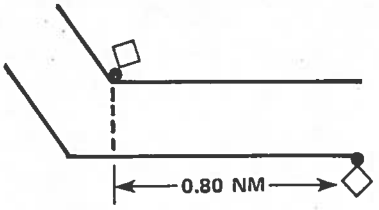
d. staggered, short-spaced,
nonconforming

e. staggered, long-spaced



f. staggered, long-spaced,
nonconforming

g. one-side



h. one-side,
nonconforming

Worksheet 5-3

WORKSHEET FOR EVALUATION OF THE RECOVERY REGION: SELECTION OF BASELINE DATA (SHEET 2 OF 3)

2. Range Sensitivity, K (check one): high $(K \geq 3)$ low $(K < 3)$

(WxR)/[D(H-h)] = K
(   )/[(-   )] = (   )

Reminder:
K: sensitivity
W: width (ft)
R: between structures (mn)
D: to front structure (mn)
H: rear structure (ft)
h: front structure (ft)

3. Crab angle: 0-2 versus 2-5 degrees

Select crab angle: 0-2 degrees 2-5 degrees >5 degrees

Calculate as:

$\tan^{-1}$ (crosstrack current, knots/transit speed, knots) = (CA)

$\tan^{-1}$ (/   ) = (   )

or see Table 4-4

Choose 2-5 degree data if one of the following is "yes".

1. CA ≥ 2 degrees yes no
2. Aid arrangements are nonconforming yes no
3. Conservatism needed yes no
4. Low risk conditions need differentiation yes no

Worksheet 5-3 (Continued)

WORKSHEET FOR EVALUATION OF THE RECOVERY REGION:
SELECTION OF BASELINE DATA (SHEET 3 OF 3)

4. SELECT BASELINE DATA:

	MN	SD	RRF
Day	____	____	____
Night/dusk/dawn	____	____	____
Range	____	____	____

Worksheet 5-3 (Continued)

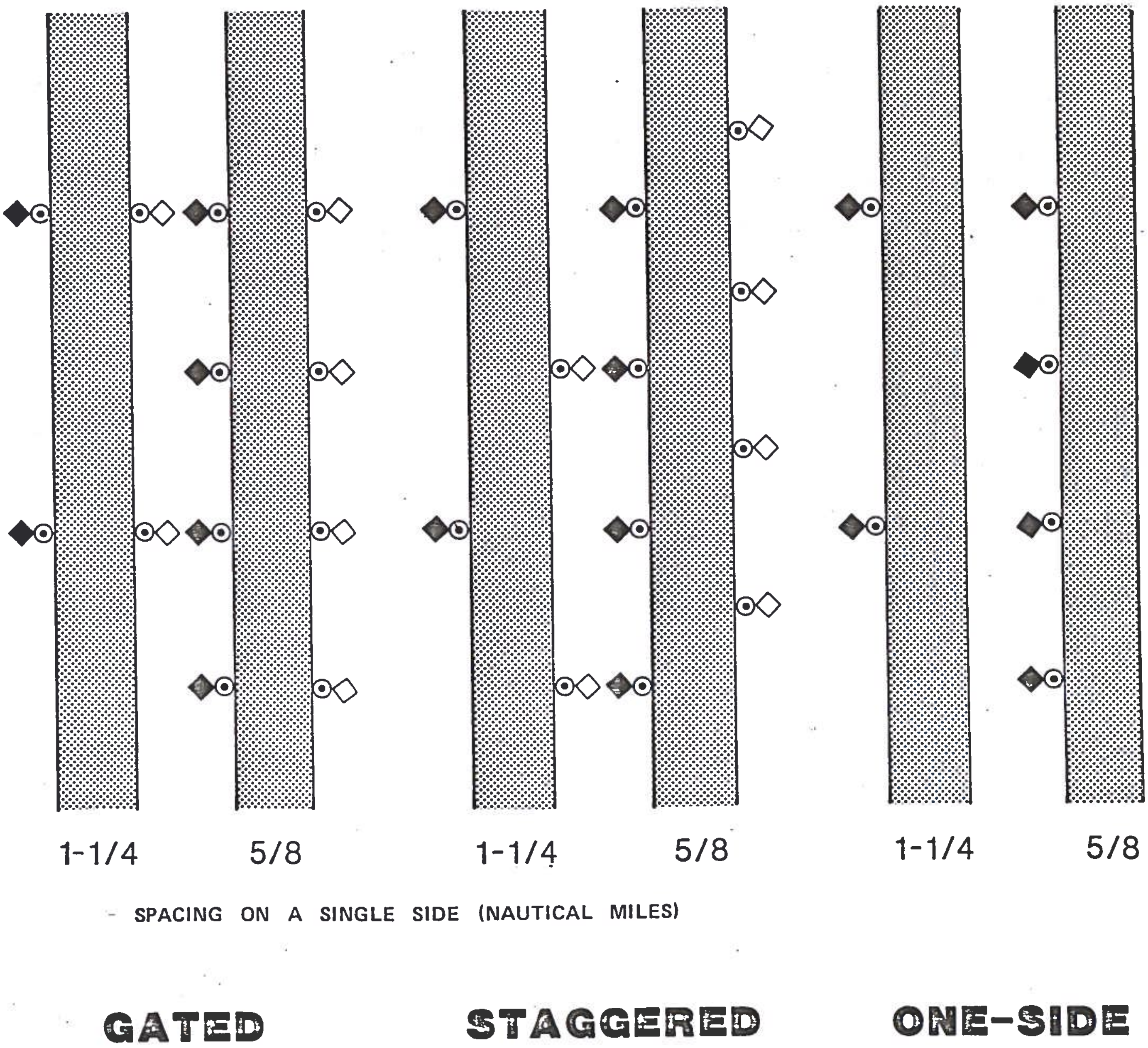
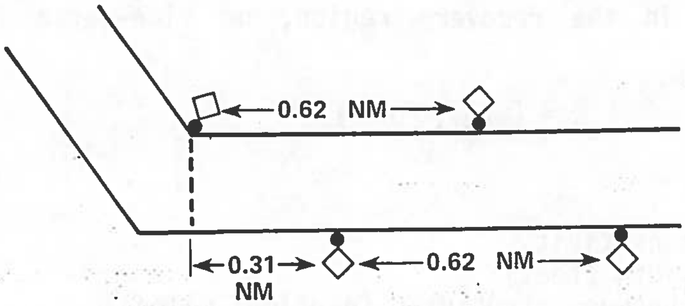
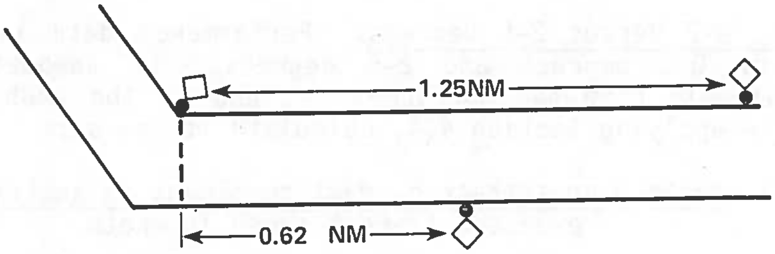


Figure 4-5. Alternative Buoy Arrangements for Straightaways

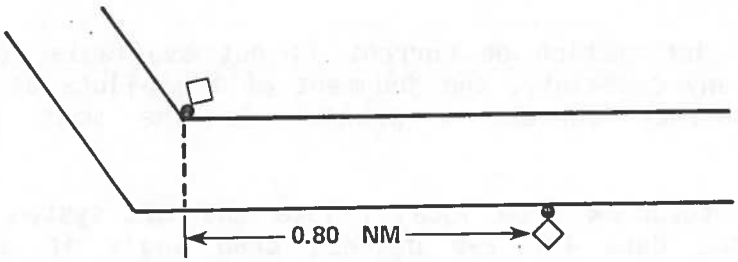
aids can be used. A sample arrangement that conforms to this rule is illustrated.



- For a staggered arrangement, if the alongtrack distance from the last aid in the turn to the first straight channel aid is ≤0.62 nm and it is on the opposite side of the channel from the last aid in the turn and the general distance along one edge between staggered aids is ≤1.25, the entries for long-spaced staggered aids can be used. A sample arrangement that conforms to this rule is illustrated.



- For a one-side channel arrangement, if the alongtrack distance to the first aid is ≤0.80 nm and that aid is to the outside of the turn, either of the entries for one-side channel marking can be used. A sample arrangement that conforms to this rule is illustrated.



If the aid arrangement does not conform to the rules given here, Item 3 below has further instructions.

2. Range Sensitivity. For ranges sensitivity should be calculated, if it has not already been done. Note the sensitivity of the range is inversely proportional to the distance from the observer to the front structure. A low sensitivity range in the turn region may become a high-sensitivity range in the recovery region, or vice-versa for a back range.

$$K = [WR]/[D(H-h)] \qquad (5\text{-}1)$$

where:

K = lateral sensitivity
W = channel width (feet)
R = distance between structures (nautical miles)
D = distance from front structure to the beginning of the recovery region
H = height of rear structure (feet)
h = height of front structure (feet)

- If K is equal to or greater than 3, it is a high-sensitivity range.
- If K is less than 3, it is a low-sensitivity range.

3. Crab Angle: 0-2 Versus 2-5 Degrees. Performance data is presented for crab angles of 0-2 degrees and 2-5 degrees. If adequate current information is available from the Worksheet 3-1 and if the crab angle was not calculated while applying Section 4.4, calculate it now as:

$$CA = \tan^{-1}\left(\frac{\text{maximum crosstrack current component in knots}}{\text{expected transit speed in knots}}\right) \qquad (5\text{-}2)$$

Approximations to this calculation appear in Table 4-4 which is repeated here. For the purposes of selecting data, apply the following rules:

- If CA is calculated as 0 to 2 degrees, select data so labeled.
- If CA is calculated as 2 to 5 degrees, select data so labeled.
- If CA is calculated as greater than 5 degrees, select data labeled 2 to 5 degrees but note on the worksheet that risk is underestimated.

If sufficient information on current is not available to calculate the crab angle with any certainty, the judgment of the pilots as to whether they consider crosstrack current a problem is the most appropriate substitute.

Based on the feedback from local pilots and the system designer's knowledge, select the data for 2-5 degrees crab angle if one of the following conditions apply. If none apply, choose the data for 0-2 degrees crab angle.

- There is indeed sufficient crosstrack current to require a crab angle of greater than 2 degrees.

TABLE 4-4. CRAB ANGLE AS A FUNCTION OF MAXIMUM CROSSCURRENT COMPONENT (KNOTS) AND EXPECTED TRANSIT SPEED (KNOTS)

	Maximum Crosscurrent Component (Knots)									
TRANSIT SPEED KNOTS	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
6	≤2	≤2	2-5	2-5	2-5	≥5	≥5	≥5	≥5	≥5
7	≤2	≤2	2-5	2-5	2-5	2-5	≥5	≥5	≥5	≥5
8	≤2	≤2	2-5	2-5	2-5	2-5	≥5	≥5	≥5	≥5
9	≤2	≤2	≤2	2-5	2-5	2-5	2-5	≥5	≥5	≥5
10	≤2	≤2	≤2	2-5	2-5	2-5	2-5	2-5	≥5	≥5
11	≤2	≤2	≤2	2-5	2-5	2-5	2-5	2-5	2-5	≥5
12	≤2	≤2	≤2	≤2	2-5	2-5	2-5	2-5	2-5	2-5
15	≤2	≤2	≤2	≤2	≤2	2-5	2-5	2-5	2-5	2-5

Note:

$$\text{Crab angle} = \tan^{-1}\left(\frac{\text{maximum crosscurrent component (knots)}}{\text{expected transit speed (knots)}}\right)$$

- The aid arrangement does not conform to the rules for placement and spacing in Item 1. If there is enough of a crosstrack current to require a crab angle of greater than 2 degrees and the aid arrangement does not conform, use the 2-5 degree crab angle data and make a note on the worksheet that risk is underestimated.

- The guidelines of Sections 3 and/or 4 have identified a factor or factors that require conservatism in design and evaluation. These factors are summarized in the Worksheets 3-1 and 4-1. If there is a need for conservatism; and there is also crosstrack current sufficient to require a crab angle of greater than 2 degrees or the aid arrangement does not conform to the rules in Item 1, use the 2-5 degree crab angle data and make a note that risk is underestimated.

- The objective is to differentiate among what are actually low risk conditions. Note that the RRF values in Table 5-6 for the 0-2 degree crab angle conditions are mostly 0.0000 and do not differentiate among conditions. One way to achieve differentiation is to assume the engineer's "design conditions." Assume greater shiphandling difficulty and use the 2-5 degree crab angle data. Make a note that risk is overestimated. If the 2-5 degree crab angle data is chosen for this reason for one alternative aid arrangement, or for one day or night or visibility condition in a region, it should be chosen for its competitors. If it is chosen for one recovery region when the intention is the evaluation of the whole waterway or the comparison with other waterways, other recovery regions should be represented in the same way.

4. Day and Night Conditions. Note that separate data is offered for day and night only for gated arrangement with a crab angle of 2-5 degrees. No distinction is necessary for other arrangements or for gates with 0-2 degree crab angle.

5. SELECT BASELINE DATA. Select baseline data for the following conditions and enter on worksheet labeled Worksheet 5-3.

	Mean	Standard Deviation	Relative Risk Factor
Day	____	____	____
Nighttime/dusk/dawn	____	____	____
Ranges	____	____	____

5.3.2 Use of Precalculated Relative Risk Factor (RRF) Values

As was the case for the turn regions, several options are available for arriving at a relative risk factor (RRF) value. The simplest option is to use the RRF values in the baseline data table in Section 5.3.1. Another possibility is to take a value from the plots presented in this subsection. The most precise and most time-consuming option is to calculate a value by the instructions given in Section 5.3.3. Caution must be exercised in comparing values obtained in different ways. The comparisons that are appropriate are discussed in reference to the turn region in Section 5.2.2 and are not repeated here.

The RRF values in the baseline data Table 5-6 were calculated for a 30,000 dwt ship in a 500-foot channel. The values of the mean and standard deviation of each condition considered are given in that table. The parameters of the ship and channel used in the calculations in Table 5-6 appear in Table 5-7, along with a sample calculation for the first entry with a 2-5 degree crab angle.

Selected conditions are also represented by plots extrapolating the baseline data over ship size and channel width. For the recovery region the plots appear as Plots 5-14 to 5-18. The plot numbers are continuous with the numbers for the turn region plots. Note that on each plot, the value for a 30,000 dwt ship in a 500-foot channel corresponds to a baseline value in Table 5-6. In that table the baseline values that correspond to a plot are indicated by the number of the plot.

In order to precalculate the RRF values, parameter values for the ship and channel were standardized. The parameters for ship size appear in Table 5-3 which is repeated here for reference. In calculating the adjusted beam for the ship, the crosstrack current component was assumed to be 0.25 knots and the transit speed 6 knots which results in the B' values entered in Table 5-3 for the recovery region. These velocities also result in a crab angle in the 2-5 degree range as shown in Table 4-4. The same channel widths used in the turn region plots were used: 300, 400, 500, 600, 700, and 800 feet. The correction factors for ship size and channel width were applied according to the table and instructions in the following subsection for calculating specific RRF values.

The instructions given earlier in this subsection for selecting baseline data are equally appropriate for selecting a plot. The plots are presented only for conditions with a crab angle of 2-5 degrees because these are expected to be most frequently needed by the system designer. With the higher crab angle, the aid arrangements most likely to be used were selected for representation by plots. If the designer needs a value for a condition that is not represented by a plot, he has two choices. He can select another condition and substitute it with a notation that risk may be under or overestimated. As an example, if he is interested in gates with a 0-2 degree crab angle, he can substitute daytime gates with a 2-5 degree angle and make a note that risk is overestimated. Or he can calculate the RRF value needed by the instructions that follow shortly. Once the appropriate plot is selected, the user can find a value for the ship size and channel width which he indicated on Worksheet 3-1 on waterway conditions. He can interpolate on the plot to find intermediate values. If he has a need for more precise values, he can calculate them. Extrapolating to values outside those plotted is not recommended.

5.3.3 Relative Risk Factor (RRF) Calculations for Specific Conditions

RRF values can be calculated by the system designer for all baseline conditions in Table 5-6 and for a variety of ship sizes and channel widths.

TABLE 5-7. PARAMETERS OF SHIP AND CHANNEL USED FOR BASELINE RELATIVE RISK FACTOR (RRF) VALUES IN THE RECOVERY REGION AND A SAMPLE CALCULATION

SHIP PARAMETERS	
Ship size	30,000 deadweight tons (dwt)
Ship length	590 feet
Ship beam	85 feet
Crosstrack current velocity	0.25 knots
Transit speed	6 knots
B' (feet)	54.79 feet
CHANNEL PARAMETERS	
Channel width	500 feet

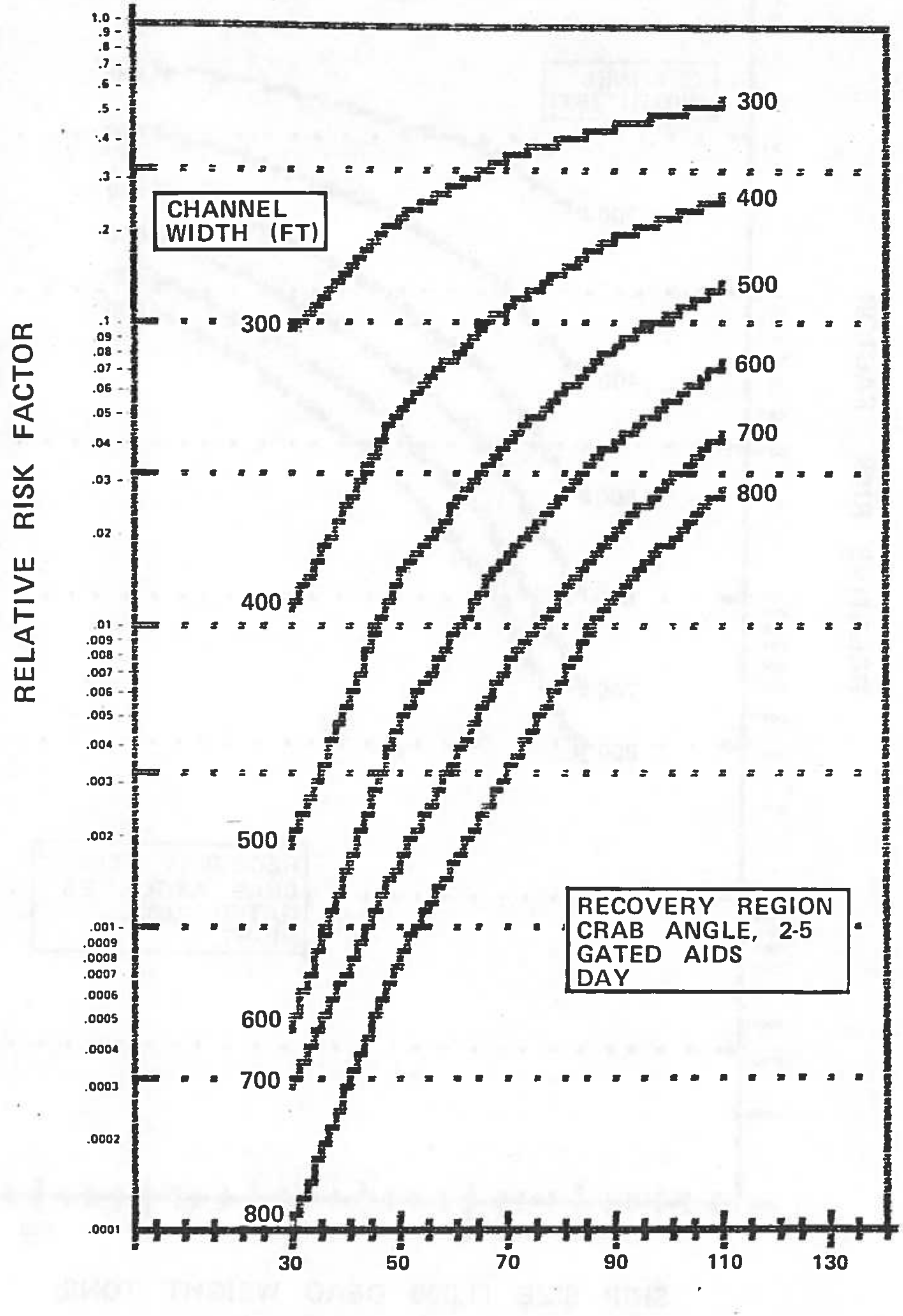
SAMPLE CALCULATION OF RRF: Crab angle, 2-5 degrees; gated aids; day

[(W/2 - (MN) - (B')]/(SD) = (NS)
[(500/2) - (97) - (54.79)]/(34) = (2.89)

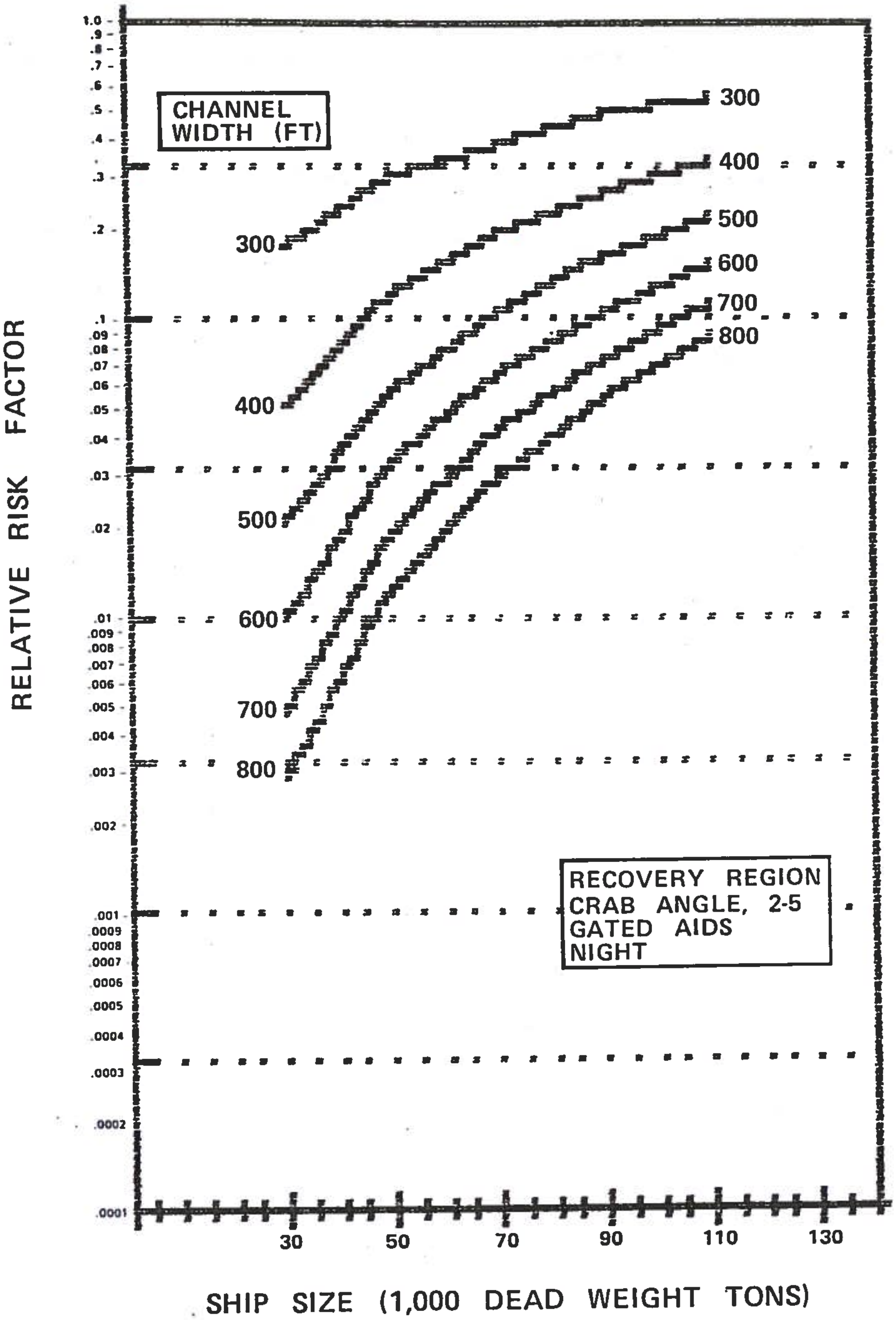
[(W/2) + (MN) - (B')]/(SD) = (NP)
[(500/2) + (97) - (54.79)]/(34) = (8.59)

