

FAA
COPY 1

Report No. FAA-CT-81-36

CONSIDERATIONS ON COLLISION RISK ANALYSIS FOR DECISION MAKING IN THE NORTH ATLANTIC (NAT) REGION



FEDERAL AVIATION ADMINISTRATION

MAR 20 1981

TECHNICAL CENTER LIBRARY
ATLANTIC CITY, N.J. 08405

MARCH 1981

FINAL REPORT

Document is available to the U.S. public through
the National Technical Information Service,
Springfield, Virginia 22161.

Prepared for
U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
TECHNICAL CENTER
Atlantic City Airport, New Jersey 08405



0008540

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the object of this report.

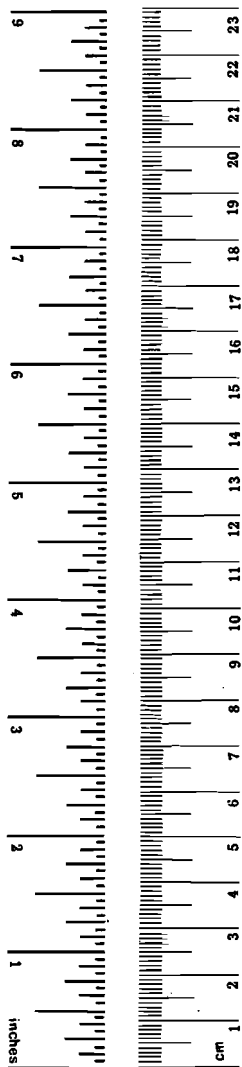
1. Report No. FAA-CT-81-36		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle CONSIDERATIONS ON COLLISION RISK ANALYSIS FOR DECISION MAKING IN THE NAT REGION				5. Report Date March 1981	
				6. Performing Organization Code	
7. Author(s)				8. Performing Organization Report No. FAA-CT-81-36	
9. Performing Organization Name and Address Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08405				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. 012-102-210	
12. Sponsoring Agency Name and Address Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08405				13. Type of Report and Period Covered Final	
				14. Sponsoring Agency Code	
15. Supplementary Notes This is a reprint of the United States Position Paper, Agenda Item 1, prepared for the 18th Meeting of the International Civil Aviation Organization (ICAO) North Atlantic Systems Planning Group (NAT/SPG-18), March 30 to April 10, 1981, Paris, France.					
16. Abstract This working paper presents the views of the United States relative to a proposed change in the North Atlantic System Planning Group's decision making procedure. This view is that the decision making process is composed of a number of interrelated parts--a target level of safety, a collision risk analysis, a minimum navigation performance specification, a monitoring procedure, a certification procedure and a set of decision criteria--and that a change to any part of this process cannot be made in isolation from the remainder of the process. It is shown that the proposed weighting procedure fails to find a basis in the overall decision making process. Rather, the weighting procedure changes only one component of the overall process, resulting in several deficiencies. It is also shown that the resulting procedure is incompatible with the other elements of the total decision making process. As a result, it is concluded that use of the proposed weighting procedure fails to assure adequate control of collision risk vis-a-vis a target level of safety, which is the principal objective of the minimum navigation performance specification.					
17. Key Words Risk Analysis North Atlantic (NAT) Track System Target Level of Safety (TLS) Statistical Decision Making Analysis of Rare Events			18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 36	22. Price

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

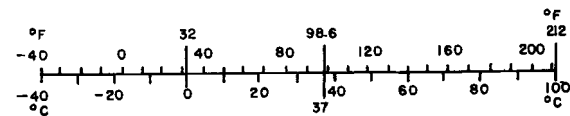
Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi 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

*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 (than add 32)	Fahrenheit temperature	°F



PREFACE

This report was prepared by Messrs. Allen Busch and Brian Colamosca of the Federal Aviation Administration (FAA) Technical Center and Professors J. S. Hunter, Neil Polhemus, and George Hazelrigg of Princeton University. (Princeton University supported this work under FAA contract DOT-FA79NA-6078.) This report is part of an FAA program to analyze various facets of collision risk in the oceanic environment. More specifically, it grew out of the efforts by the International Civil Aviation Organization (ICAO) North Atlantic Systems Planning Group (NAT/SPG) to apply the Minimum Navigation Performance Standards (MNPS) for the reduction of separation minima in the North Atlantic.