(PS) + (PP) = (RRF)
(0.0019) + (0.0000) = (0.0019)

reminder:
W: channel width
MN: mean
B': adjusted beam/2
SD: standard deviation
NS: SDs to starboard
NP: SDs to port
PS: prob to starboard
PP: prob to port
RRF: relative risk factor

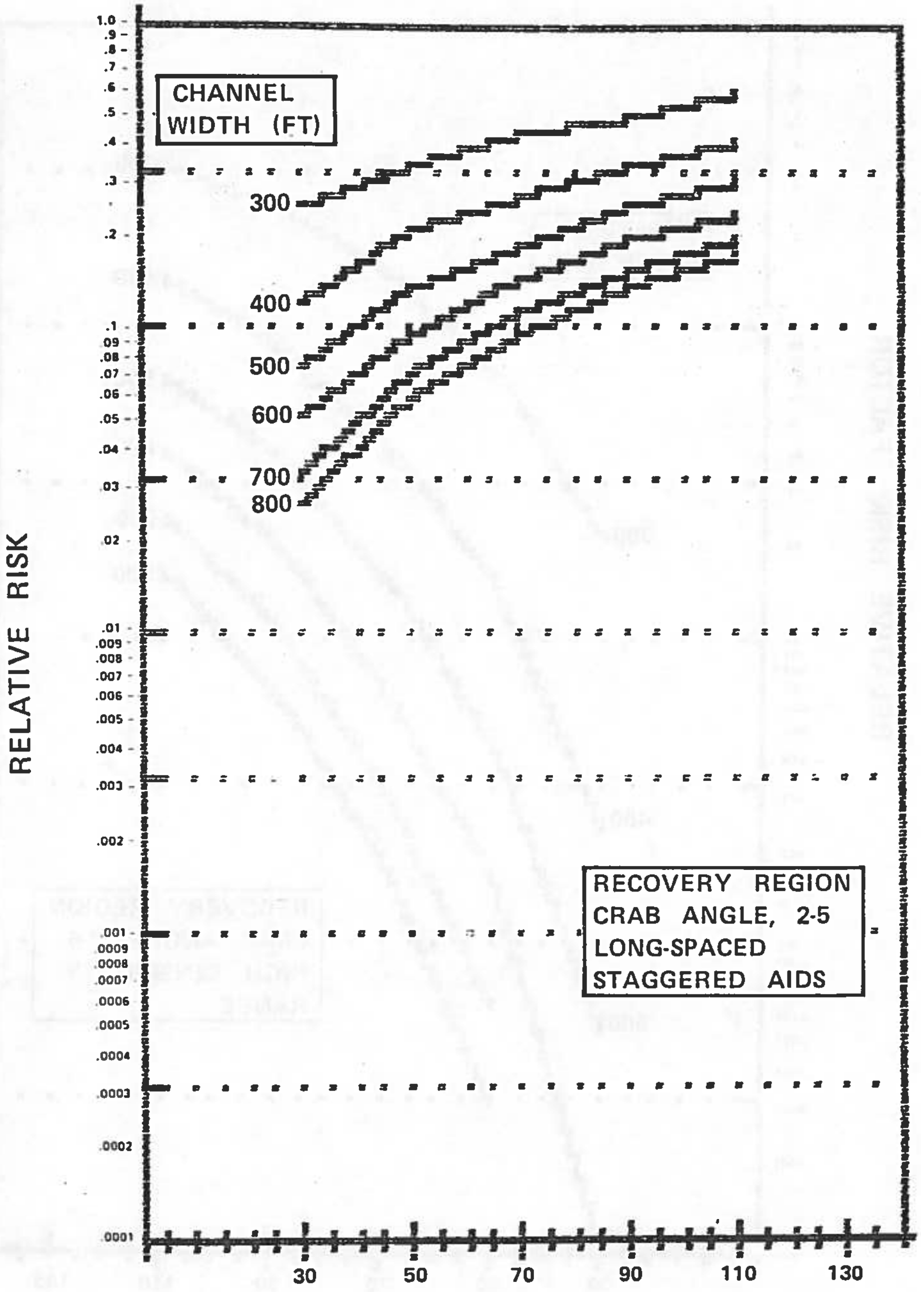

RELATIVE RISK FACTOR
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
CHANNEL WIDTH (FT)
300
400
500
600
700
800
RECOVERY REGION
CRAB ANGLE, 2-5
GATED AIDS
DAY
30
50
70
90
110
130
SHIP SIZE (1,000 DEAD WEIGHT TONS)

PLOT 5-14



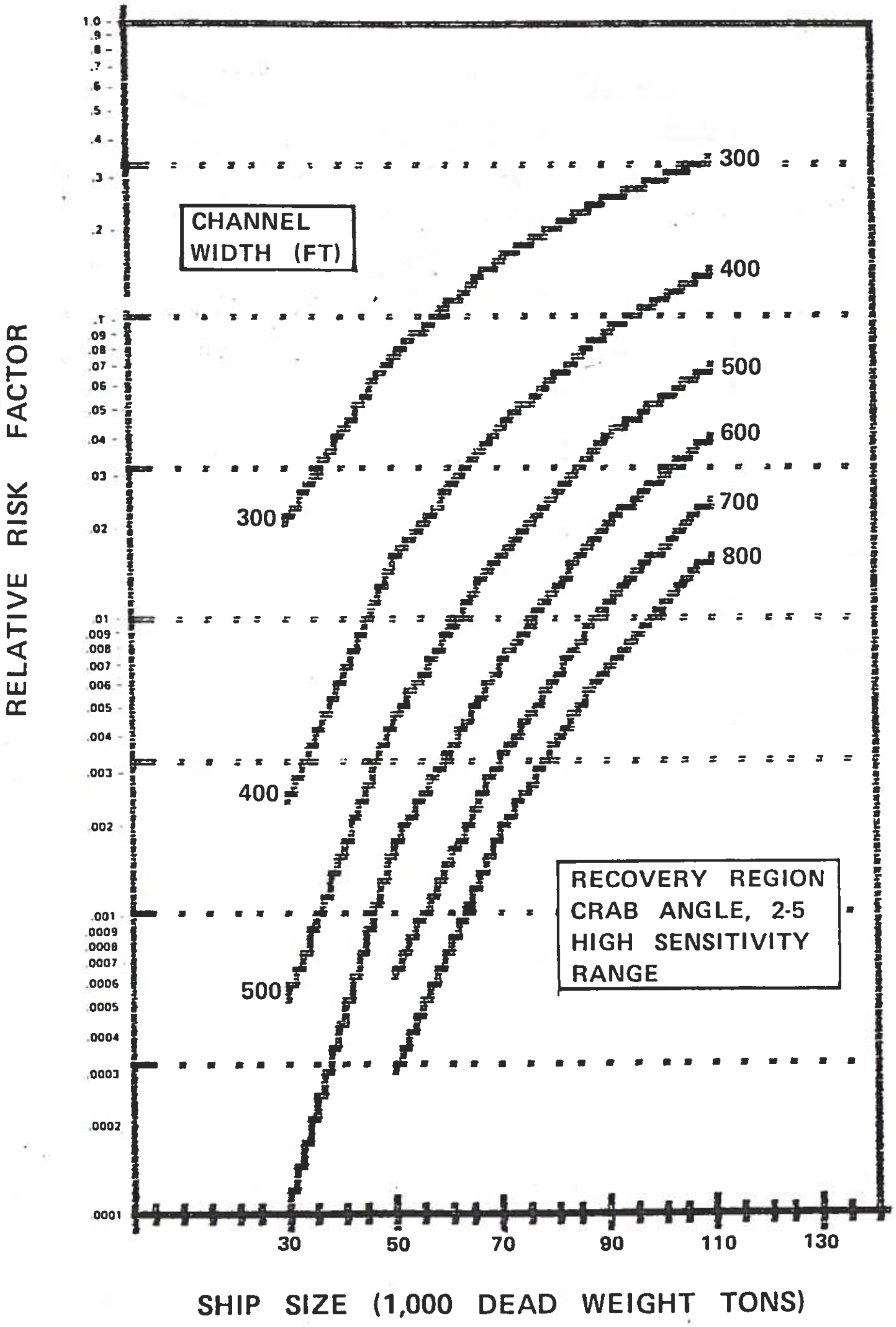
RELATIVE RISK FACTOR
CHANNEL WIDTH (FT)
300
400
500
600
700
800
RECOVERY REGION
CRAB ANGLE, 2-5
GATED AIDS
NIGHT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
30
50
70
90
110
130
SHIP SIZE (1,000 DEAD WEIGHT TONS)

PLOT 5-15



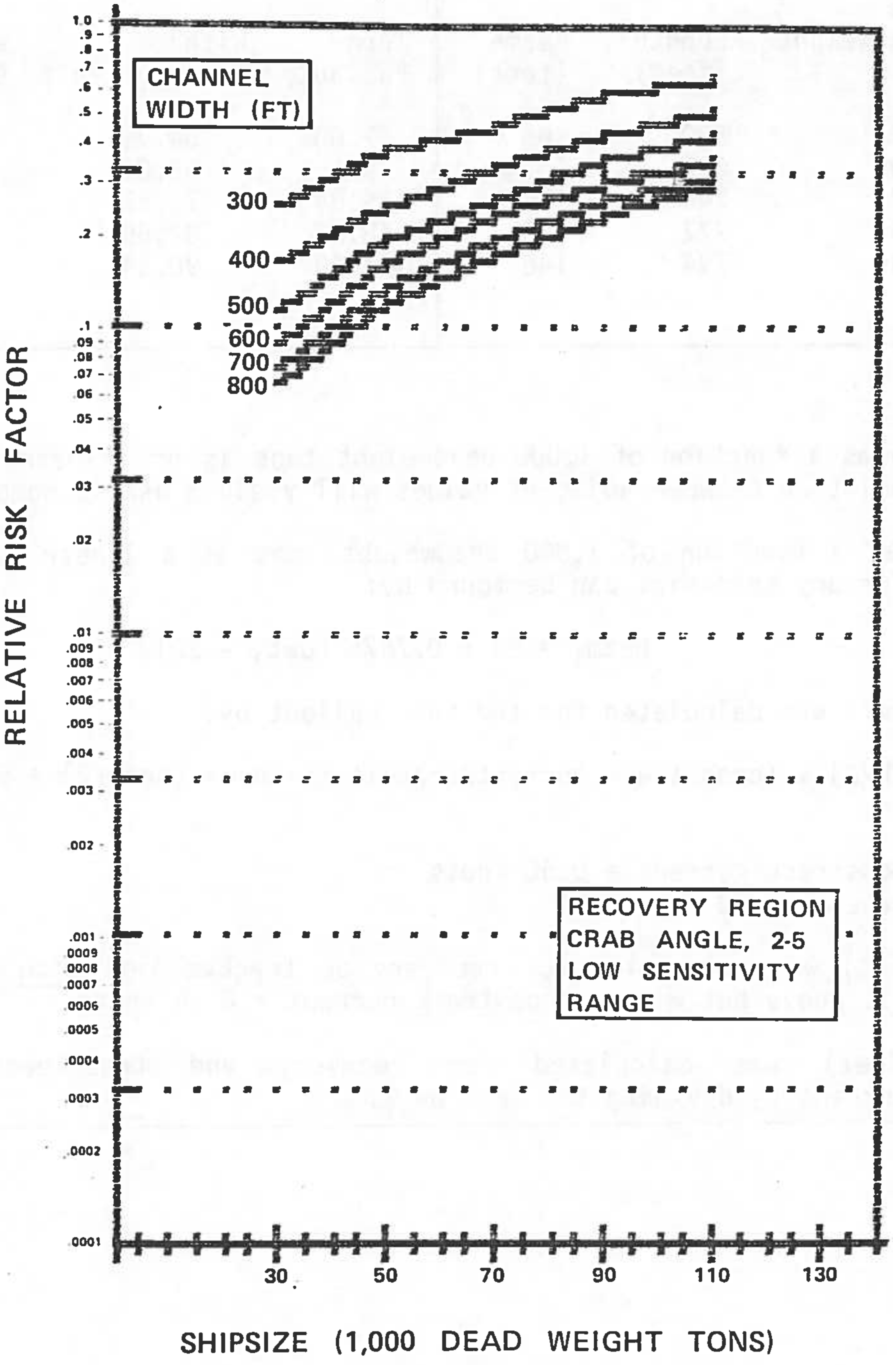
SHIP SIZE (1,000 DEAD WEIGHT TONS)

PLOT 5-16



Note that the curves for the wider channel widths do not show values for the smaller ship sizes. The missing values are less than 0.0000.

PLOT 5-17


CHANNEL WIDTH (FT)
300
400
500
600
700
800
RECOVERY REGION
CRAB ANGLE, 2-5
LOW SENSITIVITY
RANGE
RELATIVE RISK FACTOR
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
30
50
70
90
110
130
SHIPSIZE (1,000 DEAD WEIGHT TONS)

PLOT 5-18

TABLE 5-3. STANDARD SHIP DIMENSIONS USED IN CALCULATION OF RELATIVE RISK FACTOR (RRF) FOR PLOTS

Ship Size 1,000 deadweight tons	Length[1] (feet)	Beam[2] (feet)	B' (feet) Turn[3] Pullout	B' (feet) With[4] Crosscurrent	B' (feet) Without[5] Crosscurrent
30	590	85	67.00	54.79	42.50
50	683	102	79.45	65.23	51.00
70	745	116	89.04	73.52	58.00
90	777	133	98.87	82.69	66.50
110	794	148	107.80	90.54	74.00

NOTES:

1. Length as a function of 1,000 deadweight tons is not linear but a linear interpolation between adjacent values will yield a usable number.

2. Beam as a function of 1,000 deadweight tons is a linear function. The beam for any ship size can be found by:

$$\text{beam}_i = 85 + 0.7875\ (\text{dwt}_i - 30)$$

3. B' (feet) was calculated for the turn pullout by:

   (length/2) x (crosstrack current/transit speed) + (beam/2) = B'

   where
   crosstrack current = 0.50 knots
   transit speed = 6 knots

4. B' (feet) was calculated for recovery or trackkeeping with crosscurrent as in 3. above but with a crosstrack current = 0.25 knots.

5. B' (feet) was calculated for recovery and trackkeeping without crosscurrent by dividing the beam by 2.

The instructions for calculating the RRF are summarized in Worksheet 5-4, which can be copied for each recovery region and alternative aid arrangement. Note that Worksheet 5-4 begins where Worksheet 5-3 for selecting baseline data, finishes. The instructions below elaborate on the items in Worksheet 5-4.

1. Baseline Data from Worksheet 5-3 (or Table 5-6). If appropriate baseline data has not already been selected according to the instructions given in Section 5.3.1, it must be done now. The baseline RRF value is a predictor of what can be expected. If the ship being considered is larger than 30,000 dwt or the channel narrower than 500 feet; the risk will be higher. If the channel is wider, the risk will be lower. Enter the baseline values in Item 1.

2. Channel Parameters from Worksheet 3-1. The channel parameter needed in the calculations was entered in Worksheet 3-1 on waterway conditions. Either copy it from there or measure it now on the chart. Enter in Item 2.

3. Environmental Parameters from Worksheet 3-1. If crosstrack current is apparent within the recovery region, enter the value of the maximum crosstrack current component. Consider it positive whatever its direction. If the crosscurrent is present but there is not sufficient information to calculate it, use 0.25 knots. If there is a need for conservatism or a need to match precalculated RRF values, use 0.25 knots. Enter in Item 3.

4. Design Vessel Parameters from Worksheet 3-1. A design vessel was chosen and its parameters entered in Worksheet 3-1. If the parameters were not established then, it should be done now. Ship size (deadweight tons) is needed to correct the performance data. The ship's length (feet, between perpendiculars), its beam (feet), and its expected transit speed (knots) are needed to calculate the halved adjusted beam (B'). Enter the values needed in Item 4 and complete the calculations. Note that B' for a recovery remains the same, even though the baseline data changes for day, night/dusk/dawn, ranges, and different aid arrangements. Unless different crosstrack currents are assumed in different regions, it is even the same for different recovery regions.

WORKSHEET FOR EVALUATION OF THE RECOVERY REGION: CALCULATION OF THE RELATIVE RISK FACTOR (RRF) FOR SPECIFIC CONDITIONS

(SHEET 1 OF 3)

Instructions in Section 5.3.3.

Copy for each design/evaluation objective and recovery region.

Design/Evaluation Objective:______________________________

____

Region Identification:______________________________

1. Baseline Data from Worksheet 5-3 (or Table 5-6)

	MN	SD	RRF
Day	____	____	____
Night/dusk/dawn	____	____	____
Range	____	____	____

2. Channel Parameters from Worksheet 3-1

Navigable width of straight segment______________ (W)______

3. Environmental Parameters from Worksheet 3-1

Crosstrack current (knots)______________________________

or use 0.25 knots for comparability to precalculated values.

4. Design Vessel Parameters from Worksheet 3-1

Ship size (deadweight tons)______________________________

Length (feet)______________________________

Beam (feet)______________________________

Transit speed (knots)______________________________

B':

[(length/2) x (crosstrack current/transit speed)] + (beam/2) = (B')

[(/2) x (/   ] + (/2) = (feet)

Worksheet 5-4

WORKSHEET FOR EVALUATION OF THE RECOVERY REGION: CALCULATION OF THE RELATIVE RISK FACTOR (RRF) FOR SPECIFIC CONDITIONS

(SHEET 2 OF 3)

5. Correct Mean (MN) and Standard Deviation (SD)

See Table 5-8 for correction factors:

MCSHP _____ MCWID _____

SCSHP _____ SCWID _____

Calculation:

DAY

(MN) x (MCSHP) x (MCWID) = (MN')
( ) x ( ) x ( ) = ( )

(SD) x (SCSHP) x (SCWID) = (SD')
( ) x ( ) x ( ) = ( )

NIGHT/DUSK/DAWN

(MN) x (MCSHP) x (MCWID) = (MN')
( ) x ( ) x ( ) = ( )

(SD) x (SCSHP) x (SCWID) = (SD')
( ) x ( ) x ( ) = ( )

RANGE

(MN) x (MCSHP) x (MCWID) = (MN')
( ) x ( ) x ( ) = ( )

(SD) x (SCSHP) x (SCWID) = (SD')
( ) x ( ) x ( ) = ( )

Worksheet 5-4 (Continued)

WORKSHEET FOR EVALUATION OF THE RECOVERY REGION: CALCULATION OF THE RELATIVE RISK FACTOR (RRF) FOR SPECIFIC CONDITIONS

(SHEET 3 OF 3)

6. CALCULATE RELATIVE RISK FACTOR (RRF)

See Table 5-5 for PS and PP.

DAY

[(W/2) - (MN') - (B')]/(SD') = (NS)
[(/2) - (   ) - (   )]/(   ) = (   )

[(W/2) + (MN') - (B')]/(SD') = (NP)
[(/2) + (   ) - (   )]/(   ) = (   )

(PS) + (PP) = (RRF)
(   ) + (   ) = (   )

NIGHT/DUSK/DAWN

[(W/2) - (MN') - (B')]/(SD') = (NS)
[(/2) - (   ) - (   )]/(   ) = (   )

[(W/2) + (MN') - (B')]/(SD') = (NP)
[(/2) + (   ) - (   )]/(   ) = (   )

(PS) + (PP) = (RRF)
(   ) + (   ) = (   )

RANGE

[(W/2) - (MN') - (B')]/(SD') = (NS)
[(/2) - (   ) - (   )]/(   ) = (   )

[(W/2) + (MN') - (B')]/(SD') = (NP)
[(/2) + (   ) - (   )]/(   ) = (   )

(PS) + (PP) = (RRF)
(   ) + (   ) = (   )

reminder:
W: channel width from #2
MN': corrected MN from #5
B': adjusted beam/2 from #4
SD': corrected SD from #5
NS: SDs to starboard
NP: SDs to port
PS: prob to starboard
PP: prob to port
RRF: relative risk factor

Worksheet 5-4 (Continued)

5. Correct Mean (MN) and Standard Deviation (SD). Corrections factors to correct the baseline MN and SD for the ship size and channel width of interest appear in Table 5-8.

To correct the baseline data for channel width use the width of the channel that is marked by the aids. If this is not the same as the navigable width for the design vessel draft, the resulting RRF will be affected.*

If the value needed is not in the table, interpolate by the formulas given.

Select the correction factors and complete calculations as instructed in Item 5.

---

*The baseline data is corrected for the channel width marked by the aids on the assumption that the baseline data represents the piloted performance of the vessel and that the pilots adjust that performance to the width of the marked channel. If the aids are set back from the edge of the navigable channel for the design vessel, this assumption results in a higher RRF. It is undoubtedly conservative in that the pilots know that the channel is less than that marked, even though they cannot accurately estimate its exact width. If the bottom is very soft, the designer may want to note that risk is overestimated. If the aids are set inside the edge of the navigable channel for the design vessel, the RRF will be lower. The risk of hitting the aid itself is not considered.

TABLE 5-8. CORRECTION FACTORS FOR THE RECOVERY REGION

FOR ALL CONDITIONS

Ship Size 1,000 dwt	30	50	70	90	110
MCSHP[1]	1	1	1	1	1
SCSHP[2]	1	1.17	1.33	1.50	1.67

slope = 0.0084

CHANNEL WIDTH (marked by aids, in feet)

	300	400	500	600	700	800
MCWID[3]	0.67	0.83	1	1.17	1.33	1.5
SCWID[4]	0.67	0.83	1	1.17	1.33	1.5

NOTES

1. MCSHP: mean correction factor for ship size

2. SCSHP: standard deviation correction factor for ship size

   To interpolate for SCSHP, use

$$SCSHP_i = 1 + slope\ (X_i - 30)$$

   where:

   $SCSHP_i$ = correction factor for any ship size in 1,000 dwt
   X_i = ship size in 1,000 dwt
   slope = value given in table above

3. MCWID: mean correction factor for channel width

   To interpolate for MCWID, use:

$$MCWID_i = 1 + 0.5\ (W_i - 500)/300$$

   where

   $MCWID_i$ = correction factor for any channel width
   W_i = channel width

4. SCWID: standard deviation correction factor for channel width.

   Interpolate as in Note 3.

6. Calculate the Relative Risk Factor (RRF). To calculate the RRF, first calculate the number of SDs (NS) that will fit between the extreme starboard point of the ship and the edge of the channel. Start with the useful channel width (W) and divide it by two. Subtract the corrected MN crosstrack displacement of the set of tracks (MN') and one-half the adjusted beam of the ship (B'). The distance remaining between the extreme starboard point and the edge of the channel is then divided by the corrected crosstrack SD (SD'). The result is labeled NS in Worksheet 5-4. NS may be negative. For the port side start with the useful channel width (W) and divide it by two. Add the additional space allowed by the displacement of the MN' to starboard. Subtract B'. The distance remaining between the extreme port point and the edge of the channel is then divided by SD'. The result is labeled NP in Worksheet 5-4. NP may be negative. To find RRF as a probability, enter Table 5-5, which is repeated here for convenience, with NS to find PS, the probability of exceeding the starboard edge. Then use NP to find PP, the probability of exceeding the port edge. The two probabilities added together are the RRF.*

Calculate the RRF for all aid alternatives and for all turn regions of interest. Worksheets for summarizing the RRFs calculated appear at the end of Section 5.

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*If both NS and NP are 4 or greater, RRF found in this way will be 0.000 or an indeterminate amount less. The measure calculated in this way does not differentiate among low risk conditions. The system designer comparing several such low risk conditions has a number of choices. He can decide that differences among low RRFs don't matter and make decisions on some other basis. He can calculate PS and PP on his own. He can assume a slower speed and/or a greater crosstrack current in calculation, possibly bringing one or more RRF values above threshold. Or he can use (NS+NP) as a measure. (NS+NP) is a measure of the order of risk but not the magnitude.

TABLE 5-5. NORMAL DISTRIBUTION VALUES FOR THE CUMULATIVE PROBABILITIES, PS OR PP, OF A POINT FALLING BEYOND NS OR NP (SEE NOTE)

N	P(N)	N	P(N)	N	P(N)	N	P(N)
.00	.5000	.50	.3085	1.00	.1587	1.50	.0668
.01	.4960	.51	.3050	1.01	.1562	1.51	.0655
.02	.4920	.52	.3015	1.02	.1539	1.52	.0643
.03	.4880	.53	.2981	1.03	.1515	1.53	.0630
.04	.4840	.54	.2946	1.04	.1492	1.54	.0618
.05	.4801	.55	.2912	1.05	.1469	1.55	.0606
.06	.4761	.56	.2877	1.06	.1446	1.56	.0594
.07	.4721	.57	.2843	1.07	.1423	1.57	.0582
.08	.4681	.58	.2810	1.08	.1401	1.58	.0571
.09	.4641	.59	.2776	1.09	.1379	1.59	.0559
.10	.4602	.60	.2743	1.10	.1357	1.60	.0548
.11	.4562	.61	.2709	1.11	.1335	1.61	.0537
.12	.4522	.62	.2676	1.12	.1314	1.62	.0526
.13	.4483	.63	.2643	1.13	.1292	1.63	.0516
.14	.4443	.64	.2611	1.14	.1271	1.64	.0505
.15	.4404	.65	.2578	1.15	.1251	1.65	.0495
.16	.4364	.66	.2546	1.16	.1230	1.66	.0485
.17	.4325	.67	.2514	1.17	.1210	1.67	.0475
.18	.4286	.68	.2483	1.18	.1190	1.68	.0465
.19	.4247	.69	.2451	1.19	.1170	1.69	.0455
.20	.4207	.70	.2420	1.20	.1151	1.70	.0446
.21	.4168	.71	.2389	1.21	.1131	1.71	.0436
.22	.4129	.72	.2358	1.22	.1112	1.72	.0427
.23	.4090	.73	.2327	1.23	.1093	1.73	.0418
.24	.4052	.74	.2296	1.24	.1075	1.74	.0409
.25	.4013	.75	.2266	1.25	.1056	1.75	.0401
.26	.3974	.76	.2236	1.26	.1038	1.76	.0392
.27	.3936	.77	.2206	1.27	.1020	1.77	.0384
.28	.3897	.78	.2177	1.28	.1003	1.78	.0375
.29	.3859	.79	.2148	1.29	.0985	1.79	.0367
.30	.3821	.80	.2119	1.30	.0968	1.80	.0359
.31	.3783	.81	.2090	1.31	.0951	1.81	.0351
.32	.3745	.82	.2061	1.32	.0934	1.82	.0344
.33	.3707	.83	.2033	1.33	.0918	1.83	.0336
.34	.3669	.84	.2005	1.34	.0901	1.84	.0329
.35	.3632	.85	.1977	1.35	.0885	1.85	.0322
.36	.3594	.86	.1949	1.36	.0869	1.86	.0314
.37	.3557	.87	.1922	1.37	.0853	1.87	.0307
.38	.3520	.88	.1894	1.38	.0838	1.88	.0301
.39	.3483	.89	.1867	1.39	.0823	1.89	.0294
.40	.3446	.90	.1841	1.40	.0808	1.90	.0287
.41	.3409	.91	.1814	1.41	.0793	1.91	.0281
.42	.3372	.92	.1788	1.42	.0778	1.92	.0274
.43	.3336	.93	.1762	1.43	.0764	1.93	.0268
.44	.3300	.94	.1736	1.44	.0749	1.94	.0262
.45	.3264	.95	.1711	1.45	.0735	1.95	.0256
.46	.3228	.96	.1685	1.46	.0721	1.96	.0250
.47	.3192	.97	.1660	1.47	.0708	1.97	.0244
.48	.3156	.98	.1635	1.48	.0694	1.98	.0239
.49	.3121	.99	.1611	1.49	.0681	1.99	.0233
.50	.3085	1.00	.1587	1.50	.0668	2.00	.0228

NOTE: IF N IS NEGATIVE P(-N) = 1 - P(N)

TABLE 5-5. NORMAL DISTRIBUTION VALUES FOR THE CUMULATIVE PROBABILITIES, PS OR PP, OF A POINT FALLING BEYOND NS OR NP (SEE NOTE) (CONTINUED)

N	P(N)	N	P(N)	N	P(N)	N	P(N)
2.00	.0227	2.50	.0062	3.00	.0013	3.50	.0002
2.01	.0222	2.51	.0060	3.01	.0013	3.51	.0002
2.02	.0217	2.52	.0059	3.02	.0013	3.52	.0002
2.03	.0212	2.53	.0057	3.03	.0012	3.53	.0002
2.04	.0207	2.54	.0055	3.04	.0012	3.54	.0002
2.05	.0202	2.55	.0054	3.05	.0011	3.55	.0002
2.06	.0197	2.56	.0052	3.06	.0011	3.56	.0002
2.07	.0192	2.57	.0051	3.07	.0011	3.57	.0002
2.08	.0188	2.58	.0049	3.08	.0010	3.58	.0002
2.09	.0183	2.59	.0048	3.09	.0010	3.59	.0002
2.10	.0179	2.60	.0047	3.10	.0010	3.60	.0002
2.11	.0174	2.61	.0045	3.11	.0009	3.61	.0002
2.12	.0170	2.62	.0044	3.12	.0009	3.62	.0001
2.13	.0166	2.63	.0043	3.13	.0009	3.63	.0001
2.14	.0162	2.64	.0041	3.14	.0008	3.64	.0001
2.15	.0158	2.65	.0040	3.15	.0008	3.65	.0001
2.16	.0154	2.66	.0039	3.16	.0008	3.66	.0001
2.17	.0150	2.67	.0038	3.17	.0008	3.67	.0001
2.18	.0146	2.68	.0037	3.18	.0007	3.68	.0001
2.19	.0143	2.69	.0036	3.19	.0007	3.69	.0001
2.20	.0139	2.70	.0035	3.20	.0007	3.70	.0001
2.21	.0136	2.71	.0034	3.21	.0007	3.71	.0001
2.22	.0132	2.72	.0033	3.22	.0006	3.72	.0001
2.23	.0129	2.73	.0032	3.23	.0006	3.73	.0001
2.24	.0125	2.74	.0031	3.24	.0006	3.74	.0001
2.25	.0122	2.75	.0030	3.25	.0006	3.75	.0001
2.26	.0119	2.76	.0029	3.26	.0006	3.76	.0001
2.27	.0116	2.77	.0028	3.27	.0005	3.77	.0001
2.28	.0113	2.78	.0027	3.28	.0005	3.78	.0001
2.29	.0110	2.79	.0026	3.29	.0005	3.79	.0001
2.30	.0107	2.80	.0026	3.30	.0005	3.80	.0001
2.31	.0104	2.81	.0025	3.31	.0005	3.81	.0001
2.32	.0102	2.82	.0024	3.32	.0005	3.82	.0001
2.33	.0099	2.83	.0023	3.33	.0004	3.83	.0001
2.34	.0096	2.84	.0023	3.34	.0004	3.84	.0001
2.35	.0094	2.85	.0022	3.35	.0004	3.85	.0001
2.36	.0091	2.86	.0021	3.36	.0004	3.86	.0001
2.37	.0089	2.87	.0021	3.37	.0004	3.87	.0001
2.38	.0087	2.88	.0020	3.38	.0004	3.88	.0001
2.39	.0084	2.89	.0019	3.39	.0003	3.89	.0000
2.40	.0082	2.90	.0019	3.40	.0003	3.90	.0000
2.41	.0080	2.91	.0018	3.41	.0003	3.91	.0000
2.42	.0078	2.92	.0018	3.42	.0003	3.92	.0000
2.43	.0075	2.93	.0017	3.43	.0003	3.93	.0000
2.44	.0073	2.94	.0016	3.44	.0003	3.94	.0000
2.45	.0071	2.95	.0016	3.45	.0003	3.95	.0000
2.46	.0069	2.96	.0015	3.46	.0003	3.96	.0000
2.47	.0068	2.97	.0015	3.47	.0003	3.97	.0000
2.48	.0066	2.98	.0014	3.48	.0003	3.98	.0000
2.49	.0064	2.99	.0014	3.49	.0002	3.99	.0000
2.50	.0062	3.00	.0013	3.50	.0002	4.00	.0000

NOTE: IF N IS NEGATIVE P(-N) = 1 - P(N)

5.4 EVALUATION OF PERFORMANCE IN THE TRACKKEEPING REGION

This section contains the instructions and data tables for the provision of a relative risk factor (RRF) value for each trackkeeping region. Instructions for specifying the trackkeeping regions appear in Section 3.3.2. The performance data given here to represent the trackkeeping region was taken at a point where both the crosstrack displacement (the mean, MN) and the crosstrack dispersion (the standard deviation, SD) of the set of transits had reached a constant level.

5.4.1 Selection of Baseline Data

The method of calculating the RRF uses "baseline" performance data for a 30,000 dwt ship in a 500-foot channel and "corrects" it for other ship sizes and channel widths. This subsection contains instructions for the selection of baseline data from Table 5-9 for each trackkeeping region. The steps are summarized in Worksheet 5-5, which can be copied for each trackkeeping region and design alternative. The experienced designer may prefer not to use this worksheet but to enter baseline data on a worksheet in Section 5.4.3.

1. Aid Arrangement. Performance data are presented in Table 5-9 for a number of aid arrangements. Gated, staggered, and one-side arrangements were discussed in Section 4.4. To summarize that discussion, Figure 4-5 is repeated here. Ranges are discussed in Section 4.2. The calculations necessary to determine their sensitivity is repeated here. Select the appropriate arrangement for each trackkeeping region and each design alternative to be evaluated by the following rules.

- For a gated arrangement, if the spacing is up to 0.62 nm, any of the entries can be chosen, based on Item 3.

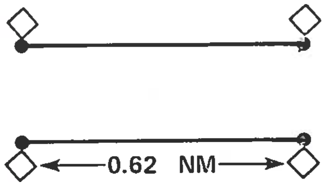


TABLE 5-9. BASELINE PERFORMANCE DATA FOR DATA TRACKKEEPING REGION

CRAB ANGLE, 0-2 degrees

MARKING	MN[1]	SD[2]	RRF[3]	NP+NS[4]
gated aids, day or night	2	31	0.0000	13.42
short-spaced, staggered aids	1	22	0.0000	18.9
long-spaced, staggered aids	5	44	0.0000	12.6
one-side channel marking	15	44	0.0000	9.44
high-sensitivity range	2	12	0.0000	34.66
low-sensitivity range	44	54	0.0000	8.83

CRAB ANGLE, 2-5 degrees

MARKING	MN[1]	SD[2]	RRF[3]
short-spaced, gated aids	30	39	0.0000
long-spaced, gated aids	76	50	0.0084
short-spaced, staggered aids	51	58	0.0064
long-spaced, staggered aids	34	75	0.0169
one-side channel marking	111	70	0.0402
high-sensitivity range	4	12	0.0000
low-sensitivity range	53	87	0.0526

NOTES:

1. Means (MN) are expressed as feet from channel centerline.
2. Standard deviations (SD) are in feet.
3. The relative risk factor (RRF) was calculated using the instructions in Section 5.3.3 and the standard conditions described in Table 5-7.
4. NP+NS comes out of the calculation of the RRF and is included only for those situations for which RRF values are too low to differentiate among alternatives.

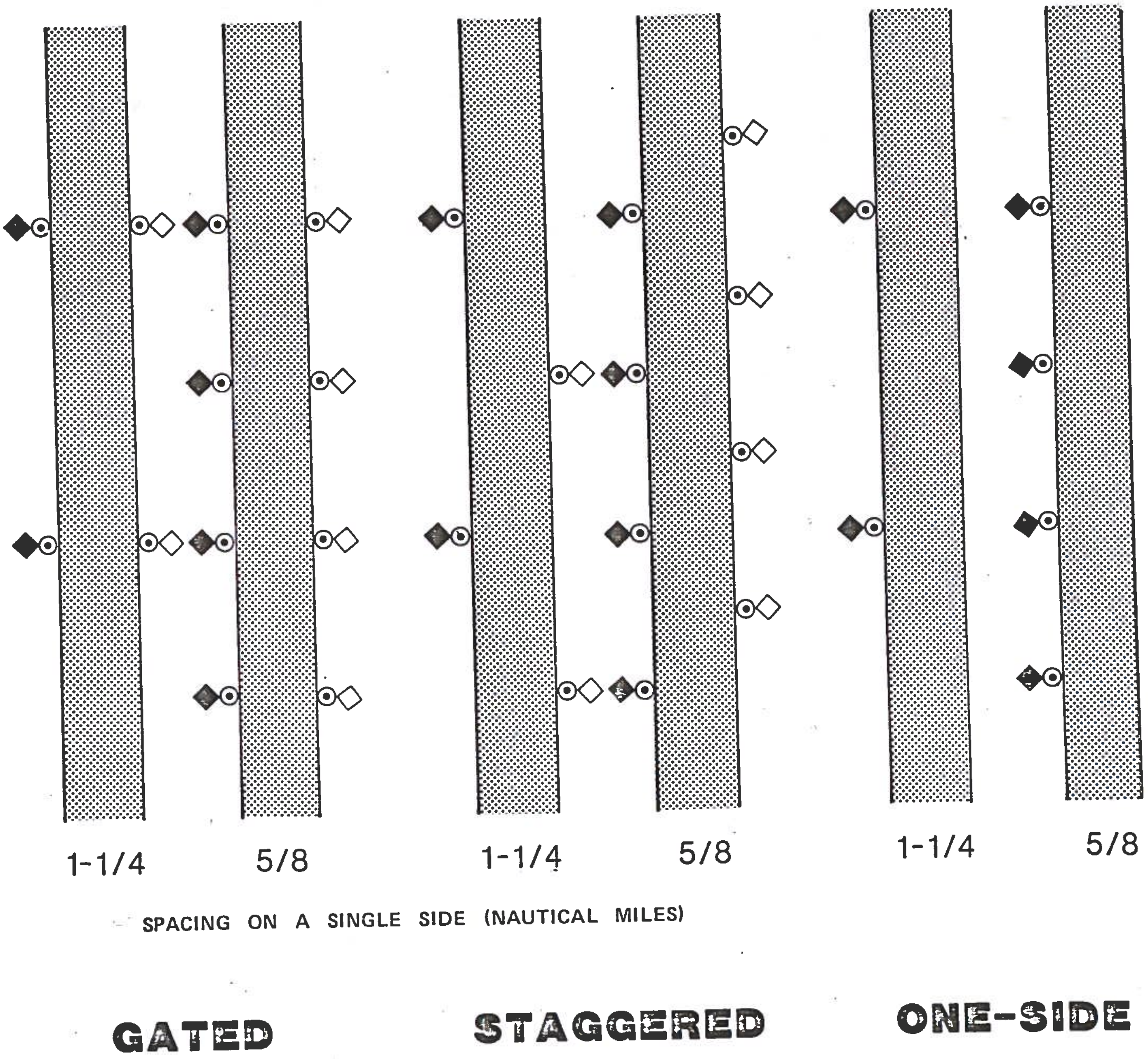
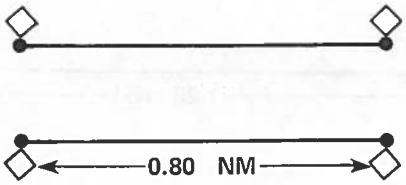
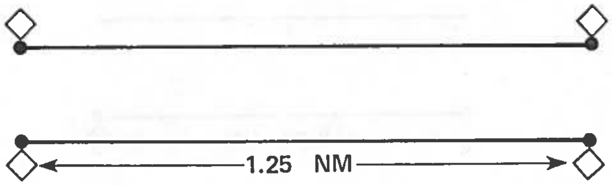


Figure 4-5. Alternative Buoy Arrangements for Straightaways

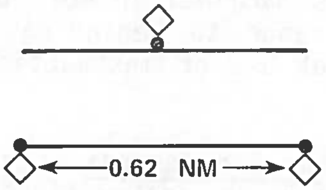
- If the spacing is up to 0.80 nm, and Item 3 does not dictate otherwise, the entry for gated aids with 0-2 degrees crab angle can be used.



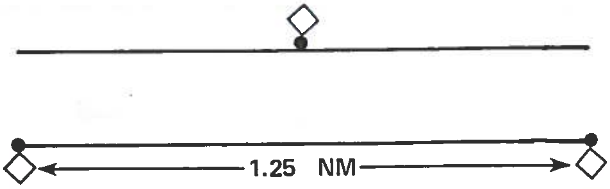
- If the spacing is up to 1.25 nm, the data for long-spaced gates with crab angle, 2-5 degrees can be used.



- If the spacing is greater than 1.25 nm, see Item 3.
- For a <u>staggered</u> arrangement, if the spacing along a single side is up to 0.62 nm, select short-spaced staggered data.

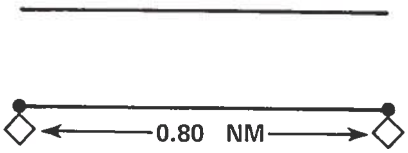


If the spacing along a single side is up to 1.25 nm, select long-spaced staggered data.



If the spacing is longer than 1.25 nm, see Item 3.

- For one-side channel marking, if the spacing is up to 0.80 nm, either entry can be used.



If the spacing is longer than 0.80 nm, see Item 3.

2. Range Sensitivity. For ranges, sensitivity should be calculated if it has not already been done. Note that sensitivity will be higher in the trackkeeping region than in the regions further from the range structures. If choice of sensitivity was marginal in more distant regions; recalculate, using distance from front range to beginning of the trackkeeping region. Use the equation in Worksheet 5-5 or instructions in Section 5.3.1 for the recovery region.

3. Crab Angle: 0-2 versus 2-5 degrees. Calculate crab angle according to equation in Worksheet 5-5 or instructions in Section 5.3.1 for the recovery region.

Select data for 2-5 degree crab angle according to the worksheet or the instructions for the recovery region.

4. Select Baseline Data. Select baseline data for the following conditions and enter on Worksheet 5-5. Note that no distinction is made between day and night for trackkeeping.

	Mean	Standard Deviation	Relative Risk Factor
Aids on edge	___	___	___
Ranges	___	___	___

5.4.2 Use of Precalculated Relative Risk Factor (RRF) Values

To find a RRF value for a trackkeeping region, the system designer has only two options. One is to use a RRF values from baseline data Table 5-9 in Section 5.4.1. The other is to calculate the value needed. Caution must be exercised in comparing values obtained in different ways. The comparisons that are appropriate are discussed in reference to the turn regions in Section 5.2.2 and are not repeated here.

The RRF values in the baseline data Table 5-9 were calculated for a 30,000 dwt ship in a 500-foot channel. The values of the mean and standard deviation of each condition considered are given in that table. The parameters of the ship and channel used in the calculation for the first entry with a 2-5 degree crab angle are the same as those in Table 5-7, illustrating the recovery region calculations.

No plots were prepared extrapolating the baseline data over ship size and channel width. These were omitted in the expectation that they would be only minimally useful. First, there are fewer trackkeeping regions than other regions. Second, the risk in those regions is so low relative to other regions that it will generally be unnecessary to include it in design considerations.

5.4.3 Relative Risk Factor (RRF) Calculations for Specific Conditions

RRF values can be calculated by the system designer for all baseline conditions in Table 5-9 and for a variety of ship sizes and channel widths. Worksheet 5-6 is provided. The correction factors needed for the trackkeeping region are provided as Table 5-10. The instructions in Section 5.3.3 for the recovery region can be used here for guidance.

WORKSHEET FOR EVALUATION OF THE TRACKKEEPING REGION: CALCULATION OF THE RELATIVE RISK FACTOR (RRF) FOR SPECIFIC CONDITIONS

(SHEET 1 OF 3)

Instructions in Section 5.4.3.

Copy for each design/evaluation objective and recovery region.

Design/Evaluation Objective:____________________

____

Region Identification:____________________

1. Baseline Data from Worksheet 5-5 (or Table 5-9)

CRAB ANGLE, 0-2 degrees				or	CRAB ANGLE, 2-5 degrees			
	MN	SD	RRF			MN	SD	RRF
Aids on edge	____	____	____		Day	____	____	____
Range	____	____	____		Night/dusk/dawn	____	____	____
					Range	____	____	____

2. Channel Parameters from Worksheet 3-1

Navigable width of straight segment__________(W)____

3. Environmental Parameters from Worksheet 3-1

Crosstrack current (knots)____________________

or use 0.25 knots for comparability to precalculated values.

4. Design Vessel Parameters from Worksheet 3-1

Ship size (deadweight tons)____________________

Length (feet)____________________

Beam (feet)____________________

Transit speed (knots)____________________

B':

[(length/2) x (crosstrack current/transit speed)] + (beam/2) = (B')

[(/2) x (/   ] + (/2) = (feet)

Worksheet 5-6

WORKSHEET FOR EVALUATION OF THE TRACKKEEPING REGION:
CALCULATION OF THE RELATIVE RISK FACTOR (RRF) FOR SPECIFIC CONDITIONS
(SHEET 2 OF 3)

5. Correct Mean (MN) and Standard Deviation (SD)

See Table 5-10 for correction factors:

MCSHP _____ MCWID _____

SCSHP _____ SCWID _____

Calculation:

DAY (or AIDS ON EDGE)

(MN) x (MCSHP) x (MCWID) = (MN')
(   ) x (   ) x (   ) = (   )

(SD) x (SCSHP) x (SCWID) = (SD')
(   ) x (   ) x (   ) = (   )

NIGHT/DUSK/DAWN

(MN) x (MCSHP) x (MCWID) = (MN')
(   ) x (   ) x (   ) = (   )

(SD) x (SCSHP) x (SCWID) = (SD')
(   ) x (   ) x (   ) = (   )

RANGE

(MN) x (MCSHP) x (MCWID) = (MN')
(   ) x (   ) x (   ) = (   )

(SD) x (SCSHP) x (SCWID) = (SD')
(   ) x (   ) x (   ) = (   )

Worksheet 5-6 (Continued)

WORKSHEET FOR EVALUATION OF THE TRACKKEEPING REGION:
CALCULATION OF THE RELATIVE RISK FACTOR (RRF) FOR SPECIFIC CONDITIONS
(SHEET 3 OF 3)

6. CALCULATE RELATIVE RISK FACTOR (RRF)

See Table 5-5 for PS and PP.

DAY (or AIDS ON EDGE)

[(W/2) - (MN') - (B')]/(SD') = (NS)
[(/2) - (   ) - (   )]/(   ) = (   )

[(W/2) - (MN') - (B')]/(SD') = (NP)
[(/2) + (   ) - (   )]/(   ) = (   )

(PS) + (PP) = (RRF)
(   ) + (   ) = (   )

NIGHT/DUSK/DAWN

[(W/2) - (MN') - (B')]/(SD') = (NS)
[(/2) - (   ) - (   )]/(   ) = (   )

[(W/2) - (MN') - (B')]/(SD') = (NP)
[(/2) + (   ) - (   )]/(   ) = (   )

(PS) + (PP) = (RRF)
(   ) + (   ) = (   )

RANGE

[(W/2) - (MN') - (B')]/(SD') = (NS)
[(/2) - (   ) - (   )]/(   ) = (   )

[(W/2) - (MN') - (B')]/(SD') = (NP)
[(/2) + (   ) - (   )]/(   ) = (   )

(PS) + (PP) = (RRF)
(   ) + (   ) = (   )

reminder:
W: channel width from #2
MN': corrected MN from #5
B': adjusted beam/2 from #4
SD': corrected SD from #5
NS: SDs to starboard
NP: SDs to port
PS: prob to starboard
PP: prob to port
RRF: relative risk factor

Worksheet 5-6 (Continued)

TABLE 5-10. CORRECTION FACTORS FOR THE TRACKKEEPING REGION

FOR ALL CONDITIONS

Ship Size 1,000 dwt	30	50	70	90	110
MCSHP[1]	1	1	1	1	1
SCSHP[2]	1	1.25	1.47	1.69	1.92

slope = 0.0114

CHANNEL WIDTH (marked by aids, in feet)

	300	400	500	600	700	800
MCWID[3]	0.67	0.83	1	1.17	1.33	1.5
SCWID[4]	0.67	0.83	1	1.17	1.33	1.5

NOTES

1. MCSHP: mean correction factor for ship size
2. SCSHP: standard deviation correction factor for ship size

To interpolate for SCSHP, use

$$SCSHP_i = 1 + \text{slope}\,(X_i - 30)$$

where:
$SCSHP_i$ = correction factor for any ship size in 1,000 dwt
X_i = ship size in 1,000 dwt
slope = value given in table above

3. MCWID: mean correction factor for channel width

To interpolate for MCWID, use:

$$MCWID_i = 1 + 0.5\,(W_i - 500)/300$$

where
$MCWID_i$ = correction factor for any channel width
W_i = channel width

4. SCWID: standard deviation correction factor for channel width

Interpolate as in Note 3.

5.5 SUMMARY OF EVALUATION FOR WATERWAY

The variety of relative risk factor (RRF) values calculated during the application of Section 5 should be arranged and summarized for inspection. Worksheet 5-7 is provided. Label the worksheet with the name and location of the waterway(s) being evaluated and with the design objective(s) intended. If the intention was to establish priorities in the waterway as it is presently marked, consider that the design objective. If the intention was to design a more conservative or a less costly arrangement than exists, consider those intentions the design objective.

Label each region evaluated. Label it as a turn, recovery, or trackkeeping region and provide it with a unique identification. A unique identification might be provided by its coordinates, by its sequence in a transit, or by a place name.