TABLE OF CONTENTS

	Page
1. INTRODUCTION	1
2. BACKGROUND	4
3. THE REICH MODEL NAVIGATION PERFORMANCE SPECIFICATION AND SYSTEM MONITORING	9
4. ALTERNATIVE RISK MODELS AND THEIR IMPLICATIONS	14
5. OPEN ISSUES	26
6. CONCLUSIONS	30

Abstract

This working paper presents the views of the United States relative to a proposed change in the North Atlantic System Planning Group's decision making procedure. This view is that the decision making process is composed of a number of interrelated parts--a target level of safety, a collision risk analysis, a minimum navigation performance specification, a monitoring procedure, a certification procedure and a set of decision criteria--and that a change to any part of this process cannot be made in isolation from the remainder of the process. It is shown that the proposed weighting procedure fails to find a basis in the overall decision making process. Rather, the weighting procedure changes only one component of the overall process, resulting in several deficiencies. It is also shown that the resulting procedure is incompatible with the other elements of the total decision making process. As a result, it is concluded that use of the proposed weighting procedure fails to assure adequate control of collision risk vis-a-vis a target level of safety, which is the principal objective of the minimum navigation performance specification.

1. Introduction

The North Atlantic (NAT) track system provides the main east-west air corridors between Europe and North America. It is the oldest and most heavily traveled oceanic organized track system (OTS); over 300 aircraft make use of the track system each day. In this capacity, the NAT track system is possibly the most important commercial link between these continents.

Operation of the NAT track system requires that decisions be made on a virtually continuous basis. System decisions can be classified as either operational or strategic. Operational decisions address clearance of aircraft onto and through the system. These decisions must be made according to a set of strategic rules to assure separation and safety of all user aircraft. The strategic decisions are made on a less frequent basis. They provide the framework within which operational decisions are made. Strategic decisions include the selection of routes, allowable flight altitudes, separation standards and so on. The strategic decisions affect the system economics, the system availability and the system safety. Any strategic system decision involves an interplay of these three factors. For example, zero collision risk could be achieved by allowing only one aircraft on the track system at any one time. However, a decision to achieve this level of safety would incur exorbitantly large penalties in system economics and system availability. Thus, in operation, some degree of safety is traded to achieve large gains in system economics and system availability. The appropriate point of tradeoff between these three factors depends, of course, on both technological factors, such as navigational system performance, and on economic factors, such as fuel cost and traffic count.

The North Atlantic track system providers and users, organized formally as the North Atlantic Systems Planning Group (NAT/SPG), seek to ensure that no changes holding out the possibility of increased system capacity or diminished cost of system operation are initiated without first assessing their potential impact upon system safety. Since the 1950's, advances in equipment and pilot skills have diminished the levels of many of the hazards affecting the safety of air commerce in the NAT. As a result, the principal concern of the system providers'

decision processes regarding system safety for the last 15 years has been control of the risk of midair collision.

In general, if separation standards and other specifications of the track system remain unchanged, technological improvements would result in increased system safety. If technology results in large increases in system safety, it may become desirable to trade some of these gains for improvements in system economics and system availability. It is generally agreed, however, that this tradeoff should be made only when significant benefits are gained.

Recently, a reduction in the basic NAT lateral separation standard from 120 nm to 60 nm was implemented (October 30, 1980). The reduction was made to realize gains in system economics and availability while continuing to satisfy an agreed-upon level of safety. A minimum navigation performance specification (MNPS) was established to assure that the tradeoffs in system safety would not be disproportionate to the gains made in system economics and availability. Development of the MNPS established a procedure within the context of the overall NAT track system decision making process to assure that strategic system decisions would be made with system safety maintaining its position of paramount concern. The MNPS so established has three major components:

1. A primary goal of achieving a target level of safety (TLS) denoting the acceptable amount of lateral collision risk for the NAT track system, not to be exceeded as a result of strategic system decisions, and a set of secondary goals concerning system availability to projected traffic over a ten-year planning horizon and an assurance to users that approved navigational system equipment will remain usable for a similar period of time.
2. A set of numerical criteria regarding important navigational performance parameters, to assure that system safety will be maintained commensurate with the TLS over the planning horizon period.
3. A monitoring and certification procedure to assure the criteria of item 2 are met in the operational system.