For each region fill in the RRFs for the subsystems of day and night/dusk/dawn. If either the analysis of waterway conditions done in Section 3 and summarized on Worksheet 3-1, or the application of performance data in the present section suggest that the RRF might over- or underestimate risk, indicate this on the worksheet by following the RRF with a plus or minus.

If there are ranges present in the waterway, fill in the RRFs in the last column. If in any region the RRF value in the first two columns is lower than the RRF for ranges, substitute the lower RRF, indicating whether it is day only. This substitution is made on the assumption that if the visibility is sufficient for ranges, it will be sufficient for closer aids.

If the design objective was the establishment of priorities in the waterway "as is", inspection of the summary worksheet will identify those regions that deserve priority. Some regions, most likely turns, will stand out as having higher risk than the rest of the waterway and deserving priority. Some regions may have conspicuously lower risk. Before concluding that service should be reduced on lower risk regions, consider the additional risk imposed by temporary conditions. The extra demands of the meeting traffic situation are discussed in Section 6; the reduced visibility situation is discussed in Section 7. The establishment of priorities is further discussed in Section 9.

Inspection of the summary sheet may also reveal differences among the subsystems. If there are many unlighted aids in a waterway, there will be differences between day and night/dusk/dawn. The problem will then be deciding whether the night/dusk/dawn subsystem provides appropriate service. Comparison of the range column with the others may reveal a considerable dependence on the ranges. The problem will be deciding whether this dependence is warranted. These issues are addressed again in Section 9 on risk management.

If the objective was design of alternatives to the present system, only some regions may be filled in, but filled in on several summary sheets. Conspicuous differences in RRF may settle the choice here. Otherwise, Section 9 suggests other comparisons that will be helpful.

SUMMARY WORKSHEET FOR EVALUATION

Instructions in Section 5.5.

Copy for each waterway and/or design objective.

Waterway Name and Location: ______________________________

Design/Evaluation Objective: ______________________________

SUBSYSTEMS

Region Identification	Day RRF (+/-?)	Night/dusk/dawn RRF (+/-?)	With Ranges RRF (+/-?)

Worksheet 5-7

SECTION 6. SPECIAL GUIDANCE FOR THE MEETING TRAFFIC SITUATION

Section 6

SPECIAL GUIDANCE FOR THE MEETING TRAFFIC SITUATION

6.1 INTRODUCTION

The earlier sections of the manual provide for the primary design and evaluation of aids-to-navigation systems for a waterway. They were prepared with the consideration of a large number of factors and the availability of a great deal of data. The frequency of meeting traffic and the size of ships that meet were introduced in Section 4 to determine how conservative the design should be. If a waterway system has been designed with any degree of conservatism by the guidelines in Section 4, it should be appropriate for meeting traffic. This section is organized with the assumption that Sections 3 and 4 and/or 5 have already been applied. It is meant as additional assurance that the system is appropriate for meeting traffic. This section contains a minimum of explanation on factors and methods that were presented in the earlier sections.

This section is arranged to serve two objectives.

1. To supplement the design guidelines. The application of the design guidelines in Section 4 may have left some choices open between alternative aid arrangements. If meeting traffic is judged by the designer to be a significant factor in the waterway, the choices should be between aid arrangements that Section 4 recommended as versatile and high performing. For the turn region, the remaining choice may be between two and three buoys in the turn. For the straightaway, the remaining choice may be on the spacing of gated aids. Examination of the demands of the meeting traffic situation is a guide in the final choice.

2. To supplement the evaluation of risk for the waterway. The performance data in this section provide a measure of the relative risk of accident -- both grounding and colliding -- in a waterway that is well-marked for meeting traffic. Even in a well-marked channel, the shiphandling problem of meeting remains. If a channel seems narrow or reaches seem short for the traffic that is meeting, a quantitative measure allows for comparison to another waterway with a better-known safety record.

This section is organized around data from one experiment designed to investigate the meeting traffic situation. The section begins by describing the simulator conditions under which the data were collected. It continues with the baseline data and describes the new performance measures used. It then presents a description of the meeting traffic situation using the new data to illustrate points. It finishes with suggestions on the use of these data to serve the two suggested objectives.

6.2 PERFORMANCE DATA AVAILABLE

The performance data presented in this section come from one experiment that was designed with background conditions very different from those in the other experiments. For this reason the risk of grounding (PS) calculated using data in this section should not be compared to the risk of

TABLE 6-3. A SAMPLE CALCULATION OF THE RELATIVE RISK FACTOR FOR MEETING TRAFFIC (RRFMT)

MEETING TRAFFIC SITUATION

OWNSHIP PARAMETERS

Ship size	30,000 deadweight tons (dwt)
Ship length	590 feet
Ship beam	85 feet
Crosstrack forces	0.50 knots
Transit speed	10 knots

B' = [(length/2) x (forces/speed)] + (beam/2) = 57 feet

TRAFFIC SHIP PARAMETERS

Ship size	30,000 deadweight tons (dwt)
Ship beam	85 feet
B' = (beam/2)	42 feet

CHANNEL PARAMETERS

Channel width (W)	500 feet

CALCULATE THE RELATIVE RISK FACTOR FOR MEETING TRAFFIC (RRFMT)

a. PS, the probability that ownship will ground to starboard

Baseline data (Table 6-1)
MNS 171 SDS 48

[(W/2) - (MNS) - (B')]/(SDS) = (NS)
[(500/2) - (171) - (57)]/(48) = (0.46)

PS = 0.3228

b. PC, the probability of collision

Baseline data (Table 6-1)
MNC 150 SDC 53

(MNC/SDC) = (NC)
(150/53) = (2.83)

PC = 0.0023

TABLE 6-3. A SAMPLE CALCULATION OF THE RELATIVE RISK FACTOR FOR MEETING TRAFFIC (RRFMT) (CONTINUED)

c. PS, the probability that traffic ship will ground to its starboard

Baseline data (Table 6-1) on straightaway
MN 103 SDS 32

[(W/2) - (MNS) - (B')]/(SDS) (NS)
[(500/2) - (103) - (42)]/(32) = 3.28

PS' = 0.0005

(PS) + (PC) + (PS') = (RRFMT)
(0.3228) + (0.0023) + (0.0005) = (0.3256)

Reminder:
W: channel width
MNS: MN/starboard
B': adjusted beam/2
SDS: SD/starboard
NS: SDs to starboard

MNC: MN/collision
SDC: SD/collision
NC: SDs to collision

PS: prob to starboard
PC: prob collision
PS' prob traffic ship to starboard
RRFMT: relative risk factor for meeting traffic

Assuming a normal distribution, it is possible to find NC, the number of standard deviations that will fit between the two ships at their mean distance, as illustrated in Figure 6-1. It is calculated as:

$$NC = MNC/SDC \tag{6-2}$$

where:

MNC: the mean of the distances between the two ships measured "skin to skin," to be used in calculating PC

SDC: The standard deviation of the distance between the two ships, to be used in calculating PC

Given NC, it is possible to find PC as the area under the normal curve where the distance between the two ships is zero (or less). The relationship is illustrated in Figure 6-2. The normal distribution table used in Section 5 is repeated with the worksheets at the end of this section.

6.2.4.3 The Probability That the Traffic Ship Will Ground to Its Starboard (PS')

The total risk at meeting includes the probability that the second ship will ground. It is expressed as the probability that the traffic ship will ground to its starboard. By designating this second grounding as to starboard, the baseline data can be taken from the same tables, with the mean expressed as a positive distance from the centerline. Also, the same calculations can be used with the positive mean subtracted from the centerline. See the sample calculation in Table 6-3 for PS'.

In the sample case, the traffic ship is still on its straightaway. This difference from ownship means that the baseline data and the beam adjustment are different from those used for ownship. If the two ships are the same size and are both on the straightaway, PS' will equal PS.

6.3 DESCRIPTION OF THE MEETING TRAFFIC SITUATION

The findings of the meeting traffic experiment are described here in terms of the factors that were evaluated and the resulting effects on performance or risk. The performance data and measures presented in the earlier subsections are available to illustrate the effects. This discussion may be sufficient to guide the system designer in his choices without the necessity of his doing any calculations. If not, directions for calculations follow.

6.3.1 The Tradeoff Between the Risk of Collision and the Risk of Grounding

The risk of meeting traffic was described in Section 6.2.4 as the total risk of grounding and collision. But the tradeoff between the two risks is also meaningful. Performance in Table 6-1 can be interpreted either way. A set of conditions may result in a higher or lower total risk. They will also result in a more or less desirable tradeoff between the two risks. A system designer who is evaluating a waterway with dangerous banks should consider the total risk. A designer evaluating a waterway with soft banks can give greater emphasis to the risk of collision.

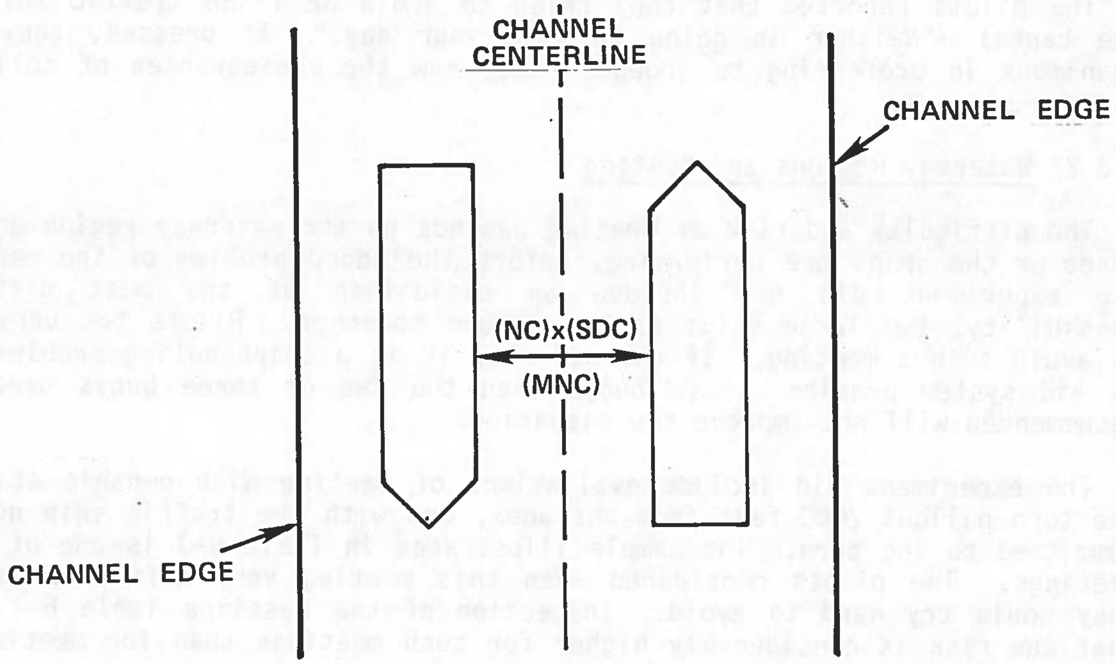


Figure 6-1. Number (NC) of Standard Deviations (SDC) That Will Fit Between The Ships at Their Mean (MNC) Closest Point of Approach (CPA)

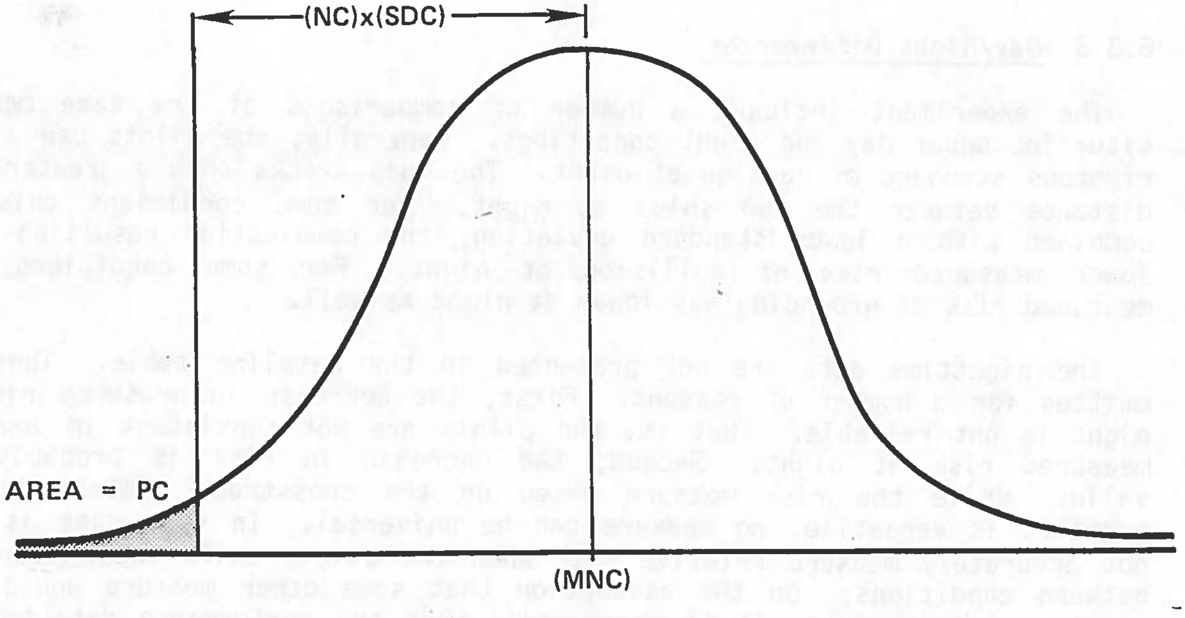


Figure 6-2. The Probability (PC) That The Distance Between The Ships (NC) x (SDC) Will Be Zero (or Less) Based on the Assumption of a Normal Distribution

The pilots reported that they tried to avoid both the traffic ship and the banks: "Neither is going to make your day." If pressed, they were unanimous in preferring to ground. They saw the consequences of collision as more serious.

6.3.2 Waterway Regions and Meeting

The difficulty and risk of meeting depends on the waterway region and the maneuver the ships are performing, before the added problem of the meeting. The experiment did not include an evaluation of the most difficult possibility, two large ships making a turn together. Pilots try very hard to avoid such a meeting. If unavoidable, it is a shiphandling problem, not an aid system problem. More buoys than the two or three buoys generally recommended will not improve the situation.

The experiment did include evaluations of meeting with ownship still in the turn pullout 2000 feet from the apex, but with the traffic ship not yet committed to the turn. The sample illustrated in Table 6-3 is one of these meetings. The pilots considered even this meeting very difficult and one they would try hard to avoid. Inspection of the baseline Table 6-1 shows that the risk is considerably higher for such meetings than for meetings in the straightaway.

For the straightaway, the experiment evaluated meetings late in the recovery region, 1 nautical mile (nm) beyond the turn apex. Risk for such meetings is quite low. No data are available for meetings in the trackkeeping regions. Risk may be even lower than in the recovery region. Very low risks contribute little to the decision process. Risk measured in the recovery region may be used for the trackkeeping region with the notation that risk may be overestimated.

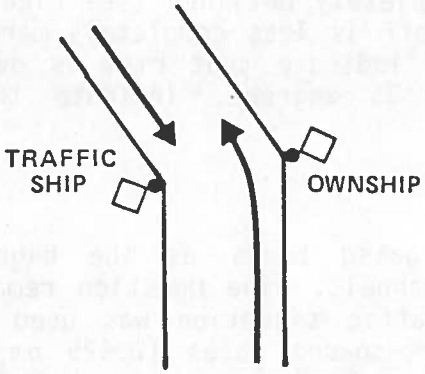
6.3.3 Day/Night Differences

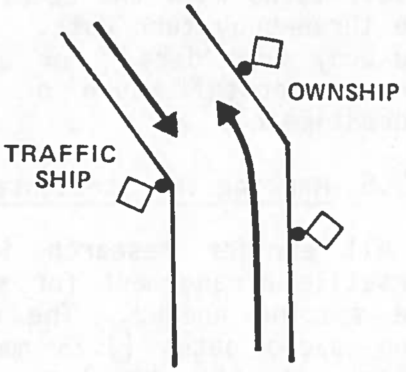
The experiment included a number of comparisons of the same meeting situation under day and night conditions. Generally, the pilots use a more rigorous standard of caution at night. The ship tracks show a greater mean distance between the two ships at night. For some conditions this was combined with a lower standard deviation, the combination resulting in a lower measured risk of collision at night. For some conditions, the measured risk of grounding was lower at night as well.

The nighttime data are not presented in the baseline table. They are omitted for a number of reasons. First, the decrease in measured risk at night is not reliable. That is, the pilots are not consistent in lowering measured risk at night. Second, the decrease in risk is probably not valid. While the risk measure based on the crosstrack distribution of transits is versatile, no measure can be universal. In this case it does not accurately measure relative risk when the pilots shift their standards between conditions. On the assumption that some other measure would show greater risk at night, it is recommended that the performance data be used with the notation that it underestimates risk at night.

6.3.4 Marking in the Turn Regions

In a waterway where meeting traffic is a concern, the choice for turn marking should be between a two- and a three-buoy arrangement. These were evaluated for meeting with ownship 2000 feet past the apex, still in a turn pullout.

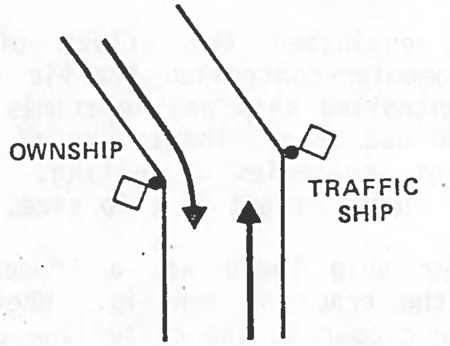




The performance data are presented in baseline Table 6-1. The two-buoy turn results in a high risk of grounding and a low risk of collision, while the three-buoy turn results in a very low risk of grounding but a slightly higher risk of collision.

The implications of these findings are compatible with recommendations in Section 4 and data in Section 5. The three-buoy turn is a versatile, self-contained system, keeping ships in the channel in a variety of situations. This is not true of the two-buoy turn. Section 4 recommended using the two-buoy turn where it was supplemented by bank forces and by the sight of land. Here, bank forces alone were not enough of a supplement with the extra demands of the meeting situation. A sight of land might have made a difference. The meeting traffic evaluation was conservatively done with a 35-degree noncutoff turn. A lesser angle or a cutoff turn would result in less of a slide to the outside. A wider channel in relation to ship size would decrease the risk of grounding. Soft banks would decrease the consequences of grounding. The choice of a two-buoy turn requires care and the consideration of a variety of factors.

A third situation was evaluated with ownship down bound in a two-buoy turn with the turn forces carrying it toward the traffic ship.



The risk of collision was quite high and the risk of grounding quite small. This is a shiphandling problem. It is unlikely that additional buoys on either side of the channel would have improved the situation.

The performance data can be used to evaluate a variety of turns. For cutoff turns with the cutoff area completely outlined (see Figure 4-3), use the three-buoy turn data. If the cutoff is less completely marked, use the two-buoy turn data. For any cutoff, indicate that risk is overestimated. For a noncutoff turn of less than 35 degrees, indicate that risk is overestimated.

6.3.5 Marking the Straightaway

All earlier research identified gated buoys as the high-performing, versatile arrangement for straight channels. The question remaining is on the spacing needed. The meeting traffic situation was used to evaluate long-spaced gates (1.25 nm) and short-spaced gates (0.625 nm). The data appear in the baseline Table 6-1. Performance is better with the short-spaced gates but the difference is small where performance is generally good.

The performance of gates is somewhat resistant to increases in spacing, but there are a number of qualifications. First, these data represent meeting in ownship's recovery region after ownship has gone through a three-buoy turn and one recovery gate before the meeting. With a less favorable history for the transit, there may be a greater need for short spacing. If meeting traffic is to be low risk, the regions should be well-marked for the basic maneuvers. Second, performance can be viewed as deteriorating when spacing increases from 0.625 nm to 1.25 nm. The implication is that performance would continue to deteriorate with longer spacing. Before spacing is increased beyond 1.25 nm, consideration should be given to the width and length of the straightaways in relation to ship size, to the presence of wind and current, and to the availability of additional information like bank effects, ranges, or adjacent land. Consideration should also be given to the suggestion made in Section 4.6 that gates be spaced closer to the turns for recovery and spaced farther apart at the center of the straightaway for trackkeeping. Meeting traffic will be of lower risk during trackkeeping. But the very small standard deviations in the recovery region can't be much lower.

6.3.6 The Effect of Ship Size

The experiment evaluated the effect of ship size in the meeting situation. The computer-controlled traffic ship was always a 30,000 dwt ship; the pilot-controlled ship was sometimes a similar 30,000 dwt ship and sometimes an 80,000 dwt ship. The tracks of the two pilot-controlled ships showed two different strategies at meeting. These strategies had an effect on risk beyond the simple effect of ship size.

With the smaller ship there was a tradeoff between the track of the traffic ship and the track of ownship. Whether the track of the traffic ship was farther or closer to the centerline of the channel, ownship's track tended to divide the available space to keep a comfortable distance from both the traffic ship and the channel's edge to starboard. This strategy is optimal. It results in a maximum mean and a minimum standard deviation for the distance between the two ships. It makes for a minimum risk of collision without driving up the risk of grounding.

The tracks of the larger ship showed less of a tradeoff. The larger ship tended to meet the traffic ship at a relatively constant crosstrack position, letting the behavior of the computer-controlled traffic ship determine the distance between them to a greater extent. The results appear as a ship size correction factor in Table 6-1. Because the traffic ship did not allow for the larger size of ownship, the mean distance between them goes down slightly. Because the tradeoff in crosstrack position was far less, the standard deviation goes up. The risk of collision goes up considerably with ship size, more than does the risk of grounding.

The reduced tradeoff with the large ship probably has a number of interrelated causes. First, and most simply, larger size means that fewer variations in crosstrack position are possible if both the traffic ship and the channel edge are to be avoided. Second, the decreased maneuverability of a larger ship generally results in the pilots' reluctance to make frequent or large use of the rudder. Third, since the meeting situation took place at the same 1 nm distance from the turn apex for both sizes of ownship, the recovery of the larger ship was less complete. All these factors are likely to be operating at sea when large ships are meeting traffic.

The meeting situation at sea involves two pilot-controlled ships. If two pilot-controlled ships show a greater total tradeoff, use of the simulator data to estimate the risk of collision between two small ships results in overestimation. If a smaller ship at sea makes an extra effort to get out of the way of a larger ship, use of the simulator data overestimates risk when the two ships are of different sizes, too. The simulator data may be most accurate in estimating the risk of collision between two large ships showing a minimum of tradeoff in crosstrack position.

The crosstrack position of ownship's center of gravity was not greatly affected by ship size and no correction factors are given here to correct that mean and standard deviation. Calculating PS, the risk of grounding to starboard, using the wider beam of the larger ship will result in a somewhat higher risk of grounding. If a very conservative total risk of meeting for large ships is wanted, use the ship size correction factors given in Section 5.

6.3.7 Implications

The meeting traffic experiment was designed and this section is organized on the assumption that a conservative marking for the basic maneuvers in a waterway is the best marking to serve meeting traffic. The observed performance supports this assumption. The conservative three-buoy turn decreases the risk of meeting close to the turn. A well-marked turn and recovery region make for a low-risk meeting in the straightaway. Given a well-marked turn and recovery, gates -- an intrinsically conservative arrangement -- in the straightaway can be extended at least to 1.25 nm with only a minor increase in risk.

When shiphandling conditions are difficult, conservative aid arrangements provide the best information possible. Aid density beyond the arrangements recommended in the manual will not help the situation. The two ships involved in the meeting traffic situation mean an increase in the possibility that the shiphandling difficulty is greater than what can be helped by aids. Note that even with a three-buoy turn, the risk in the turn region is much higher than it is in the straightaway. Note that risk goes up with ship size but goes up at a greater rate with the increase in the size of two ships. Section 6.4.2 and Section 9 consider further the possibility that aids will not improve safety.

6.4 USE OF THE DATA

The introduction to Section 6 suggests that it be used to supplement the design guidelines or the evaluation procedures of the earlier sections. Further suggestions for these uses follow.

6.4.1 Design Guidelines

Section 6 can be read as design guidelines, as was Section 4, to familiarize the system designer with the factors that affect risk. Possibly this familiarity alone will guide the designer in designing his system.

Performance data assigned to competing alternative arrangements may assist in design selections. This is a use that was suggested for performance data in Section 5.

6.4.2 Evaluation Procedures

If the performance data is to be used in the selection of alternative aid arrangements with all other factors kept constant, the procedure is simple. Baseline values can be used directly out of Table 6-1 without correction. If the ship size (30,000 dwt) and the channel width (500 feet) are not the true values, they will have a constant difference from the true values for all alternatives and can be used as a relative measure of aid arrangement performance. Worksheet 6-1 can be used to organize the material.

Ship size may be a factor. An increase in the size of the ships transiting a waterway may have prompted a redesign of an aid system. In such a case, there is a known history of safety -- or risk -- with the smaller ship. Risk calculated for the smaller ship and the historical aid arrangement can be used as a standard in designing for the larger ship. For the meeting situation the performance data can be used to determine whether more buoys in the turns or shorter spacing in the straightaways will bring risk with the larger ship down to what it was with the smaller ship. To calculate risk for the two situations use the baseline data in Table 6-1; the correction factors in Table 6-2; Worksheet 6-1; and Table 5-5 representing the normal distribution which is repeated here.

WORKSHEET FOR THE CALCULATION OF THE RELATIVE RISK FACTOR FOR MEETING TRAFFIC (RRFMT) (SHEET 1 OF 4)

Instructions in Section 6.4

Copy for every design/evaluation objective and region.

Design/evaluation objective:____

____

Region Identification:____

1. <u>Sketch of meeting traffic situation</u> (channel, aids, and location and direction of two ships at meeting)

Worksheet 6-1

WORKSHEET FOR THE CALCULATION OF THE RELATIVE RISK FACTOR FOR MEETING TRAFFIC (RRFMT) (SHEET 2 OF 4)

2. Ownship Parameters (larger ship or ship making more difficult maneuver)

Ship size ______________________ deadweight tons

Ship length ______________________ feet

Ship beam ______________________ feet

Crosstrack velocity for turns or crosscurrent ______________________ knots

Transit speed ______________________ knots

B' = [(length/2) x (velocity/speed)] + (beam/2)
[(/2) x (/   )] + (/2) = (feet)

3. Traffic Ship Parameters

Ship size ______________________ deadweight tons

Ship length ______________________ feet

Ship beam ______________________ feet

Crosstrack velocity for turns or crosscurrent ______________________ knots

Transit speed ______________________ knots

B' = [(length/2) x (velocity/speed)] + (beam/2)
[(/2) x (/   )] + (/2) = (feet)

4. Channel Parameter

Width ______________________ feet

5. CALCULATE RRFMT (See Section 6.2.4)

a. PS, the probability that ownship will ground to starboard

Baseline data (Table 6-1)

MNS __________ SDS __________

[(W/2) - (MNS) - (B')]/(SDS) = (NS)
[(/2) - (   ) - (   )]/(   ) = (   )

PS = (   )

Worksheet 6-1 (Continued)

WORKSHEET FOR THE CALCULATION OF THE RELATIVE RISK FACTOR FOR MEETING TRAFFIC (RRFMT) (SHEET 3 OF 4)

5. CALCULATE RRFMT (continued)

b. PC, the probability of collision

Baseline data (Table 6-1)

MNC__________ SDC__________

Correction factor for ship size (Table 6-2)

MCC__________ SCC__________

Correction factor for channel width (Table 6-2)

MCWID__________ SCWID__________

Correct MNC and SDC:

(MNC) x (MCC) x (MCWID) = (MNC')
( ) x ( ) x ( ) = ( )

(SDC) x (SCC) x (SCWID) = (SDC')
( ) x ( ) x ( ) = ( )

Calculate NC:

(MNC'/SDC') = (NC)
(/) = ( )

PC = ( )

c. PS' the probability that traffic ship will ground to its starboard

Baseline data (Table 6-1)

MNS__________ SDS__________

[(W/2) - (MNS) - (B')]/(SDS) = (NS)
[(/2) - ( ) - ( )]/( ) = ( )

PS' = ( )

(PS) + (PC) + (PS') = (RRFMT)
( ) + ( ) + ( ) = ( )

Worksheet 6-1 (Continued)

WORKSHEET FOR THE CALCULATION OF THE RELATIVE RISK FACTOR FOR MEETING TRAFFIC (RRFMT) (SHEET 4 OF 4)

Reminder:

W: channel width
MNS: MN/starboard
B': adjusted beam/2
SDS: SD/starboard
NS: SDs to starboard

MNC: MN/collision
SDC: SDs/collision
MCC: ship size correction or MN
SCC: ship size correction for SD
MCWID: channel width correction for MN
SCWID: channel width correction for SD
MNC': corrected MNC
SDC': corrected SDC
NC: SDs to collision

PS: prob to starboard
PC: prob collision
PS': prob traffic ship to starboard
RRFMT: relative risk factor for meeting traffic

Worksheet 6-1 (Continued)

TABLE 5-5. NORMAL DISTRIBUTION VALUES FOR THE CUMULATIVE PROBABILITIES, PS OR PP, OF A POINT FALLING BEYOND NS OR NP (SEE NOTE) (CONTINUED)

N	P(N)	N	P(N)	N	P(N)	N	P(N)
2.00	.0227	2.50	.0062	3.00	.0013	3.50	.0002
2.01	.0222	2.51	.0060	3.01	.0013	3.51	.0002
2.02	.0217	2.52	.0059	3.02	.0013	3.52	.0002
2.03	.0212	2.53	.0057	3.03	.0012	3.53	.0002
2.04	.0207	2.54	.0055	3.04	.0012	3.54	.0002
2.05	.0202	2.55	.0054	3.05	.0011	3.55	.0002
2.06	.0197	2.56	.0052	3.06	.0011	3.56	.0002
2.07	.0192	2.57	.0051	3.07	.0011	3.57	.0002
2.08	.0188	2.58	.0049	3.08	.0010	3.58	.0002
2.09	.0183	2.59	.0048	3.09	.0010	3.59	.0002
2.10	.0179	2.60	.0047	3.10	.0010	3.60	.0002
2.11	.0174	2.61	.0045	3.11	.0009	3.61	.0002
2.12	.0170	2.62	.0044	3.12	.0009	3.62	.0001
2.13	.0166	2.63	.0043	3.13	.0009	3.63	.0001
2.14	.0162	2.64	.0041	3.14	.0008	3.64	.0001
2.15	.0158	2.65	.0040	3.15	.0008	3.65	.0001
2.16	.0154	2.66	.0039	3.16	.0008	3.66	.0001
2.17	.0150	2.67	.0038	3.17	.0008	3.67	.0001
2.18	.0146	2.68	.0037	3.18	.0007	3.68	.0001
2.19	.0143	2.69	.0036	3.19	.0007	3.69	.0001
2.20	.0139	2.70	.0035	3.20	.0007	3.70	.0001
2.21	.0136	2.71	.0034	3.21	.0007	3.71	.0001
2.22	.0132	2.72	.0033	3.22	.0006	3.72	.0001
2.23	.0129	2.73	.0032	3.23	.0006	3.73	.0001
2.24	.0125	2.74	.0031	3.24	.0006	3.74	.0001
2.25	.0122	2.75	.0030	3.25	.0006	3.75	.0001
2.26	.0119	2.76	.0029	3.26	.0006	3.76	.0001
2.27	.0116	2.77	.0028	3.27	.0005	3.77	.0001
2.28	.0113	2.78	.0027	3.28	.0005	3.78	.0001
2.29	.0110	2.79	.0026	3.29	.0005	3.79	.0001
2.30	.0107	2.80	.0026	3.30	.0005	3.80	.0001
2.31	.0104	2.81	.0025	3.31	.0005	3.81	.0001
2.32	.0102	2.82	.0024	3.32	.0005	3.82	.0001
2.33	.0099	2.83	.0023	3.33	.0004	3.83	.0001
2.34	.0096	2.84	.0023	3.34	.0004	3.84	.0001
2.35	.0094	2.85	.0022	3.35	.0004	3.85	.0001
2.36	.0091	2.86	.0021	3.36	.0004	3.86	.0001
2.37	.0089	2.87	.0021	3.37	.0004	3.87	.0001
2.38	.0087	2.88	.0020	3.38	.0004	3.88	.0001
2.39	.0084	2.89	.0019	3.39	.0003	3.89	.0000
2.40	.0082	2.90	.0019	3.40	.0003	3.90	.0000
2.41	.0080	2.91	.0018	3.41	.0003	3.91	.0000
2.42	.0078	2.92	.0018	3.42	.0003	3.92	.0000
2.43	.0075	2.93	.0017	3.43	.0003	3.93	.0000
2.44	.0073	2.94	.0016	3.44	.0003	3.94	.0000
2.45	.0071	2.95	.0016	3.45	.0003	3.95	.0000
2.46	.0069	2.96	.0015	3.46	.0003	3.96	.0000
2.47	.0068	2.97	.0015	3.47	.0003	3.97	.0000
2.48	.0066	2.98	.0014	3.48	.0003	3.98	.0000
2.49	.0064	2.99	.0014	3.49	.0002	3.99	.0000
2.50	.0062	3.00	.0013	3.50	.0002	4.00	.0000

NOTE: IF N IS NEGATIVE P(-N) = 1 - P(N)

TABLE 5-5. NORMAL DISTRIBUTION VALUES FOR THE CUMULATIVE PROBABILITIES, PS OR PP, OF A POINT FALLING BEYOND NS OR NP (SEE NOTE)

N	P(N)	N	P(N)	N	P(N)	N	P(N)
.00	.5000	.50	.3085	1.00	.1587	1.50	.0668
.01	.4960	.51	.3050	1.01	.1562	1.51	.0655
.02	.4920	.52	.3015	1.02	.1539	1.52	.0643
.03	.4880	.53	.2981	1.03	.1515	1.53	.0630
.04	.4840	.54	.2946	1.04	.1492	1.54	.0618
.05	.4801	.55	.2912	1.05	.1469	1.55	.0606
.06	.4761	.56	.2877	1.06	.1446	1.56	.0594
.07	.4721	.57	.2843	1.07	.1423	1.57	.0582
.08	.4681	.58	.2810	1.08	.1401	1.58	.0571
.09	.4641	.59	.2776	1.09	.1379	1.59	.0559
.10	.4602	.60	.2743	1.10	.1357	1.60	.0548
.11	.4562	.61	.2709	1.11	.1335	1.61	.0537
.12	.4522	.62	.2676	1.12	.1314	1.62	.0526
.13	.4483	.63	.2643	1.13	.1292	1.63	.0516
.14	.4443	.64	.2611	1.14	.1271	1.64	.0505
.15	.4404	.65	.2578	1.15	.1251	1.65	.0495
.16	.4364	.66	.2546	1.16	.1230	1.66	.0485
.17	.4325	.67	.2514	1.17	.1210	1.67	.0475
.18	.4286	.68	.2483	1.18	.1190	1.68	.0465
.19	.4247	.69	.2451	1.19	.1170	1.69	.0455
.20	.4207	.70	.2420	1.20	.1151	1.70	.0446
.21	.4168	.71	.2389	1.21	.1131	1.71	.0436
.22	.4129	.72	.2358	1.22	.1112	1.72	.0427
.23	.4090	.73	.2327	1.23	.1093	1.73	.0418
.24	.4052	.74	.2296	1.24	.1075	1.74	.0409
.25	.4013	.75	.2266	1.25	.1056	1.75	.0401
.26	.3974	.76	.2236	1.26	.1038	1.76	.0392
.27	.3936	.77	.2206	1.27	.1020	1.77	.0384
.28	.3897	.78	.2177	1.28	.1003	1.78	.0375
.29	.3859	.79	.2148	1.29	.0985	1.79	.0367
.30	.3821	.80	.2119	1.30	.0968	1.80	.0359
.31	.3783	.81	.2090	1.31	.0951	1.81	.0351
.32	.3745	.82	.2061	1.32	.0934	1.82	.0344
.33	.3707	.83	.2033	1.33	.0918	1.83	.0336
.34	.3669	.84	.2005	1.34	.0901	1.84	.0329
.35	.3632	.85	.1977	1.35	.0885	1.85	.0322
.36	.3594	.86	.1949	1.36	.0869	1.86	.0314
.37	.3557	.87	.1922	1.37	.0853	1.87	.0307
.38	.3520	.88	.1894	1.38	.0838	1.88	.0301
.39	.3483	.89	.1867	1.39	.0823	1.89	.0294
.40	.3446	.90	.1841	1.40	.0808	1.90	.0287
.41	.3409	.91	.1814	1.41	.0793	1.91	.0281
.42	.3372	.92	.1788	1.42	.0778	1.92	.0274
.43	.3336	.93	.1762	1.43	.0764	1.93	.0268
.44	.3300	.94	.1736	1.44	.0749	1.94	.0262
.45	.3264	.95	.1711	1.45	.0735	1.95	.0256
.46	.3228	.96	.1685	1.46	.0721	1.96	.0250
.47	.3192	.97	.1660	1.47	.0708	1.97	.0244
.48	.3156	.98	.1635	1.48	.0694	1.98	.0239
.49	.3121	.99	.1611	1.49	.0681	1.99	.0233
.50	.3085	1.00	.1587	1.50	.0668	2.00	.0228

NOTE: IF N IS NEGATIVE P(-N) = 1 - P(N)

When a quantitative measure of risk is available, the next step is interpreting a value as high or low, acceptable or not. The most immediate method for interpreting a value is to compare it to a value for a situation with a better known history of safety. The procedure just suggested using a history of transits with a smaller ship is an example of such an interpretation. The use of standards for the interpretation of risk is more completely discussed in Section 9 on risk management procedures. A brief treatment here shows its applicability to the RRFMT measure.

A critical part of the procedure is the selection of appropriate standard values. In the example, the standard is a value calculated for the same region in the same waterway with only the factors of interest, ship size and aids changed. Any difference in the values of risk measured can only be attributable to those factors. A comparison in the same region and the same waterway is the most certain. But it will not always be possible.

If a different waterway is to be used as a standard, it should be matched on as many factors as possible. Ideally, only the factor being investigated should be different: for example the largest ship size with a history on each waterway. Worksheet 6-2 is provided as a guide. It is based on Section 3 on the specifications of waterway conditions. The following steps are recommended.

1. Briefly describe conditions in each category for the subject waterway, the one being evaluated.

2. Briefly describe conditions for a proposed standard waterway, one with a better-known history.

3. Compare the two waterways on each factor. Indicate whether risk in the proposed standard waterway is likely to be higher, lower, or equivalent to the subject waterway as a result of each factor. Inspect the whole list of factors and decide whether the overall risk for the proposed standard is likely to be higher, lower, or equivalent. Decide whether the match is close enough to be useful.

4. In the subject waterway select several turn and recovery regions that are of relatively high risk for the waterway. In the standard waterway select turn and recovery regions that match as well as possible in physical characteristics and aid arrangements. Calculate the RRFMT for all selected regions, using Worksheet 6-1 as a guide. Summarize the values on Worksheet 6-3.

5. Inspect the array of values. If the values in the subject waterway are equivalent to or lower than those in the standard waterway, it is reasonable to conclude that the subject waterway is as safe.

If the comparison shows that the subject waterway is not safe and the aid arrangements are already conservative, meeting traffic is a shiphandling problem. Safety can only be improved by changes in operations or by dredging. These possibilities are discussed in Section 9.

WORKSHEET FOR THE SELECTION OF A STANDARD WATERWAY

See Section 6.4.2 and Section 3.2

	DESCRIPTION		
FACTOR	SUBJECT WATERWAY	STANDARD WATERWAY	Risk of Standard is too low, too high, appropriate
Channel and Turn Characteristics	____	____	____
	____	____	____
	____	____	____
Environmental Conditions and Frequencies	____	____	____
	____	____	____
	____	____	____
Operational Practices	____	____	____
	____	____	____
	____	____	____
Size of Design Vessel	____	____	____
Frequency of Design Vessel Meeting	____	____	____
View of Land	____	____	____
	____	____	____
Consequences of Accident	____	____	____
	____	____	____
Aids in Regions Considered	____	____	____
	____	____	____
	____	____	____

Similarity of Overall Risk? ____________________

Worksheet 6-2

WORKSHEET TO COMPARE RRFMT IN TWO WATERWAYS

See Section 6.4.2

REGION IDENTIFICATION	SUBJECT WATERWAY	STANDARD WATERWAY	Region is safe?

Subject waterway is safe? ______________________________

Worksheet 6-3

SPECIAL GUIDANCE FOR THE REDUCED VISIBILITY/RADAR SITUATION

Section 7

SPECIAL GUIDANCE FOR THE REDUCED VISIBILITY/RADAR SITUATION

7.1 INTRODUCTION

It is Coast Guard policy to provide aids to navigation systems for visual piloting. This manual has been prepared in conformity with this policy. Sections 4 and 5 provide for the primary design and evaluation of aid systems for visibility adequate for visual piloting. For the use of ranges "adequate" visibility is sufficient to see both structures 100 percent of the time from the beginning of the staightaway that the range is intended to mark. For aids on the edge of the channel, it is 1.25 nm, or a distance sufficient to see the longest spaced aid or pair of aids ahead 100 percent of the time. The earlier sections suggested that frequent reduced visibility was a factor requiring a conservatism in design. This section is organized with the assumption that Section 3 and Sections 4 and/or 5 have already been applied. It is meant to further evaluate the resulting design(s) under conditions of reduced visibility. The data represent piloting with conventional radar and aids equipped with passive reflectors.

This section provides guidelines and data to serve a number of objectives.

1. To supplement system design guidelines. The section provides assurance that a conservative aid system designed using Sections 4 and/or 5 provides the best reduced visibility performance that can be expected, using conventional radar and aids equipped with passive reflectors.

2. To supplement performance evaluation. Data for evaluating performance under adequate visibility were provided in Section 5. This section provides data for evaluating performance under reduced visibility for conservative arrangements only. Performance under the two conditions in the same waterway can be compared by inspection. It is not expected that performance will be equal, even with conservative aid system design. Section 9 contains instructions for further evaluation by comparison to a waterway with a better-known safety record.

3. To establish a baseline for radio aids piloting. The section contains performance data for piloting in zero visibility with conventional radar and aids equipped with passive reflectors. Comparison with these data provides a preliminary evaluation of radio aids for use in restricted waterways.

This section is organized around data from one experiment designed especially to investigate the reduced visibility/radar piloting situation. The section begins by describing the simulator conditions under which the data were collected. It continues with a description of the performance observed, presenting the new data to illustrate points. It finishes with suggestions on the use of these data to serve the suggested objectives. Because the system designer is assumed to be already familiar with Section 3 and Sections 4 and/or 5, it contains a minimum of explanation about concepts and methods that appeared there.

7.2 SIMULATOR EVALUATION OF PERFORMANCE

7.2.1 Conditions from the Visual Experiments

In designing the reduced visibility/radar experiment, scenarios were selected from the visual experiments described in Section 2. These are the experiments on which Sections 4 and 5 are based. In order that the data be as comparable as possible, the simulated conditions were as similar as possible to those of earlier experiments: the channel dimensions, the ship hydrodynamic models, the wind and current, the aid arrangements, the visual scene when available, the pilots' association that participated, the transits asked of them, and the performance measures taken were all the same. The differences between the two experiments were in the visibility and in the availability of radar.

7.2.2 Radar in the Simulator Experiments

The characteristics of the generic 3-centimeter radar developed for the experiment at Ship Analtyics' Connecticut facility are summarized in Table 7-1. The implications of its characteristics for performance are discussed in Section 7.2.3

A secondary objective of the experiment was to investigate the pilots' use of radar. The investigation consisted of discussions with the pilots about their use of radar at sea and of systematic observation of their use of it on the simulator.

The following is a summary of the findings on radar use.

1. The tradeoff between visual and radar methods. The pilots reported that at sea they prefer visual methods, preferring not to get underway when visibility is restricted. When forced to get underway under marginal conditions, they do not combine methods, but give dominance to one, using the other for confirmation. The one chosen for dominance is the one that is expected to be useful for most of the transit. The performance observed on the simulator supported the report that the methods are not combined. There was evidence that the methods interfered with, as well as enhanced, each other.

2. The use of radar features. There was considerable uniformity among the pilots and among the conditions tested in the use of the operator-selectable radar features. The pilots all used the head up display, the mechanical cursor, the heading flash, and either the variable range marker or the range rings. They used the lowest ranges scales, 1/2, 1, and 1-1/2 nautical miles (nm) for the turn; going up to 3 nm in the straightaways. Only the frequency of changes in range scale was related to the difficulty of the conditions, with more frequent changes for the more difficult conditions. There was no obvious relationship between feature use and the resulting ship track performance.

3. Facility with course cursor piloting. All the pilots used course cursor piloting (cursor on the desired course, heading flash for comparison). There were differences in their facility with this method that

TABLE 7-1. THE SIMULATOR RADAR

EQUIPMENT SPECIFICATIONS ASSUMED

Wave length: 3 centimeters
Pulse length: 0.06 microseconds
Pulse repetition rate: 3600 pules per second
Nominal peak power: 25 kilowatts
Power output for short scale operations: 5.4 watts

Horizontal beam width: 0.8 degrees
Vertical beam width: 20 degrees
Horizontal polarization
Rotation rate: 30 rotations per minute
Antenna height adjusted for ship size

INDICATOR

Generic 16-inch plan position indicator

OPERATOR-SELECTABLE FEATURES

Display modes: head up, north up
Ranges scales: 1/2, 1, 1-1/2, 3, 6, 12, 24 nautical miles (nm)
Range rings: 0.08, 0.16, 0.25 0.50, 1, 4 nm
Heading flash
Electronic bearing line
Variable range marker

DISPLAY

Perfect position information
Buoy images spread for beam width
All operator-selectable features
Blind zone adjusted for ship size
No sweep
No clutter

were not related in any simple way to experience factors. These differences were reflected in the precision of ship track performance.

The pilots' use of radar is discussed more fully in the original report on this experiment.[2]

7.2.3 Interpretation of the Performance Data

The conditions under which the simulator data were collected affect the interpretation of the data and its comparability to other sets of data.

1. Simulator radar and performance at sea. The simulator radar differed from a radar set at sea in that it showed perfect position information and showed no sweep or clutter. On the other hand, it had none of the enhancements that are more frequent on radar today. The two considerations may result in simulator performance that is representative of what can be expected at sea.

It should be emphasized that the reduced visibility/radar performance observed here was obtained by pilots with both federal and state licenses and with recent experience with radar, large ships, and narrow channels. Other shiphandlers will not necessarily show performance as good.

2. Simulator radar and simulator visual performance. The visual performance data were collected under "worst case" conditions of a slow 6-knot speed to increase the shiphandling difficulty and the conservatism of the data. The 6-knot speed is realistic for reduced visibility conditions and is not a worst case. The simulator radar data may not provide as conservative an estimate of risk as do the visual.

7.2.4 Description of the Reduced Visibility/Radar Situation

Three levels of visibility were used in the experiment. They were as follows:

- 1-1/2 nautical miles (nm), a distance longer than the longest buoy spacing
- 1/4 nm, a distance long enough to see all buoys in a turn region or both buoys of a gated pair
- zero visibility (no visual information)

Conditions with some visibility showed a daytime visual scene. Nighttime conditions were not evaluated.

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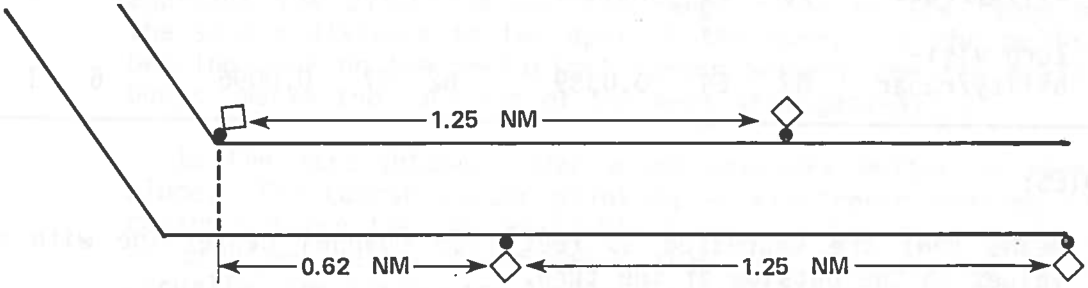
[2] J. Multer and M.W. Smith. "Aids to Navigation Radar I Principal Findings: Performance in Limited Visibility of Short-Range Aids with Passive Reflectors." CG-D-79-83, U.S. Coast Guard, Washington, D.C., December 1983, NTIS AD-A137596.

The following discussion uses the data from the three conditions, and visual piloting data from earlier experiments, to illustrate what was learned about radar piloting and its implications for the design and evaluation of short range aids to navigation systems.

7.3 TRADEOFFS BETWEEN VISUAL AND RADAR PILOTING

It is sometimes suggested that low-density buoy arrangements (very few buoys per nautical mile) should never be a problem at sea because radar is always available and radar features enhance the information presented by only a few buoys. A low-density buoy arrangement with a one-buoy turn and long-spaced staggered buoys evaluated in several visual experiments was included in the radar experiment to explore this possibility. The buoys were arranged as illustrated.