The criteria and monitoring procedures are primarily directed toward estimating the frequency of larger lateral errors. These were keyed to the use of 60 nm lateral track spacing. It was expected that system monitoring would show that the criteria necessary for 60 nm spacing were being met as stated and that 60 nm spacing lateral spacing could, thus, be implemented without delay.

Modifications have been suggested to the monitoring and evaluation process motivated by a belief that certain types of observed errors impacted risk less heavily than did others. The U.S. has stated that these proposed modifications, referred to as "weighting," were not given adequate consideration with regard to their impact on the criteria designed to assure meeting the MNPS goals. This led to a considerable amount of disagreement and discussion within the NAT/SPG and the issue has yet to be resolved.

The purpose of this working paper is to consider the implications of the proposed modifications as they affect the safety criteria, MNPS, monitoring procedure, certification procedures and decision criteria and to maintain a sound and consistent framework for continued decision making in the NAT region as these new areas are explored. It is recognized that many issues which need discussion and resolution are not resolvable by mathematical procedures alone. Thus there are many issues which must be addressed by the system decision makers. Insofar as mathematical models are used to provide guidance to the decision making process, they must be soundly and consistently structured. This paper explores these issues and sets a potential framework for their resolution.

2. Background

In 1964 lateral separation of tracks in the NAT region was 120 nm. It was proposed at that time that the separation be reduced to 90 nm as a means of improving track system economics and availability. The action to reduce the

separation to 90 nm was not taken at that time due to a lack of confidence that system safety would be acceptable.

To set the stage for subsequent reductions in lateral route spacing in the NAT track system, ICAO set up the NAT/SPG in 1965. One purpose of the NAT/SPG was to undertake a study of lateral separation and to develop the framework of a decision making process for subsequent reduction in separation standards. In these early years the NAT/SPG group made two very important contributions. First was the development of a collision risk model now referred to as the Reich Model. The Reich Model provides an estimate of collision risk on a two-direction, parallel route track system in a non-radar environment. The second major contribution was the development and numerical quantification of the TLS. This threshold of collision risk was presented as a criteria to bound and condition strategic decisions in the NAT region and was derived as the result of analyzing actuarial data on aircraft accidents. The NAT/SPG employed the model and TLS to establish a decision making process which, in essence, states that strategic decisions, such as changes in separation standards, are permissible only if they result in a modeled estimate of track system collision risk which is equal to or better than the TLS.

Part of the NAT/SPG's overall activities included the collection of a substantial set of OTS navigational performance data. These data were obtained as radar traces from both ground-based radars and from radars on ocean station vessels. It is important to note that at this time the principal methods of navigation in the NAT region consisted of LORAN, LORAN-Doppler and non-directional beacons, augmented occasionally with other systems such as celestial.

The decision making process established by the NAT/SPG was then applied to the existing 120 nm separation system in the NAT region and to the proposed 90 nm separation system. It was found that the existing system satisfied the safety

criteria which had been set, but that with the existing navigational systems and their demonstrated navigational performance, the proposed 90 nm separation system did not meet the TLS.

In its initial deliberations, the NAT/SPG did not set a specific value for the TLS. Rather, a range of values was suggested from $.15 \times 10^{-7}$ to $.4 \times 10^{-7}$ accidents per track system flying hour.* Later, recognizing that technological improvements would enable improvements in track system safety, the NAT/SPG suggested a single goal value for the TLS of $.2 \times 10^{-7}$ accidents per hour.

In the process of developing the decision making procedure, two factors emerged:

1. Acceptance of the Reich Model as a means for providing an estimate of the OTS collision risk associated with alternative strategic decisions and,
2. the utility of the TLS in bounding choices from among the alternatives.

In judging 120 nm separation to be safe while rejecting the lower lateral standard, the NAT/SPG established a calibration of model-estimated risk in terms of the actuarially derived TLS and, thus, established a calibration of the decision making process itself.