Data is summarized in Table 7-2 for this aid arrangement under three different conditions: adequate visibility/no radar, adequate visibility/radar, and zero visibility/radar. These data illustrate the following discussion.

7.3.1 Low Buoy Density, Adequate Visibility, and Radar

Pilots generally report that they prefer visual piloting as long as the visibility is adequate for it. Therefore, to provide conservative and unambiguous performance data for visual piloting, no radar was available during the collection of the main body of data on which Sections 4 and 5 are based. To evaluate the degree of conservatism in the visual data, a single scenario with adequate visibility for visual piloting (1-1/2 nm) and with radar available was included in the radar experiment.

Performance on the simulator for this scenario is summarized in Table 7-2 by the second row of data. In the turn region, with one-turn buoy and the first straightaway buoy visible and the radar available, the turn performance was among the best observed in the research project. The radar did enhance the visual in the turn. However, performance in the straightaway was an artifact of the experimental situation. The pilots knew that the experiment was intended to focus on the reduced visibility/radar situation and used the opportunity of having both visual and radar available to familiarize themselves with the radar simulation. At least some of them steered the course of the channel in the crosscurrent to "correlate" the resulting set in the visual scene and on radar. In this case having both adequate visibility and radar resulted in poor performance. On the pilots' use of radar, there was evidence that some of the pilots used the buoys (staggered or gated) one at a time as they passed them, as they do for visual piloting. These pilots would have been helped by shorter spacing. Other pilots, who used the buoys as a series to which to compare the heading flash, would not have been helped by shorted spacing. (The latter tend to show better performance anyway.) In marking a waterway for reduced visibility, short spacing should be considered only after a three-buoy turn has been selected. There is no savings in using fewer aids in the turn and more in the straightaway.

7.4.2 Ship Size in Reduced Visibility

The experiment evaluated the effect of ship size in the reduced visibility situation. The data were used to develop the correction factors for ship size in Table 7-4. Ship size has a very large effect on the risk of a transit in reduced visibility. A comparison with the correction factors for visual piloting in Tables 5-4, 5-8, and 5-10, shows that the effect is even larger in reduced visibility than in adequate visibility. A larger ship increases the requirement that the pilot have timely information about its position and status in the channel and that he make early adjustments to its heading and track. When there is uncertainty about a ship's position and status, performance with the larger, less maneuverable ship suffers more.

7.4.3 Implications for Marking

The reduced visibility experiment was designed and this section is organized on the assumption that a conservative marking for adequate visibility is the best marking for reduced visibility. The observed performance supports the selection of the conservative three-buoy turn and gated aids for the reduced visibility situation. (The zero visibility data not yet presented provides additional evidence that gates are superior.)

The effect of gate spacing was not evaluated in the reduced visibility situation. The larger body of data on adequate visibility piloting had shown that the spacing of gates did not have a large effect on performance. See Tables 5-6 and 5-9 for baseline data for the straightaway. However, indirect evidence suggests shorter gate spacing would be a help in the reduced visibility/radar situation. First, the data on the tradeoffs between visual and radar information described in Section 7.3 showed that the availability of radar does not compensate for low-density buoy arrangement. A second, certainly related finding, was that at least some pilots use the buoys one at a time on radar, rather than as a series. Higher-buoy density or shorter spacing would be a help to them, whether they use the buoys on the radar or visually as they pass close to them. If ship size or wind and current add to the difficulty, it is recommended that 0.80 nm to the first recovery gate be considered a maximum spacing for the straightaway.

TABLE 7-4. CORRECTION FACTORS FOR THE REDUCED VISIBILITY SITUATION

TURN REGION, SHIP SIZE (1,000 deadweight tons)					
	30	50	70	90	110
MCSHP[1]	1	1.55	2.09	2.64	3.18
			slope = 0.0273		
SCSHP[2]	1	1.72	2.44	3.16	3.88
			slope = 0.0360		

RECOVERY REGION, SHIP SIZE (1,000 deadweight tons)					
	30	50	70	90	110
MCSHP	1	1	1	1	1
SCSHP	1	1.42	1.85	2.27	2.70
			slope = 0.0212		

TRACKKEEPING REGION, SHIP SIZE (1,000 deadweight tons)					
	30	50	70	90	110
MCSHP	1	1	1	1	1
SCSHP	1	1.52	2.05	2.58	3.10
			slope = 0.0262		

ALL REGIONS, CHANNEL WIDTH (marked by aids, in feet)						
	300	400	500	600	700	800
MCWID[3]	0.67	0.83	1	1.17	1.33	1.5
SCWID[4]	0.67	0.83	1	1.17	1.33	1.5

TABLE 7-4. CORRECTION FACTORS FOR THE REDUCED VISIBILITY SITUATION (CONTINUED)

NOTES

1. MCSHP: mean correction factor for ship size

2. SCSHP: standard deviation correction factor for ship size

   To interpolate for SCSHP, use

$$SCSHP_i = 1 + \text{slope}\ (X_i - 30)$$

   where:
   $SCSHP_i$ = correction factor for any ship size in 1,000 dwt
   X_i = ship size in 1,000 dwt
   slope = value given in table above

3. MCWID: mean correction factor for channel width

   To interpolate for MCWID, use:

$$MCWID_i = 1 + 0.5\ (W_i - 500)/300$$

   where
   $MCWID_i$ = correction factor for any channel width
   W_i = channel width

4. SCWID: standard deviation correction factor for channel width.

   Interpolate as in Note 3.

7.5 USE OF THE REDUCED VISIBILITY DATA

The introduction to Section 7 suggests that it can be used to supplement the design guidelines or the evaluation procedures of the earlier sections. Further suggestions for these uses follow.

7.5.1 Design Guidelines

Section 7 can be read as design guidelines, as was Section 4, to familiarize the system designer with the factors that affect risk. Possibly this familiarity alone will guide the designer in designing his system.

Performance data assigned to competing turn arrangements may assist in design selections. This is a use that was suggested for performance data in Section 5. If the performance data are to be used in selecting alternative turn arrangement with all other factors kept constant, the procedure is simple. Baseline values can be used directly out of Table 7-3. If the ship size (30,000 dwt) and the channel width (500 feet) are not the waterway values, they will have a constant difference from the true values for all alternatives and can be used as a relative measure of aid arrangement performance.

An increase in the size of the ships transiting a waterway may have prompted a redesign of a system. The available performance data show that the rate of increase in risk with ship size is much greater in reduced visibility than in adequate visibility. It is unlikely that additional aids will bring the reduced visibility risk with a larger ship down to what it is with a smaller ship. It is recommended that the aid system be designed for the larger ship in adequate visibility. If the risk in reduced visibility is excessive, the solution is not in aids. The pilots reported that ship size is a major factor in their decision as to whether to undertake a reduced visibility transit. The data corroborate their concern for this factor. When risk is unacceptable, the solution is in operational restrictions. Suggestions for determining when risk is unacceptable appear in Section 7.5.2 and in Section 9. The possibility of operating restrictions is discussed in Section 9.

7.5.2 Evaluation Procedures

The general evaluation procedure recommended in the manual is to calculate the RRF for a region or for all the regions of a waterway and then interpret the degree of risk by comparison to some other selected condition. The most obvious first comparison for reduced visibility risk is the risk for the same waterway in adequate visibility. In Section 5 Worksheet 5-7 was used to summarize risk in adequate visibility for the subsystems of day, night, and ranges. Evaluation of risk in the reduced visibility situation adds a fourth subsystem or column.

To evaluate the reduced visibility subsystem, use the worksheets from Section 5, with the baseline data in Table 7-3 and the correction factors in Table 7-4. The new evaluation must be less certain because baseline data are available for only a few conditions. Recommendations for generalization of the available baseline data follow. The recommendations assume the reader is familiar with Section 5.

TURN REGION

1. Turn configuration: The data are for noncutoff turns. For cutoff turns and bends, use the data and indicate that risk is overestimated. For greater precision for cutoff turns, calculate the RRF allowing extra space to port for the cutoff. Risk is still somewhat overestimated because there is no allowance for the change to a longer turn radius that is allowed by a cutoff.

2. Angle of turn: For turn angles of less than 20 degrees, make a notation that risk is overestimated.

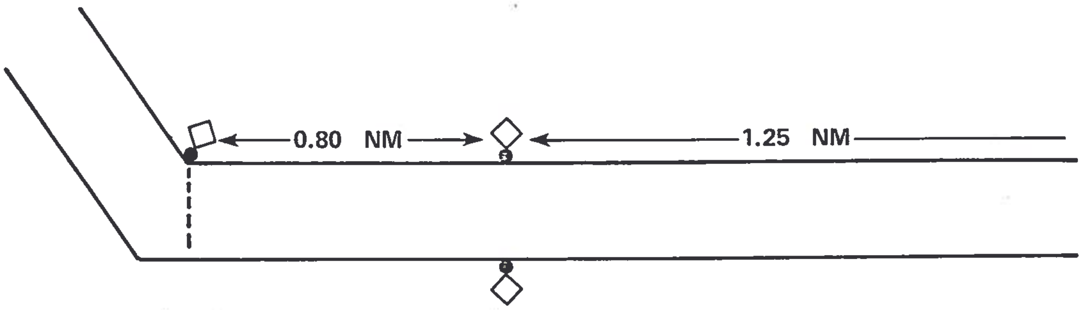
3. Aid arrangement:

For noncutoffs, one-buoy arrangements were not evaluated because it is less likely that they will be used where reduced visibility is frequent. If they are of interest, use the two-buoy turn data with the notation that risk is underestimated. Data is available for the two- and three-buoy turns.

For cutoffs, use the two-buoy turn data for a one- or two-buoy turn. If the cutoff area is outlined, use the three-buoy turn data. In any case, make a notation that risk is overestimated.

RECOVERY REGION

1. Aid arrangement: For gates the spacing evaluated was as illustrated.



If spacing is longer, make a notation that risk is underestimated, if, shorter, that is overestimated. The distance to the first recovery gate is critical in this determination.

No staggered arrangements were evaluated under the reduced visibility (1/4 nm) condition on the assumption that such arrangements are unlikely where reduced visibility is frequent. If such arrangements are of interest, use the data for gates with a notation that risk is underestimated.

2. Crab angle: 0-2 versus 2-5 degrees: Data for recovery with or without crab angle should be selected for reduced visibility to be consistent with the selection for adequate visibility.

TRACKKEEPING

1. Aid arrangement: For gated aids if the spacing is longer than 1.25 nm; make a notation that risk is underestimated; if shorter, overestimated.

For staggered aids, make a notation that risk is underestimated.

2. Crab angle: 0-2 versus 2-5 degrees: Data for trackkeeping with or without crab angle should be selected for reduced visibility to be consistent with the selection for adequate visibility.

To summarize the resulting evaluation, Worksheet 7-1 is provided to supplement Worksheet 5-7. A comparison of the fourth subsystem to the other three shows the increase in risk with reduced visibility. Note that the reduced visibility data were collected under daytime conditions. Given the same meteorological visibility, nighttime lights usually have a greater range than daytime daymarks. However, performance data in Section 5 (baseline Tables 5-1, 5-6, and 5-9) show that for a constant detection distance, the flashing nighttime aids provide poorer performance, especially for the higher-risk maneuvers. Data are not available to examine the tradeoff between the greater range of the nighttime aids and the constancy and detail of the daytime aids, once they are available.

If an aid system, designed with a reasonable degree of conservatism for adequate visibility, shows a considerable increase in risk with reduced visibility; the designer may consider adding aids for the reduced visibility situation. Unlighted aids may be a good candidate for this. If ship size or wind and current are considerations, it may not be possible to bring the reduced visibility risk down to the level for adequate visibility. Or it may be possible, but the frequency of reduced visibility transits may not justify the expense. In such cases operational restrictions may be the solution. Section 9 considers this possibility.

Section 9 elaborates on the possibility of interpreting the RRF by comparison to other conditions. The RRF for reduced visibility can be interpreted as acceptable or not by comparison to a standard waterway with a better-known safety -- or risk -- record. Instructions for the selection of such a waterway are included. Also included are instructions for calculating a composite relative risk factor (CRRF) for a waterway. This is done by summing across the risk of each of the subsystems (now four) weighted by the proportion of transits under that subsystem. The new measure provides for an overall comparison between the two waterways.

7.6 BASELINE DATA FOR ZERO VISIBILITY PILOTING

The experiment evaluated zero visibility conditions with the pilots using conventional radar and aids fitted with passive reflectors. These data are meant to provide a standard against which to compare radar enhancements, racons, or all-weather navigational systems. To provide a conservative evaluation of new aids, the performance was planned to be the best possible with traditional methods. The pilots had both federal and state licenses and had recent experience with large ships, narrow channels, and radar. Additionally, the zero visibility conditions were run late in the

SUMMARY WORKSHEET FOR EVALUATION
(To Supplement Worksheet 5-7)

Copy for each waterway and/or design objective.

Waterway Name and Location: ____________________

Design/Evaluation Objective: ____________________

REGION IDENTIFICATION	REDUCED VISIBILITY, DAY (RRF (+/-?)

Worksheet 7-1

experimental day when the pilots were relatively familiar with the radar simulation. At sea pilots would be more familiar with conventional radar than with a new system. (The greater familiarity is one reason why the experimental zero visibility performance is superior to 1/4 nm visibility performance. This superiority should not be interpreted to mean that the pilots should wait for zero visibility conditions. Concentration on a single method undoubtedly played a role as well.)

The baseline data are presented in Table 7-5. The correction factors in Table 7-4 may be used with them. The recommendations in Section 7.5.2 for generalizing the available baseline data can be used. Worksheets for calculating the RRF can be taken from Section 5. Worksheet 7-2 is given for summarizing the data and comparing it to another system.

TABLE 7-5. BASELINE PERFORMANCE DATA FOR ZERO VISIBILITY/RADAR PILOTING
(USING CONVENTIONAL RADAR AND SHORT RANGE AIDS WITH PASSIVE REFLECTORS)

	REGION								
				RECOVERY			TRACKKEEPING		
				CRAB ANGLE, 0-2 DEGREES					
AIDS				MN[1]	SD[2]	RRF[3]	MN	SD	RRF
1-buoy turn/ long-spaced staggered				36	25	0.0000	1	14	0.0000
3-buoy turn/ long-spaced gates				37	21	0.0000	3	24	0.0000
	TURN			RECOVERY			TRACKKEEPING		
				CRAB ANGLE, 2-5 DEGREES					
	MN	SD	RRF	MN	SD	RRF	MN	SD	RRF
1-buoy turn/ long-spaced staggered	67	64	0.0359	62	57	0.0096	6	71	0.0073
3-buoy turn long-spaced gated	74	50	0.0158	69	46	0.0030	32	35	0.0000

NOTES:

1. Means (MN) are expressed as feet from channel centerline with positive values to the outside of the turn.
2. Standard deviations (SD) are in feet.
3. The relative risk factor (RRF) was calculated using the instructions in Section 5 and the standard conditions in Table 5-3.

SUMMARY WORKSHEET FOR COMPARING ZERO VISIBILITY/RADAR AND RADIO AIDS

Waterway Name and Location:

Radar enhancement, racon, or all-weather navigational system evaluated:

REGION IDENTIFICATION	ZERO VISIBILITY/ RADAR RRF (+/-?)	NEW SYSTEM RRF (+/-?)	NEW SYSTEM AS EFFECTIVE?

Overall effectiveness of new system?

Worksheet 7-2

SECTION 8. EVALUATION OF RADIO AIDS PERFORMANCE

8.3 DESCRIPTION OF RADIO AID PERFORMANCE

Summaries of performance with perfect position and velocity data are presented below by display type.

(1) Graphic display with vector

- Good maneuvering performance with scaled ownship's image
- Good trackkeeping performance in track-up orientation
- Good maneuvering performance with heading vector
- Good trackkeeping performance with course vector
- True motion feature compatible with existing navigation system
- Moderate cost system
- Very high user acceptance (preferred display); minimal familiarization required; perceived to have moderate accuracy and high reliability in the real world application

(2) Predictor steering

- Good overall performance
- High cost
- High user acceptance; perceived to have high accuracy and low reliability in the real world application

(3) Perspective

- Good maneuvering performance with 90-degree field of view (point of the turn was visible longer)
- Poor trackkeeping performance with both 60- and 90-degree fields of view (difficulty returning to the centerline)
- Moderate cost system
- Moderate user acceptance (subjects originally anticipated high performance with this display but could not achieve their goals)

(4) Digital distance display

- Poorest overall performance, highest overall variability in maneuvering and trackkeeping among pilots
- General inability to safely negotiate the turn
- Difficulty in determining the amount and timeliness of initial turn rudder, subsequent turn rudder, and check rudder
- Excessive overshoot by some subjects and undershoot by others both in the bend and attempting to steady up on the centerline
- Low cost system
- Very low user acceptance primarily the result of insufficient experience with the display. Also the premise that no pilot would attempt this maneuver in the real world with such scant information

(5) Digital turn recommendations

- High variability in overall performance among subjects
- Decreased variability in maneuvering performance when turn information was initiated automatically instead of operator selected
- Major difficulty in recovering from the turn and steadying up on the centerline

- Some difficulty in determining when to initiate the turn, even when the information was provided automatically
- Comparable performance regardless of whether course error, heading to steer, or no steering cue was displayed
- Comparable performance regardless of whether distance to leadline or time to leadline was displayed
- Low cost system
- Lower user acceptance resulting from inability to "prove" the display and become familiar with it to the subjects' satisfaction; perceived to have high accuracy and high reliability in the real world application

8.4 PERFORMANCE DATA

The conditions under which the simulator data were collected affect the interpretation of the data and its comparability to other sets of data.

1. Comparisons among radio aid display formats. The data presented in the following tables comes from experiments designed especially for such comparisons. They are the most certain use of the data.

2. Simulator radio aids performance and expected performance at sea. The simulator radio aids differed from what would be expected at sea in that it showed perfect position and velocity information, a condition impossible at sea. On the other hand, on the simulator the use of the displays was completely new to the pilots, a condition that should not exist at sea. These two offsetting considerations may result in simulator performance that is representative of what can be expected at sea.

3. Simulator radio aids and simulator visual performance. The visual performance data was collected with "worst case" conditions of a low 6-knot speed to increase the shiphandling difficulty and the conservatism of the data. The 6-knot speed is probably realistic rather than worst case for the radio aids situation. On the other hand, the pilots were more familiar with the visual situation, both from their at-sea experience and from time spent on the simulator. The two sets of data may make an appropriate comparison. Visual performance data appear in Section 5.

4. Simulator radio aids and simulator radar data. The two situations share the perfect position information and the appropriateness of the 6-knot speed. However, the pilots were familiar with the use of radar to the extent that the simulator and real world radars were similar. They had no experience with the radio aids before the data was collected. In the radar experiment the opportunity to run some of the scenarios under limited visibility meant greater familiarity with the channel and the ship during the zero visibility conditions. In the radio aids experiments were was no such opportunity. The radio aids data are probably a more conservative estimate of risk than is the radar data. Radar performance data appear in Section 7.

Performance data are provided for the radio aids situation. The use of such data has been discussed all through the manual and little is repeated here. There is a general discussion on the use of the data in Section 2.

Instructions for breaking up the waterway into regions appears in Section 3.3. Instructions and worksheets for calculating the relative risk factor (RRF) for each region appear in Section 5 and are summarized in Worksheets 5-2, 5-4, and 5-6, which can be copied and used here. The baseline data are provided here in Tables 8-1, 8-2, 8-3. The most appropriate correction factors, those for the zero visibility radar situation, are repeated here as Table 7-4. Worksheet 8-1 can be used as a guide to comparisons.

TABLE 8-1. BASELINE RADIO AIDS PERFORMANCE FOR TURN REGION

Perfect Position and Velocity Data Available

NONCUTOFF TURNS >20 degrees

DISPLAY FORMAT	MN[1]	SD[2]	RRF[3]
Graphic display with vector	117	66	0.1587
Predictor steering	73	59	0.0314
Perspective	91	111	0.2101
Digital distance display	19	280	0.5134
Digital turn recommendations	53	107	0.1270

NOTES:

1. Means (MN) are expressed in feet from channel centerline with positive values to the outside of the turn.
2. Standard deviations (SD) are in feet.
3. The relative risk factor (RRF) was calculated using the formula described in Section 2.6.3 and the standard conditions described in Section 5.2.2.

TABLE 8-2. BASELINE RADIO AIDS PERFORMANCE FOR RECOVERY REGION

Perfect Position and Velocity Data Available

CRAB ANGLE, 0-2 degrees

DISPLAY FORMAT	MN[1]	SD[2]	RRF[3]	NP+NS[4]
Graphic display with vector	6	28	0.0000	7.19 + 6.76
Predictor steering	16	21	0.0000	10.06 + 8.53
Perspective	29	30	0.0000	7.47 + 5.54
Digital distance display	14	19	0.0000	11.01 + 9.54
Digital turn recommendations	1	48	0.0000	4.09 + 4.04

CRAB ANGLE, 2 to 5 degrees

DISPLAY FORMAT	MN	SD	RRF
Graphic display with vector	42	85	0.0385
Predictor steering	23	54	0.0007
Perspective	116	55	0.0749
Digital distance display	44	187	0.3093
Digital turn recommendations	109	306	0.5508

NOTES:

1. Means (MN) are expressed in feet from channel centerline with positive values to the outside of the turn.

2. Standard deviations (SD) are in feet.

3. The relative risk factor (RRF) was calculated using the formula described in Section 2.6.3 and the standard conditions described in Section 5.2.2.

4. NP+NS comes out of the calculation of the RRF and is included only for those siuations for which the RRF values are too low to differentiate among alternatives.

TABLE 8-3. BASELINE RADIO AIDS PERFORMANCE FOR TRACKKEEPING REGION

Perfect Position and Velocity Data Available

DRIFT ANGLE, 0-2 degrees

DISPLAY FORMAT	MN[1]	SD[2]	RRF[3]	NP+NS[4]
Graphic display with vector	24	34	0.0000	6.45 + 5.03
Predictor steering	48	51	0.0019	4.77 + 2.89
Perspective	35	31	0.0000	7.43 + 5.17
Digital distance display	11	23	0.0000	8.97 + 8.01
Digital turn recommendations	1	47	0.0000	4.17 + 4.13

DRIFT ANGLE, 2 to 5 degrees

DISPLAY FORMAT	MN	SD	RRF
Graphic display with vector	65	48	0.0034
Predictor steering	32	29	0.0000
Perspective	109	71	0.1131
Digital distance display	18	87	0.0283
Digital turn recommendations	118	339	0.5878

NOTES:

1. Means (MN) are expressed in feet from channel centerline with positive values to the outside of the turn.
2. Standard deviations (SD) are in feet.
3. The relative risk factor (RRF) was calculated using the formula described in Section 2.6.3 and the standard conditions described in Section 5.2.2.
4. NP+NS comes out of the calculation of the RRF and is included only for those siuations for which the RRF values are too low to differentiate among alternatives.

TABLE 7-4. CORRECTION FACTORS FOR THE REDUCED VISIBILITY SITUATION

TURN REGION, SHIP SIZE (1,000 deadweight tons)	30	50	70	90	110
MCSHP[1]	1	1.55	2.09	2.64	3.18
		slope = 0.0273			
SCSHP[2]	1	1.72	2.44	3.16	3.88
		slope = 0.0360			

RECOVERY REGION, SHIP SIZE (1,000 deadweight tons)	30	50	70	90	110
MCSHP	1	1	1	1	1
SCSHP	1	1.42	1.85	2.27	2.70
		slope = 0.0212			

TRACKKEEPING REGION, SHIP SIZE (1,000 deadweight tons)	30	50	70	90	110
MCSHP	1	1	1	1	1
SCSHP	1	1.52	2.05	2.58	3.10
		slope = 0.0262			

ALL REGIONS, CHANNEL WIDTH (marked by aids, in feet)	300	400	500	600	700	800
MCWID[3]	0.67	0.83	1	1.17	1.33	1.5
SCWID[4]	0.67	0.83	1	1.17	1.33	1.5

TABLE 7-4. CORRECTION FACTORS FOR THE REDUCED VISIBILITY SITUATION (CONTINUED)

NOTES

1. MCSHP: mean correction factor for ship size

2. SCSHP: standard deviation correction factor for ship size

   To interpolate for SCSHP, use

$$SCSHP_i = 1 + slope\ (X_i - 30)$$

where:
$SCSHP_i$ = correction factor for any ship size in 1,000 dwt
X_i = ship size in 1,000 dwt
slope = value given in table above

3. MCWID: mean correction factor for channel width

   To interpolate for MCWID, use:

$$MCWID_i = 1 + 0.5\ (W_i - 500)/300$$

where
$MCWID_i$ = correction factor for any channel width
W_i = channel width

4. SCWID: standard deviation correction factor for channel width.

   Interpolate as in Note 3.