During the late 1960's and 1970's two new navigation systems were implemented in the NAT OTS, INS and OMEGA. Both of these systems represent a substantial improvement in both accuracy and reliability over the majority of systems in use at the time of the initial NAT/SPG study. As a result, the past decade has seen significant navigational performance, improvements in the NAT region. Two additional changes have taken place over this period of time. First, system traffic has continued to grow making it more difficult for each potential

* One collision equals two accidents.

user to access the system efficiently. Second, fuel costs have increased dramatically. These factors led to a desire to reduce lateral separation thus permitting more optimal route availability by allowing for more flights closer to the minimum time track. It was reasoned that the improvements in navigational performance effected in the system over the previous ten years, coupled with the proposed changes in lateral separation, would result in an overall level of system lateral collision risk which not only would meet the TLS, but which in addition would not be any worse than that achieved in 1968. Disclosures in the mid 1970's that NAT LORAN A chains would be decommissioned within a few years led system users depending upon this navigational aid to examine replacement alternatives. In response to user requests for guidance in this examination, the NAT/SPG set out to develop the MNPS, which was intended to state the level of navigational performance necessary to support a 60 nm NAT lateral separation standard.

The MNPS was developed during 1975 and adopted by ICAO in May of 1976. It became effective December 29, 1977, concurrent with the decommissioning of the LORAN A chain in the North Atlantic region. The MNPS reads as follows:

- a) The standard deviation of the lateral track errors shall be less than 6.3 nm,
- b) the proportion of the total flight time spent by aircraft 30 nm or more off track shall be less than 5.3×10^{-4} ,
- c) the proportion of the total flight time spent by aircraft between 50 and 70 nm off track shall be less than 13×10^{-5} .

It is worth observing that, as originally developed, the MNPS criteria b) and c) above were stated in terms of probabilities rather than in terms of proportion of total flight time. The latter interpretation of these probabilities, as a proportion of total flight time, was made for the convenience of equipment manufacturers and system users in their interpretation of the specification.

Criteria b) and c) have since become known as the η and ζ criteria and are to be applied to the operational system to assure compliance with the TLS. Criterion a) arises because of a need to certificate aircraft and navigational system types for operation in the NAT MNPS system. Criterion a) relates to a parameter which can be easily measured in a short period of time with relatively few aircraft and few observations, as opposed to criteria b) and c) which may require observation over extended periods of time and on numerous aircraft. Thus, criterion a) gives confidence that a new aircraft or navigational system can be introduced into the NAT MNPS system without a significant adverse effect on total system safety.

Between May 1976 and December 1977 preliminary certifications of aircraft and navigational systems against the NAT MNPS were conducted by states of registry. At the same time, monitoring continued in the NAT MNPS system making use of radar observations taken principally at Shannon, Ireland. Once again, application of the risk model and data collected led to the conclusion that the system, at its then current 120 nm lateral track spacing, met the TLS. Compliance with the MNPS for 60 nm lateral track spacing, however, was not demonstrated by the data, thus thwarting plans for an early change from 120 nm to 60 nm lateral track spacing.

Concurrently, members of the NAT/SPG expressed the opinion that a critical look at the decision making process established in the 1960's was in order. In this examination, it was proposed to account for the presumed structure of the flight paths associated with certain large errors. The contention was that not all navigational error types of an equal observed magnitude contribute equally to collision risk. After examination of monitoring data, a new analysis was proposed, representing a use of the Reich Model and mathematical constructs intended to

estimate the risk contributed by certain error types noted to have occurred in the monitoring data. Re-examining the data with this new analysis provided estimates of collision risk that were different from (and usually lower than) the collision risk estimated by previously established procedures. It is important to recognize, however, that all that was proposed was a change in the procedure for assessing the impact of a specific class of errors. Thus, despite the resulting implication of a lower level of modeled risk than had been previously estimated, no actual change in system risk was effected.