SUMMARY WORKSHEET TO COMPARE RADIO AIDS

Waterway Name and Location: ____________________

Radar enhancement, racon, or all-weather navigational system evaluated:

____

REGION IDENTIFICATION	SYSTEM A RRF (+/-?)	SYSTEM B RRF (+/-?)	SYSTEM B AS EFFECTIVE?

Comparability of systems? ____________________

Worksheet 8-1

SECTION 9. RISK MANAGEMENT PROCEDURES

Section 9

RISK MANAGEMENT PROCEDURES

9.1 INTRODUCTION

The unique contribution of this manual is a procedure for evaluating the performance of an aids to navigation system. The manual is based on a large collection of simulator data supported by a sampling of data collected at sea. The collection and nature of both sets of data were described in Section 2. The manual contains procedures guiding the designer in first analyzing the conditions on his waterway (Sections 3 and 4), and then in selecting performance data to evaluate the quality of the aid system serving the waterway (Section 5). The quality of the aid system is quantified by the relative risk factor (RRF), a <u>risk assessment</u> measure that estimates the probability that there will be a grounding for the specified conditions.

The RRF provides a quantitative measure of performance as a tool in both the design of aid systems and in the <u>management of associated risk</u>. While it is valuable, the RRF by its nature has limitations. It is a relative measure, assumed to be proportional to the actual probability of grounding under a set of conditions, rather than an absolute measure of the probability of grounding. (The derivation and characteristics of the measure are described more fully in Section 2.) As a relative measure, it is appropriately used in design and management techniques that require the comparison of alternative aid systems rather than techniques that require an absolute measure.

Selecting appropriate comparisons is a management matter, determined by the objectives of the district system designer. Objectives may vary from the design of an effective aid arrangement for a limited region of a single waterway to the assignment of priorities for resources among the waterways of a district. It is primarily the responsibility of the designer, and not the role of the manual, to specify those objectives. This section does recommend a number of possible management objectives, and outlines techniques for using the RRF to meet those objectives.

<u>Waterways Analysis and Management System (WAMS)</u> (COMDTINST M16500.11) calls for, among other things, periodic waterway evaluations. These evaluations must include an assessment of the existing aid system, specifically aimed at determining whether it meets the needs of the user. The comparative techniques described in this section are particularly appropriate for this application. They should not only assess the ability of the aid system to assist the mariner, but suggest corrective measures if needed. This section, combined with the rest of the manual and the more general guidelines in Chapter 4, <u>Aids to Navigation Manual - Administration</u> (COMDTINST M16500.7) will strongly support that portion of the WAMS waterway evaluation dealing with the design and evaluation of the short range aid system.

There are two basic techniques that proceed by comparing alternative aids systems. They are recommended as the most appropriate and most effective uses of the RRF.

1. Designing for comparable risk at least cost. This is the primary technique recommended. It is based on the assumption that an aid system design which achieves RRF values similar to those of an existing and accepted system has the same expectations for safety as the existing system. The system chosen to provide a standard level of risk may be that in the same waterway under specific conditions or that in a different, judiciously selected, waterway. The design process should consider not only the level of risk achieved by an aid system, but its cost. The manual has not been written to dictate design but to present a number of alternatives. The least costly possibility that will achieve the selected level of risk should be implemented.

2. Designing for minimum risk. This is a secondary technique, based on the assumption that a system that achieves a minimum RRF for a waterway provides the maximum safety relative to alternative aid system designs for that waterway. This technique will probably prove more costly to implement and should be used only when the circumstances justify additional cost.

This section contains guidelines for using these two basic techniques to meet a variety of management objectives. To some extent these techniques have been discussed in earlier sections of the manual.

9.2 DESIGNING FOR COMPARABLE RISK AT LEAST COST

Designing for comparable risk at least cost is recommended as the primary technique because it includes the possibility of controlling cost. It is a versatile technique, limited only by the ingenuity of the designer in finding an appropriate standard level of risk for comparison. The use of this technique is discussed here to meet a variety of management objectives. The objectives are clustered here by the degree of complexity involved in selecting a comparison. This selection, although extremely important, is an inexact process. Waterways and conditions are never identical. It will be up to the system designer to decide if the degree of similarity constitutes a valid comparison. Considerable guidance is contained in this section, but the final selection of appropriate conditions is, and must remain,an operational decision.

9.2.1 Managing Risk Within a Single Waterway

The most straightforward RRF comparisons involve values calculated for the regions of a waterway under existing conditions and with existing markings. These comparisons can be used for the following management objectives.

- To seek uniform risk within a waterway
- To prioritize work within a waterway
- To justify reductions in service within a waterway

The steps required to design for these objectives follow.

1. Analyze the conditions in the waterway as they presently exist, using Section 3.2 as a guide to the relevant issues. Divide the waterway into turn, recovery, and trackkeeping regions as directed in Section 3.3.

2. As an optional second step, use the guidelines of Section 4 to identify obvious marking inconsistencies. Section 4 can act as a preliminary, nonquantitative evaluation of the quality of the system.

3. Apply the data and instructions of Section 5 to find an RRF value for each region of the waterway and for each of the subsystems of daytime, nighttime, and long visibility with ranges if present. Summarize the calculated values on Worksheet 5-7 provided at the end of Section 5. For convenience it is repeated here.

4. Plot RRFs on the "totem pole" provided as Figure 9-1. The basis of the totem pole is the ordinate of the RRF plots used in Section 5, showing RRF values over a range of 0.0001 to 1.* In Figure 9-1, the totem pole is repeated four times for the four subsystems of day and night with adequate visibility, long visibility with ranges, and extremely reduced visibility (the last is optional here). The RRF values summarized in Worksheet 5-7 can be indicated on the totem pole for a graphic presentation of the relationships among the regions of the waterway. For illustration Figure 9-2 has been filled out for Waterway X for the day and nighttime subsystems.

5. Inspect the RRF values for conspicuous regions or subsystems.

The establishment of uniform risk throughout a waterway is recommended as a first, basic objective of management in a waterway. Some regions may stand out as being of conspicuously higher risk than others. There are limitations to how uniform the risk can be among the regions of a waterway: turns regions will always have the highest risk, followed by recovery regions, with trackkeeping regions being the lowest. Allowances have to be made for the intrinsic differences in the risk of the various maneuvers. The highest risk will probably be turns, probably higher angle, noncutoff turns. Note that this is the case in Waterway X illustrated in Figure 9-2. Higher risk regions should receive attention and be considered for a high priority in the assignment of available resources for the improvement of service. There may be conspicuous differences among the subsystems. If there is a dependence on unlighted aids, there will be differences between the day and nighttime subsystems, again most likely in the regions of difficult turns. Note that this is the case in Waterway X illustrated in Figure 9-2. In such a case, the nighttime subsystem should be carefully considered for its adequacy in supporting nighttime transits. Does it provide adequate service? Is there a need for the nighttime risk to be brought down to the level of daytime risk by substituting lighted aids? If there are ranges present, there may be a considerable difference between visibilities that allow their use and visibilities that do not. Does the

---

*Note that the ordinate taken from the multicycle logarithmic scale used for the plots preserves the order of the RRF values but not the intervals between them. The resolution is high for the lower RRF values but decreases for the higher values. The values from 0.1 to 1 are compressed into the top quarter of the scale.

SUMMARY WORKSHEET FOR EVALUATION

Instructions in Section 5.5.

Copy for each waterway and/or design objective.

Waterway Name and Location:____

Design/Evaluation Objective:____

SUBSYSTEMS

Region Identification	Day RRF (+/-?)	Night/dusk/dawn RRF (+/-?)	With Ranges RRF (+/-?)

Worksheet 5-7

WATERWAY NAME AND LOCATION : ______________________________

DESIGN/EVALUATION OBJECTIVE : ______________________________

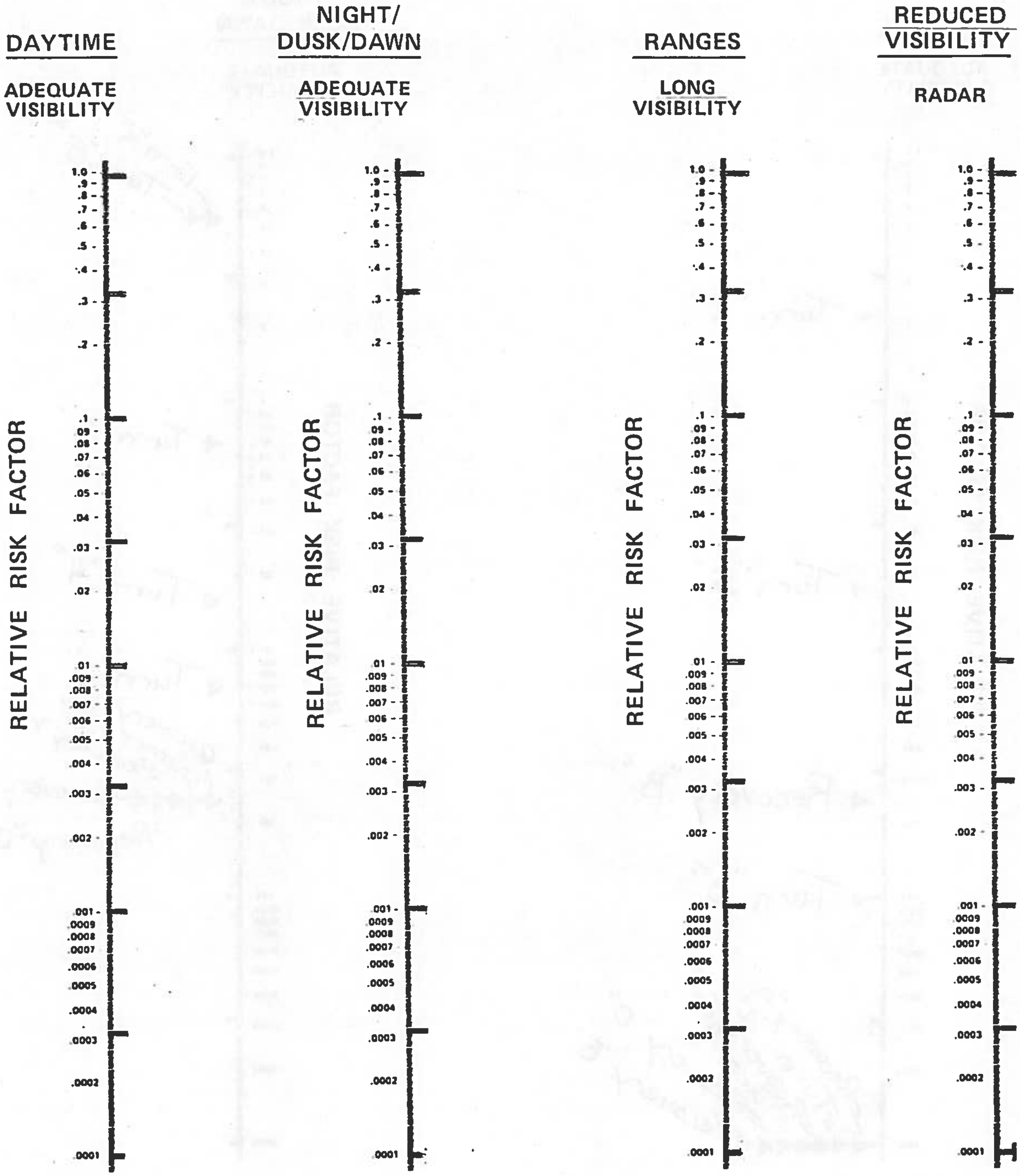


Figure 9-1. "Totem Pole" for Graphic Summary of Relative Risk Factor (RRF) Values for Single Waterway

WATERWAY NAME AND LOCATION : Waterway X

DESIGN/EVALUATION OBJECTIVE : Evaluate as is.

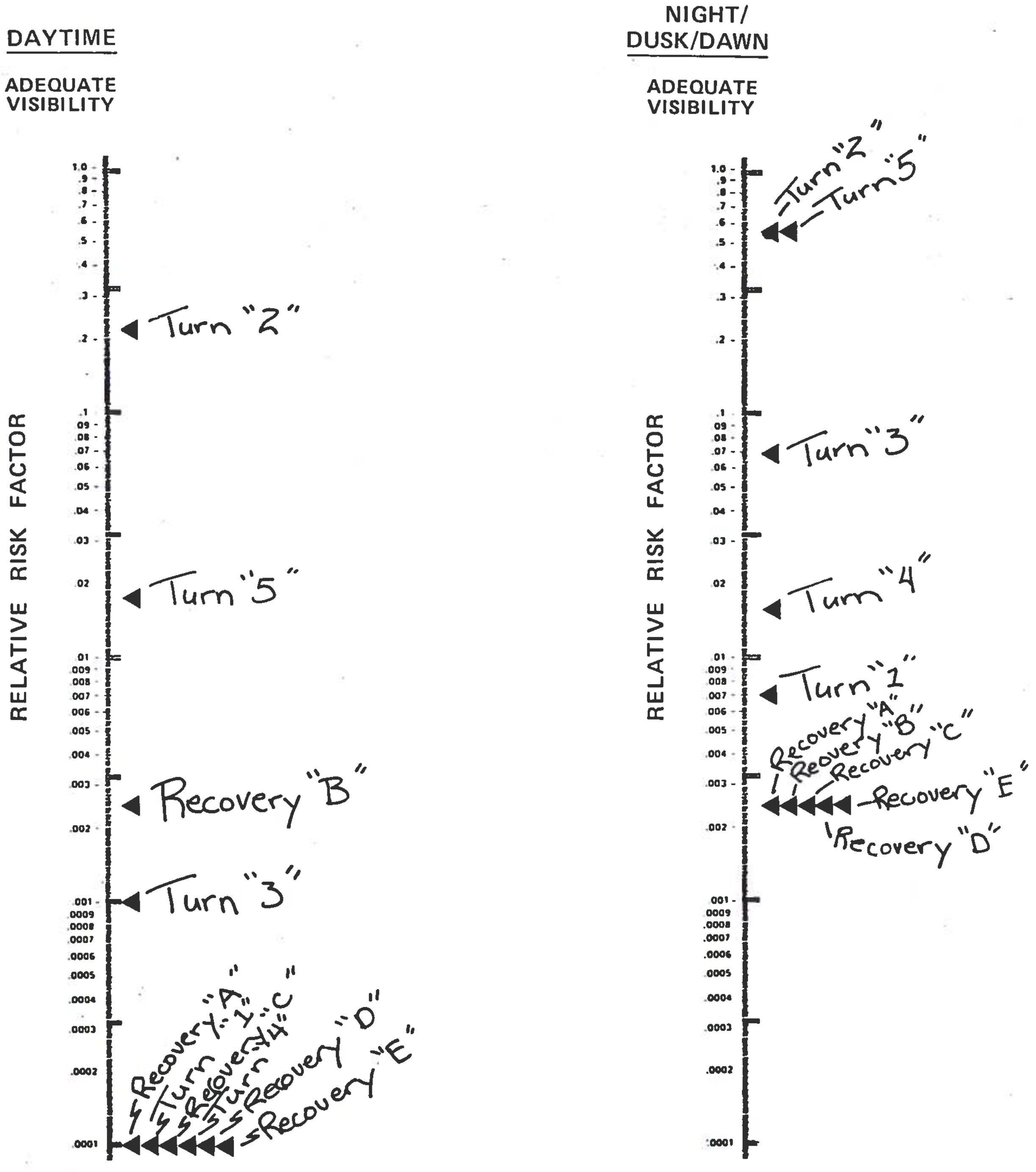


Figure 9-2. Graphic Summary of Relative Risk Factor (RRF) Values for Waterway X

expected visibility justify dependence on the ranges? Is there a need to improve the buoy arrangements for those transits when the visibility does not allow the use of the ranges?

A companion objective to the establishment of uniform risk is the assignment of priorities for work within a waterway. The regions deserving high priority can be identified using the totem pole presented as Figure 9-1. They are the ones with higher risk, especially high risk that appears isolated at the top of the totem pole. Note that for Waterway X illustrated in Figure 9-2, the pattern suggests that turn "2" and turn "5" should have high priorities and that turn "5" is especially inappropriately marked at night.

If some regions of a waterway have conspicuously high risk, some may have conspicuously low risk, suggesting them as candidates for low priority and even for a reduction in service. When resources are scarce, the possibility of a justifiable reduction in service is a temptation. The designer is advised to first be certain that the region is indeed overmarked by reviewing Sections 3 and 4, looking for risk factors (as example, currents, shoals, close turns) that may have been overlooked. As a Step 6 to be added to the list above, the search for risk factors should be continued by considering the transient high-risk conditions of meeting traffic discussed in Section 6 and reduced visibility discussed in Section 7, and by looking into the historical reasons for the region's having been marked as it was.

When reduction in service is being considered, it is especially important to anticipate the reaction of the mariners using the waterway and to involve them early in the decision process. If the reduction in service is part of a policy of seeking uniform risk within a waterway, it may involve shifting a buoy from a region of very low risk only to establish it in a nearby region of very high risk. Whenever possible, such a change should be presented as an increase in total service in a waterway, rather than as a reduction in service in one region. Such a shift will probably be the least controversial instance of reduction in service.

9.2.2 Managing Change Within a Single Waterway

The discussion in Section 9.2.1 assumed that conditions within the waterway were static. Sometimes the designer will be consulting the manual with the objective of managing change within a single waterway. The mariners may request a change in the aid system or a change in operations (like an increase in ship size) may precipitate a redesign. These management objectives can be stated as follows:

- To evaluate design proposals or requests
- To respond to changing needs
- To justify reductions within a waterway

To meet these objectives Step 3 in Section 9.2.1 should be repeated for the second set of conditions. If the change in a waterway involves one factor or a minimum number of factors; Steps 4 and 5, the comparisons required, may still be straightforward.

The discussion in Section 9.2.1 suggested comparisons among the regions and subsystems of a single waterway. Such comparisons are simple in that all the needed calculations have already been done and organized for use. They are also reasonably certain in that there are few unwanted differences between conditions to bias the comparisons. Managing change may also involve simple and certain comparisons when the historical condition of the waterway provides a standard level(s) of risk against which to compare the changed conditions. For example, if an improvement in the nighttime subsystem is being considered, the historical nighttime system provides an upper level of risk and the historical daytime subsystem provides a lower level to the risk that could reasonably be expected. For another example, if an increase in ship size is of concern, the historical risk achieved with the smaller ship can be expected to provide a standard. If risk with the new larger ship is higher, trial and error experimentation with more conservative aid arrangements, according to the design guidelines of Section 4, may bring it down to the standard. If risk with the larger ship can only be brought down so that its daytime level is comparable to nighttime risk with the smaller ship, consideration should be given to restricting the larger ship at night. Section 9.3 contains a further discussion of operational restrictions.

Changes in operations within a particular waterway may also justify a reduction in service. For example, larger ships may discontinue visits to a particular port. Trial and error experimentation with less conservative aid arrangements may show that smaller ships can achieve the same level of risk with fewer aids. Again, the designer is cautioned to consider all the factors that may contribute to risk or to the mariners' perception of risk, even in the apparently-lower-risk situation.

9.2.3 Selecting a Standard Level of Risk in Another Waterway

Risk levels calculated within the subject waterway will not always provide the needed standards. Consider again the example from Section 9.2.2 of the increase in ship size resulting in an increase above the historical level of risk. An increase in the conservatism of the aid system may fail to bring the risk down to the desired level or the cost of bringing it down may be excessive. Another possible approach is to compare the new, higher level or risk, not to the historical risk in the same waterway; but to the historical risk in another waterway where the larger ship does have a history of safe transits. Compare the risk the larger ship would achieve in the subject waterway to the risk it achieves in the selected waterway. A second waterway could be used to provide a standard in other contexts. For another example, the safety of a waterway when its range is obscured might be established by comparing it to a waterway with similar conditions and buoys that never had a range. Using a second waterway to establish a standard is less simple in that it involves additional work in the selection and analysis of the other waterway. It is also less certain in that the possibility for bias in the comparison is increased.

When a second waterway is to be selected, it is methodologically preferable to let the characteristics of the subject waterway direct the selection and determine the characteristics needed in the standard waterway. Practically or politically, a certain waterway, or waterways, may dominate a district, either by volume of shipping or by reputation as a safe port. Therefore, it may appear to be the most appropriate standard, whatever its characteristics. In either case, the following steps for the selection and analysis of a standard port and for the comparison are meant to minimize bias. The two waterways should be as similar as possible, on as many factors as possible, differing only in the factor that is under consideration.* For the examples given, the considered factors would be the maximum ship size that has historically used the waterway and the presence/absence of a range. (A similar procedure appeared in Section 6.4.2.)

1. Briefly describe conditions in each category for the subject waterway, the one being evaluated, on the worksheet presented as Figure 9-3. Use Section 3.2 as a guide.

2. Briefly describe conditions for a proposed standard waterway, one with a better-known or better-accepted history on the worksheet.

3. Compare the two waterways on each factor. Indicate whether risk in the proposed standard waterway is likely to be higher than, lower than, or equivalent to the subject waterway as a result of each factor. Inspect the whole list of factors and decide whether the overall risk for the proposed standard is likely to be higher, lower, or equivalent. Decide whether the match is close enough to be useful.

4. In the subject waterway select several turn and adjacent recovery regions that are of relatively high risk for the waterway. In the standard waterway select turn and recovery regions that match as well as possible in physical characteristics of the waterway and as many of the factors that are not under consideration as possible. Calculate the RRF for all selected regions, using worksheets from Section 5 as guides. Summarize the values on Worksheet 9-1. Side-by-side totem poles are provided in Figure 9-1.

5. Inspect the array of values summarized on Worksheet 9-1 or on Figure 9-1. If the values in the subject waterway are equivalent to or lower than those in the standard waterway, it is reasonable to conclude that the subject waterway is as safe. Repeat for each subsystem.

If the comparison shows the subject waterway is not safe and the aid arrangements are already conservative, other means must be considered to improve safety. Some possibilities are discussed in Section 9.3.

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*The logic is that of an "experiment". One variable is selected as the independent variable with two levels: for example, small ship/large ship, range/no range, two-buoy turn/three-buoy turn. The dependent variable or performance measure is the RRF. The greatest certainty about the effect of the independent variable on the dependent variable comes when all other potential variables that might affect the measured value of the dependent variable are constant across the two levels of the selected independent variable. For example, transits with a small and large ship are best compared when the physical characteristics of the channel and the aids available are the same.

WORKSHEET FOR THE SELECTION OF A STANDARD WATERWAY

Instructions in Section 9.2.3

Subject waterway name and location: ____________________

Standard waterway name and location: ____________________

	DESCRIPTION		
FACTOR	SUBJECT WATERWAY	STANDARD WATERWAY	Risk of Standard is too low, too high, appropriate
Channel and Turn Characteristics	________	________	______
	________	________	______
	________	________	______
Environmental Conditions and Frequencies	________	________	______
	________	________	______
	________	________	______
Operational Practices	________	________	______
	________	________	______
	________	________	______
Size of Design Vessel	________	________	______
Frequency of Design Vessel Meeting	________	________	______
View of Land	________	________	______
	________	________	______
Consequences of Accident	________	________	______
	________	________	______
Aids in Regions Considered	________	________	______
	________	________	______
	________	________	______

Risk of standard is appropriate? ____________________

Worksheet 9-1

9.2.4 Managing Risk Within a District

Because waterways within a district compete for resources, the district system designer must ultimately compare risk between waterways within the district. Possible management objectives can be stated as follows.

- To prioritize work within a district
- To seek uniform risk within a district
- To justify reductions within a district

These objectives require comparisons between waterways without regard to how comparable or how similar they are. There will be differences among waterways in a district in the general level of risk that can be expected. For example, visibility may be reduced more frequently in one waterway than another, currents may be more difficult, ship size may be larger relative to channel dimensions, or transits, and therefore meetings, may be more frequent. For comparison between intrinsically different waterways, a performance measure that incorporates a broader range of factors is desirable.

Information should be available to compute a composite RRF (CRRF), considering the RRF for higher- or lower-risk conditions in a waterway and the proportion of transits for which those conditions occur. The calculation can be done as follows:

$$\mathrm{CRRF} = \sum_{i=1}^{n} Q_i \ \mathrm{RRF}_i \qquad (9\text{-}1)$$

where:

CRRF = composite relative risk factor for a region
n = number of conditions considered
Q_i = proportion of transits on which $\mathrm{condition}_i$ is expected to occur
RRF_i = RRF for $\mathrm{condition}_i$

Candidate conditions to include in the CRRF appear in Table 9-1.