The development and adoption of new collision risk analyses, and the assessment of spacing reduction based on these analyses, raises many issues which need to be discussed and resolved. Among these are the following:

1. Potential need for a redefinition of the TLS in light of the results provided by a new collision risk analysis.
 2. The adequacy of the current MNPS in light of a new collision risk analysis.
 3. The adequacy of presently collectable data, in particular that relative to waypoint errors, for use in the new collision risk analysis.
 4. The requirement for a new statistical testing procedure for the MNPS criteria in light of the new collision risk analysis.
 5. The need for a new monitoring procedure in light of the changes imposed by adoption of a new collision risk analysis.
3. The Reich Model, Navigation Performance Specification and System Monitoring

Undisputed is the fact that midair collisions in the North Atlantic are, and will continue to be, rare events. The achievement of the TLS of .2 accidents per 10^7 track system flying hours implies a rate of approximately one collision per 150 years of operation in the NAT OTS. At such low rates of expected occurrence, a decision to make a system change can have a profound impact on system risk without being immediately evident in the observed collision rate. It has been

estimated that, at current levels of OTS traffic density data, it would take over 160 million track system flying hours (over 400 years) with no accidents in order to be even 50 percent confident by direct estimation of the accident rate that the system is operating below the TLS.

Because the observed accident rate cannot provide a sufficiently precise or timely estimate of risk in the system, it cannot be used either in a predictive mode to analyze the impact of potential system changes or in a descriptive mode to assess risk in the current system. It is consequently necessary to turn to an analytical model of some sort. The purpose of a mathematical model is to decompose the data requirements for risk estimation from those needed for direct estimate, which are not available, to a set of measurable or estimable data from which an imputed risk estimate may be obtained. Such models are capable of allowing decisions to be made with available data, in consonance with the TLS.

Good models express the relationships among the system factors in as simple a manner as possible. The impact of changing various factors on system variables should be determinable in a straightforward manner. Further, any inherent relationships between the system factors should be carefully incorporated in the model. As more assumptions need to be made, these should be accommodated in a consistent fashion. Also, where the output of the model is a risk estimate, assumptions should tend to the conservative. Wherever possible, model parameters should be structured so that they may be estimated from available data.

It must be recognized that risk, as estimated by the model, is not likely to be identical to the actual risk in the system. Since assumptions have to be made and parameters estimated, there exists at best a proportional relationship between model-estimated risk and system risk. This does not, however, mean that a model

is not useful. In fact, the model can provide information to the decision making process in two areas: in estimation of absolute levels of risks, even though the modeled risk is likely to be a conservative estimate of actual system risk, and in making comparisons between alternative systems or of the impact of system changes. As long as the model remains unchanged, comparison of model risks will enable the decision makers to assess the relative impact of alternative strategic decisions.

The MNPS decision making process initially employed in the NAT region is based on several assumptions. Among the most important within the context of the current discussion is that navigational performance is position and time-invariant, i.e., that the distribution of lateral errors does not vary with position over the ocean. This allows for the use of historical data in determining the probability distribution of lateral track keeping errors, using observed deviations from track as aircraft first come under radar surveillance upon exiting the track system as essentially a snapshot of the distributional characteristics of performance which would be observed at any position along the track. Based upon observed data, a double double exponential (DDE) distribution has been fitted and used in determining MNPS criteria which must be achieved to meet a specified TLS.

The Reich Model has been found over the years to be mathematically sound and consistent. Estimation of important system parameters such as occupancy and the distribution of lateral errors is feasible given existing data. While not all aspects of the model are verifiable by observing the North Atlantic track system in operation, the Reich Model and the observed DDE navigational performance distributional form allow certain criteria to be established to insure that at a spacing of 60 nm the specified TLS will be achieved.

The MNPS provides such a set of specifications. If all three MNPS criteria are met, the model-estimated risk is less than the target level of safety.

The η criterion constrains the proportion of time spent more than half a separation standard away from the assigned track and is a primary parameter of risk. Its numerical value of 5.3×10^{-4} is specifically linked to the DDE distribution and was determined by taking a minimum allowable probability of 30 nm or greater lateral deviation over all relevant combinations of DDE distributional parameters which produced a model risk exactly equal to the TLS. The ζ requirement, related to the proportion of the total flight time spent between 50 and 70 nm off track, was constructed to insure that the assumption of a DDE distribution is not violated by a peak at the separation standard. In the operational system both the η and ζ criteria must be satisfied to assure compliance with the TLS. The σ criterion was constructed to provide a constraint on the navigation system accuracy for certification. This requirement provides a preliminary indication that a navigational system has the potential to comply with the MNPS.