To select and include conditions in the CRRF, follow these steps.

1. For each waterway to be compared, find the completed copy of Worksheet 3-1. It should include the proportion of transits occurring under various transient conditions. If the worksheets were not completed earlier, complete them now.

2. Compare the worksheets (3-1) for the several waterways. Identify conditions on which the expected proportion of transits differ meaningfully between waterways. These should be included when calculating the CRRF. The transits may be apportioned to any combination of conditions as long as:

$$\sum_{i=1}^{n} Q_i = 1 \qquad (9\text{-}2)$$

TABLE 9-1. CANDIDATE CONDITIONS FOR INCLUSION IN THE COMPOSITE RELATIVE RISK FACTOR (CRRF)

CONDITIONS	PROPORTION OF TRANSITS
Daytime	Q_i
Night/Dusk/Dawn	$1 - Q_i$
Crab Angle $<$ 2 degrees	Q_i
Crab Angle $>$ 2 degrees	$1 - Q_i$
Long Visibility, Ranges	0.XX
Adequate Visibility	0.YY
Reduced Visibility	0.ZZ
	1.00
Design vessel	Q_i
Smaller vessels	$1 - Q_i$
Design vessel transits meeting traffic	Q_i
Design vessel transits not meeting	$1 - Q_i$
COMBINED CONDITIONS (EXAMPLES)	
Daytime	0.45
Night/Dusk/Dawn	0.35
Reduced Visibility	0.10
	1.00
Daytime, Crab angle $<$2 degrees	0.67
Night/dusk/dawn, crab angle $\geqslant$2 degrees	0.33
	1.00

Table 9-1 includes examples. (Conditions and proportions of transits may be more or less meaningful for some regions of the waterway. As examples, ship size and nighttime transits are most meaningful in turns; visibility is most meaningful in recovery regions with ranges; meeting traffic is most meaningful in the pilots' preferred meeting zones.)

3. For each waterway select a number of representative regions. For example, the one, two, or three most difficult turns and an adjacent recovery region for each. Find, if available, or calculate the RRF for each of these regions for each of the conditions of interest, using the worksheets in Section 5 as guides. (For meeting traffic use RRFMT calculated according to Section 6.4.)

4. Calculate CRRF for each region and each waterway using the Worksheet 9-3.

5. Compare CRRF for two waterways using Worksheet 9-2 or Figure 9-3 (totem pole).

The new comparisons can be used to support the objectives listed at the beginning of 9.2.4. The totem pole can be used to assign priority or to seek uniform risk. Priority should be given to the waterway with the highest-risk regions, or with a cluster of high-risk regions. If service must be reduced, select the waterways without high-risk regions.

9.3 DESIGNING FOR MINIMUM RISK

The designer may want to design an aids to navigation system to achieve minimum risk. Possible management objectives to be met in this way follow.

- To ensure safety for sensitive cargoes
- To establish lower limit of risk for waterway

Waterways which must support the transportation of high-risk cargoes (for example, liquefied natural gas), especially in areas of high population density or sensitive environments, are candidates for this type of design. Such a design will always be the most costly to implement, even when care is taken that the aids are not excessive for the level of risk achieved. The situation should warrant the cost.

The designer can use the minimum-risk design technique to establish the lower limit of risk possible for a waterway. The intention may not be to implement the design, but to compare what-is to what-might-be. For a given case, the comparison might support the argument -- addressed to the mariner -- that the existing system is at or very close to the minimum risk. Or it might support the argument -- addressed to Headquarters -- that it is far from the minimum risk and needs the assignment of additional resources.

The following steps will design for minimum risk.

1. Analyze the conditions in the waterway as they presently exist, using Section 3.2 as a guide to the relevant issues. Divide the waterway into turn, recovery, and trackkeeping regions as directed in Section 3.3

WORKSHEET TO COMPARE RRF IN TWO WATERWAYS

Instructions in Section 9.2.3.

Copy and repeat for each subsystem.

Subject waterway name and location: ____________________

Standard waterway name and location: ____________________

REGION IDENTIFICATION	SUBJECT WATERWAY	STANDARD WATERWAY	Subject is safe as standard?

Subject waterway is safe? ____________________

Worksheet 9-2

WORKSHEET FOR THE CALCULATION OF THE COMPOSITE RELATIVE RISK FACTOR FOR TWO WATERWAYS

Instructions in Section 9.2.4.

Identification of waterways A.______________________________

B.______________________________

Conditions and proportions A.______________________________

B.______________________________

SELECTED REGIONS WATERWAYS

A	B
$\sum_{i=1}^{n}(Q_i)\times(RRF_i)=(CRRF)$	$\sum_{i=1}^{n}(Q_i)\times(RRF_i)=(CRRF)$

( ) x ( ) ( ) x ( )
\+ ( ) x ( ) + ( ) x ( )
\+ ( ) x ( ) = ( ) + ( ) x ( ) = ( )

( ) x ( ) ( ) x ( )
\+ ( ) x ( ) + ( ) x ( )
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( ) x ( ) ( ) x ( )
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Worksheet 9-3

IDENTIFICATION OF WATERWAYS : A. ________________________

B. ________________________

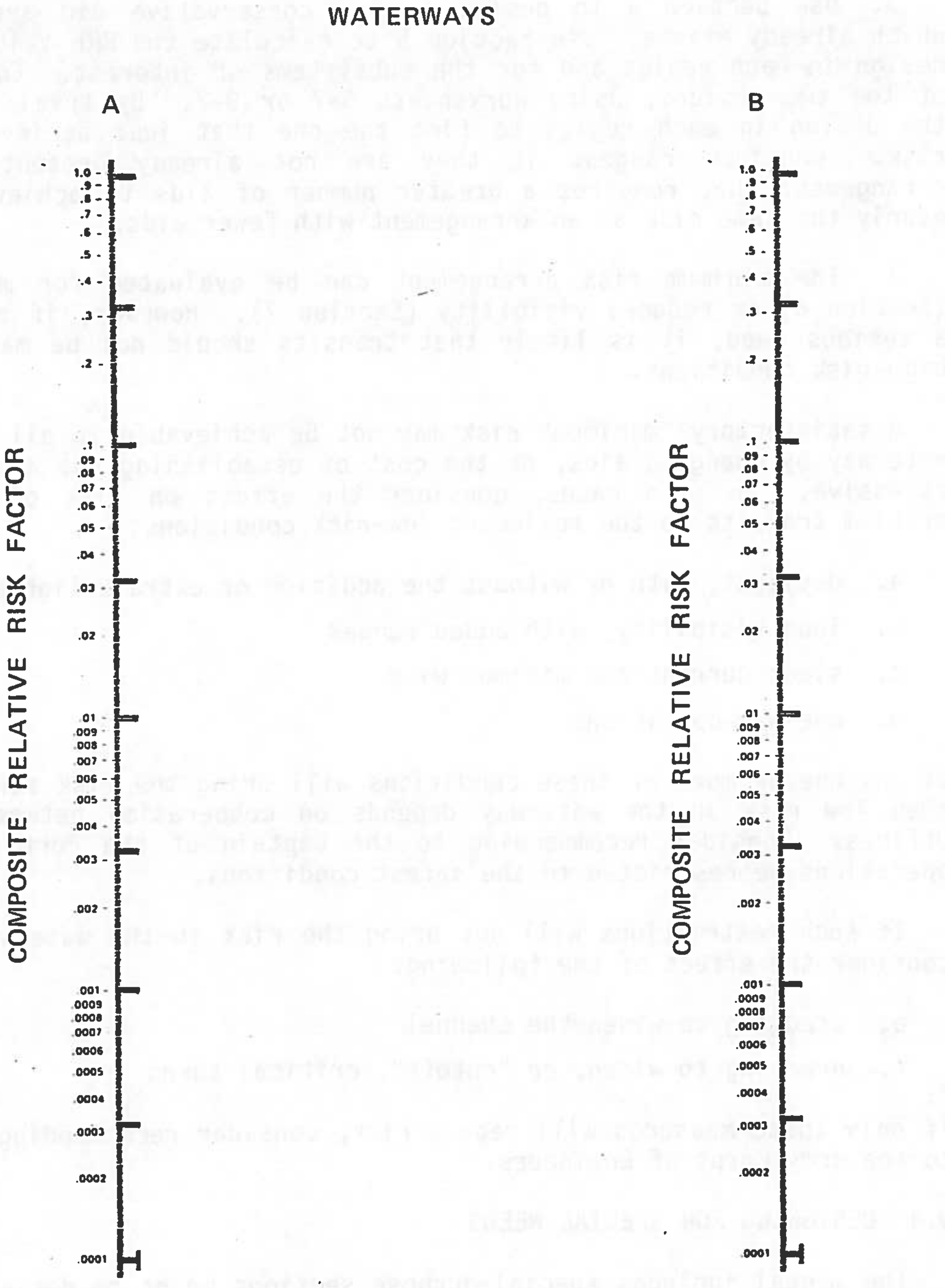

Figure 9-3. "Totem Pole" for Graphic Summary of Composite Relative Risk Factor (RRF) Values to Compare Waterways

2. Apply the data and instructions of Section 5 to find an RRF value for each region of the waterway and for each of the subsystems of daytime, nighttime (optional) and long visibility with ranges, if they are present. Summarize the calculated values on Worksheet 5-7. It is repeated in Section 9.2.1.

3. Use Section 4 to design a more conservative aid system than that which already exists. Use Section 5 to calculate the RRF values for the new design in each region and for the subsystems of interest. Compare the risk of the two designs, using Worksheets 5-7 or 9-2. By trial and error vary the design in each region to find the one that just achieves the minimum risk. Consider ranges, if they are not already present. Reject any arrangement that requires a greater number of aids to achieve the same or nearly the same risk as an arrangement with fewer aids.

4. The minimum risk arrangement can be evaluated for meeting traffic (Section 6) or reduced visibility (Section 7). However, if minimum risk is a serious need, it is likely that transits should not be made under these high-risk conditions.

A satisfactory "minimum" risk may not be achievable in all regions of the waterway by changing aids, or the cost of establishing the aid system may be excessive. In such cases, consider the effect on risk of confining the problem transits to the following low-risk conditions:

a. daylight, with or without the addition of extra unlighted aids

b. long visibility, with added ranges

c. slack current and minimum wind

d. one-way operations

If any one or more of these conditions will bring the risk sufficiently low, then low risk in the waterway depends on cooperation between Coast Guard Offices. Consider recommending to the Captain of the Port that high-risk operations be restricted to the safest conditions.

If such restrictions will not bring the risk in the waterway low enough, consider the effect of the following:

e. dredging to widen the channel

f. dredging to widen, or "cutoff", critical turns

If only these measures will reduce risk, consider recommending this dredging to the Army Corps of Engineers.

9.4 DESIGNING FOR SPECIAL NEEDS

The manual includes special-purpose sections meant to design and evaluate aid systems to meet transient high-risk conditions that may be especially frequent or difficult in some waterways. These management objectives can be stated as follows:

- To ensure service for meeting traffic
- To ensure service for reduced visibility

The special needs of the meeting traffic situation are considered in Section 6. If meeting traffic is perceived as especially frequent or especially difficult in a given waterway, that section should be consulted. One should not attempt to design for minimum risk in the meeting traffic situation. Nor is it likely that aid system design can achieve a risk for the transient meeting traffic situation that is comparable to that same waterway and region for a one-way transit. In designing for comparable risk, the most appropriate objective is to seek uniform risk of meeting traffic within the waterway by comparing regions. As an alternative, the risk level in another waterway can be used as a standard. The waterway chosen as a standard should be as comparable in conditions as possible, but have a better-understood or better-accepted safety record.

It is, or course, inappropriate to try to design for minimum risk in the reduced visibility situation. Nor should one expect to achieve a risk in reduced visibility comparable to that for the same waterway and region in adequate visibility. The most appropriate objective is to seek uniform risk in reduced visibility within the waterway by comparing regions. Again, risk in another waterway with a better-understood or better-accepted safety record can be used as a standard.

If severely-reduced visibility is a frequent problem in a waterway, the designer may want to consider radio aids as an all-weather navigation system. Data for radio aid systems with a variety of display formats are presented in Section 8. "Comparable risk" for these data is presented in Section 7. Section 7 contains data on the zero visibility performance of aids arranged for visual piloting, equipped with passive reflectors, and used with conventional radar. These data were collected especially to provide a standard of comparable risk for radio aids.

9.5 THE LAST WORD ON RISK MANAGEMENT

William D. Ruckelshaus, former Administrator of the U.S. Environmental Protection Agency, has the last word on risk management: "Although there is an objective way to assess risk, there is, of course, no purely objective way to manage it, nor can we ignore the subjective perception of risk in the ultimate management of a particular [risk]. To do so would be to place too much credence in our objective data and ignore the possibility that occasionally one's intuition is right. No amount of data is a substitute for judgment."[5]

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[5] William D. Ruckelshaus. "Science, Risk, and Public Policy." Science, Vol. 221, 1026-1028.

GLOSSARY OF TERMS

adequate visibility
For the manual, 1.50 nautical miles or long enough to see the longest-spaced aids. (Section 2.2.5)

adjusted beam (B')
In calculating the relative risk factor ship's beam is adjusted for crab angle with a pivot at midship and divided by two. (Section 2.6.3)

aids off channel edge
Aids that act as landmarks for position information but do not mark safe water. (Section 4.2)

aids on channel edge
Aids that outline safe water of a channel, sidemarks. (Section 4.2)

alongtrack position
The position along the length of the channel. (Section 2.4.3)

$$B' = \left(\frac{\text{ship's length}}{2}\right) \left(\frac{\text{cross channel component of current}}{\text{ship's minimum transit speed}}\right) \left(\frac{\text{ship's beam}}{2}\right)$$

(Section 2.6)

back range
Range aft of the ship during a transit. (Section 4.2.3)

baseline values
Performance data for a 30,000 dwt ship in a 500-foot channel. These data are the basis on which performance data for other ship sizes and channel widths can be derived. (Section 5)

bend
A gradual turn in the channel that does not have a defined turn apex. (Sections 3, 4.3)

buoy
A floating marker. For the purposes of the manual generally moored at the channel edge to mark the navigable limits of a channel. (Section 4.2.2)

buoy density
The number of buoys per nautical mile. (Section 4.4)

CA
Crab angle. The angle between the ship's heading and the channel course. (Section 4.4)

CAROF
Computer Aided Operations Research Facility. The Maritime Administration's simulator at Kings Point, New York. (Section 2)

centerline range
Range with axis on the channel centerline.

CF
correction factors. Multipliers that allow the extension of the data to ship sizes and channel widths other than those tested. (Sections 2, 5)

CG
Center of gravity of the ship

composite relative risk factor (CRRF)
Relative risk factor weighted for frequency of conditions.

$$\sum_{i=1}^{n}(Q_i)x(RRF_i)=(CRRF)$$

where:

CRRF = composite relative risk factor for a region
n = number of conditions considered
Q_i = proportion of transits on which condition_i is expected to occur
RRF_i = RRF for condition_i

conservative
Any bias is in a safe or cautious direction. A conservative estimate of risk may overestimate it; a conservative system design may contain more aids than strictly necessary. Either results in a reserve of safety for infrequent conditions, not unnecessary risk.

CPA
Closest point of approach. (Section 6.2.4)

crab angle (CA)
The angle between the ship's heading and the channel course.

$$CA = \tan^{-1}\left(\frac{\text{maximum crosscurrent component in knots}}{\text{expected transit speed in knots}}\right)$$

CRRF
composite relative risk factor. (Section 9)

crosscurrent
Current velocity perpendicular to the channel axis. (Section 4.4)

crosswind
Wind velocity perpendicular to the channel axis. (Section 4.4)

cutoff turn
A turn widened by dredging at the inside of the angle to allow more room for the turn. (Sections 3, 4.3)

detection distance
The distance at which an aid will be detected given the meteorological visibility, the visible area of the aid, and its contrast against the background.

digital display
A display that provides trackkeeping and turning information to enable a pilot to transit the waterway while using only alphanumeric or numeric symbols. (Section 8)

DK
Distance of trackkeeping region. The remainder of the straightaway after the turn and recovery distances have been established. (Section 3.3)

DR
Distance of recovery region. This distance depends on the size of the ship. (Section 3.3)

DT
Distance from the turn region. This distance if 0.5 nm in each direction of the turn apex. (Section 3.3)

dwt
Dead weight tonnage. The capacity, in long tons, in fuel, stores, etc., of a vessel. The difference between loaded and light displacement tonnage.

effectiveness
Performance or quality of an aid system. (Section 4.2)

evaluation
Providing a measuring of quality or performance for an aid system. (Section 5)

fixed aid
A beacon or structure. May be placed where the bottom is good rather than where it is most effective. (Section 4.2)

floating aid
A buoy. May be positioned at the channel edge to mark the navigable limits of the channel. Because it is floating, it is less effective than fixed aid. (Section 4.2)

forward range
A range ahead of the ship during a transit. (Section 4.2.3)

gated buoys
Buoys arranged in pairs on a line perpendicular to the channel axis. (Section 4.4)

graphic display
A display that provides a pictorial representation of ownship in the waterway. (Section 8)

guidelines
A qualitative description of the relationship between conditions in a waterway and performance to be expected from an aid system. (Section 4)

high sensitivity range
Range with K greater than 3. See range sensitivity.

implementation
The 1982 draft manual was used in a real waterway to test the design and evaluation process. The present manual was then refined as necessary. (Section 2.7)

K
Measure of range sensitivity. See range sensitivity. (See Section 4.2.3)

landmarks
Provide relative motion cues but do not necessarily outline safe water. (Section 4.2)

light rhythm
Temporal pattern of flashing lights. Affects both conspicuity and information rate of aid. (Section 4.3.4)

lighted aid
Performs the same function during the day or during the night. (Section 4.2)

LNG
Liquefied natural gas (carrier)

local knowledge
A mariner's expertise, experience and intimate familiarity with waterway characteristics. (Section 4.2)

long spacing
Aids spaced 1.25 nm apart. (Section 4.4)

low sensitivity range
Range with K less than 3. See range sensitivity.

MCC
Mean correction factor for use when calculating the risk of collision. (Section 6.2)

MCSHP
Mean correction factor for ship size. (Sections 2, 5)

MCWID
Mean correction factor for channel width. (Sections 2,5)

MN
Mean or average, of the crosstrack position of a set of transits. (Sections 2.5, 5)

MN'
Corrected mean

$$MN' = (MN)(MCSHP)(MCWID)$$

where:

MN: Baseline mean crosstrack position (fleet)
MCSHP: Mean correction factor for ship size
MCWID: Mean correction factor for channel width
(Sections 2.6, 5)

MNC
Mean of a set of distances between the two ships measured "skin-to-skin", used for calculating risk of collision. (Section 6.2)

MNS
Mean of a set of ownship transits, used for calculating risk of grounding to starboard. (Section 6.2)

natural range
Two objects on shore that can be lined up by a mariner and used as a range.

NC
The number of standard deviations that will fit between the two ships at their average distance.

$$NC = MNC/SDC$$

where:

MNC: The mean of the distances between the two ships measures "skin to skin", to be used in calculating PC
SDC: The standard deviation of the distance between the two ships, to be used in calculating PC
See PC. (Section 6.2.4.2)

nm
nautical mile

noncutoff turn
Turn dredged to form an abrupt angle. (Section 4.3)

NP
Number of standard deviations that will fit between the extreme point of the ship and the channel edge to port.

$$NP = [(W/2) + (MN') - (B')]/(SD')$$

where:

W: channel width
MN': corrected mean
B': ship's beam adjusted for crab angle (feet/2)
SD': corrected standard deviation
(Sections 2, 5)

NS

Number of standard deviations that will fit between the extreme point of the ship and the channel edge to starboard.

$$NS = [(W/2) - (MN') - (B')]/(SD')$$

where:

W: channel width
MN': corrected mean
B': ship's beam adjusted for crab angle (feet/2)
SD': corrected standard deviation

one-side buoys

Buoys placed on only one side of the channel to mark the channel's boundary. (Section 4.4)

ownship

In simulation, the pilot-controlled ship as compared to a computer-controlled traffic ship. (Section 6.2.4)

PC

Probability of collision upon meeting a traffic ship. See relative risk factor for meeting traffic. (Section 6.2)

perspective display

A display that portrays the perspective scene as viewed out the forward bridge windows. (Section 8)

PP

Probability of grounding to port. See relative risk factor. (Sections 2,5)

predictor steering display

A display that uses ownship's hydrodynamic equations to compute and display a predicted track. (Section 8)

PS

Probability of grounding to starboard. See relative risk factor. (Sections 2,5)

quarterline range

Range with the axis one quarter of the distance from the channel edge. Appropriate for two-way traffic. (Section 4)

radio aids to navigation systems

Systems which find a ship's position by using radio signals (such as Loran C) for directional guidance. (Section 8)

range

Two structures placed in a line to mark, generally, the centerline of a channel. (Section 4.2.3)

range sensitivity

The ease with which an observer will detect the crosstrack error of his position.

$$K = [WR]/[D(H-h)]$$

where:

K = lateral sensitivity
W = channel width (feet)
R = distance between structures (nautical miles)
D = distance from front structure to the point of interest (nautical miles)
H = height of rear structure (feet)
h = height of front structure (feet)

(Section 4.2.3)

recovery region

Encloses the pilot's efforts to recover from the turn and to find the appropriate track in the new straightaway. (Section 3.3)

reduced visibility

A quarter of a nautical mile or just long enough to see all buoys in a turn or both buoys of a gated pair. (Sections 2.2.5, 7)

relative risk factor (RRF)

Principal performance measure used for risk assessment

$$RRF = PS + PP$$

where:

PS: probability the extreme starboard point will cross the starboard channel edge
PP: probability the extreme port point will cross the port channel edge

(Sections 2.6, 5)

relative risk factor for meeting traffic (RRFMT)

$$RRFMT = PS + PC + PS'$$

where:

PS: the probability that the extreme starboard point of ownship will exceed the starboard edge of the channel
PC: the probability that the two ships will collide
PS': the probability that the extreme point of the traffic ship will exceed the edge of the channel on its starboard

(Section 6.2.4)

risk

Defined for the manual as proportional to the relative risk factor for a condition. (Section 2.6)

risk assessment
Applying a measure of quality to an aid to navigation system, here, the relative risk factor. (Section 9)

risk management
Decisionmaking that depends on a broad range of factors, including a risk assessment measure. (Section 9)

RMS
Root mean square. (Section 8)

RRF
Relative Risk Factor. (Section 2)

RRFMT
Relative Risk Factor for Meeting Traffic. (Section 6.2.4)

SCC
Standard deviation correction factor for use when calculating the risk of collision. (Section 6.2)

SCSHP
Standard deviation correction factor for ship size. (Section 5)

SCWID
Standard deviation correction factor for channel width. (Section 5)

SD
Standard Deviation. A measure of dispersion or variability of the set of tracks. (Sections 2.5, 5)

SD'
Corrected standard deviation

$$SD' = (SD)(SCSHP)(SCWID)$$

where:

SD: Baseline crosstrack standard deviation (feet)
SCSHP: Standard deviation correction factor for ship size
SCWID: Standard deviation correction factor for channel width

(Section 2.6)

SDC
Standard deviation for a set of transits of the distance between two ships "skin to skin", used for calculating the risk of collision. (Section 6.2)

SDS
Standard deviation of the set of ownship transits used for calculating the risk of grounding to starboard. (Section 6.2)

short spacing
Aids spaced 0.625 nm apart. (Section 4.4)

sidemark
An aid at the edge of the channel. (Section 4.2)

SRA
Short Range Aid

staggered buoys
Buoys arranged so one aid at a time appears on alternate sides of the channel. (Section 4.4)

subsystem
Aids available to the mariner under different environmental conditions: day, night, visibility long enough for ranges, and reduced visibility. (Section 5.1)

synchronized lights
Lights on several aids that flash simultaneously. (Section 4.3.4)

trackkeeping region
This region encloses the channel segment where the pilot is satisfied with the ship track and need not leave it. (Section 3)

turn apex
The inside of a turn. (Section 4.3)

turn pullout
The point where crosstrack acceleration due to the turns is greatly reduced and close to zero. This point has the highest probability of grounding in the turn region. (Section 4.3)

turn region
This region encloses the severest maneuver and occurs within 0.5 nm in each direction from the turn apex. (Section 3.3)

unlighted aids
Allow close spacing for day or reduced visibility. Their performance is questionable at night. (Section 4.2)

validation
A comparison of pilot performance at sea to that on the simulator for purposes of validating the simulator. (Section 2)

visibility
The distance in nautical miles at which an object may be seen. (Sections 2, 3)

W
Channel width expressed in feet

WAMS
Waterways Analysis and Management System

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