In summary, historical data were used to identify the DDE distribution as appropriate for lateral errors. Following an assessment of actuarial data, a TLS of .2 accidents per 10^7 track system flying hours was agreed to. This TLS was used in the context of a model structured along Reich's original assumptions. The MNPS constraints were then developed to insure that, assuming a DDE distribution, the model risk would not exceed the TLS if the constraints were met.

In order to determine whether the system as currently operating satisfies the MNPS criteria, assessment of achieved navigational performance by analysis of data collected from the NAT was proposed. In particular, statistical testing procedures were formulated by constructing conflicting hypotheses, and rules established for determining which, how and when a particular hypothesis may be accepted. Careful consideration of decisions which could result in unsafe or costly errors was undertaken.

As an example, consider the ζ requirement. Here, the proportion of flight time spent between 50 and 70 nm off track is required to be less than 1.3×10^{-4} . Establishing the MNPS criterion as the null hypothesis and twice that value as the alternative, statistical procedures were established to select between:

$$H_0: \zeta = 1.3 \times 10^{-4}$$

$$H_1: \zeta = 2.6 \times 10^{-4}$$

Based upon available data, it must be decided either to accept the null hypothesis, implying the MNPS requirement was being met, or to accept the alternative, implying that the MNPS criterion was not being met and, consequently, the TLS was being exceeded.

The following table shows the problem faced by the decision maker:

<u>DECISION:</u>	<u>TRUE STATE OF NATURE</u>	
	H_0 IS TRUE	H_1 IS TRUE
ACCEPT H_0	CORRECT DECISION	TYPE II ERROR (UNSAFE)
REJECT H_0	TYPE I ERROR (COSTLY)	CORRECT DECISION

As illustrated, any statistical testing procedure, in attempting to select between two alternatives, is subject to two types of errors. A Type I error, in which it is concluded incorrectly that the ζ criterion is not being met, could result in a costly decision not to reduce lateral spacing. A Type II error, in which it is concluded incorrectly that the ζ requirement is being met, could result in a decision to reduce spacing when by doing so the TLS will be exceeded. Any statistical testing procedure established must take special care to control the probability of both types of errors.

Since the distribution of lateral errors obtained when aircraft first come under radar surveillance was assumed to be representative of performance everywhere across the ocean, the testing procedures could be based on a count of observed large deviations. Using a Poisson distribution, it was decided to control the probability of both types of decision errors at 0.05. Two statistical testing procedures were then considered: a fixed sample size test in which a fixed number of aircraft would be observed and then a decision made between the hypotheses, and a sequential scheme in which, as each aircraft was monitored, a decision would be made to accept H_0 , to reject H_0 , or to continue sampling. For the assessment of ζ , the fixed sample size test would have required monitoring 120,900 aircraft, while the expected sample size in the sequential procedure, if ζ was being achieved, was less than 70,000. Further, if performance was much better or much worse than expected, the sequential procedure could lead to a decision even more quickly. For these reasons, the sequential sampling scheme was proposed.

It should be noted that these procedures were established to control the chances of incorrectly accepting a hypothesis at 5 percent. Use of a smaller fixed sample size, or making a conclusion while the sequential sampling plan indicated that continued testing is necessary, increases the chance of a wrong conclusion. As established, the procedures were mathematically sound and the chance of wrong conclusions known to be small.

4. Alternative Risk Models and Their Implications

Periodic examination of observed lateral deviations to determine compliance with MNPS requirements began in early 1978 using a sequential sampling plan as one statistical testing procedure. Results of this testing did not indicate that the ζ criterion was being met with sufficient statistical confidence to induce the NAT/SPG to approve a 60 nm lateral track separation standard. Analysis of

individual errors from several periods of monitoring data indicated the existence of more waypoint and air traffic control loop errors than expected. As remedial action was being devised and applied, a detailed scrutiny of these errors was made. It became apparent that some of the errors impacted risk less than others, since they posed a threat only in the vicinity of one waypoint, or only while exiting from the track system. These observations prompted a review of the manner in which the risk model was being used, to ascertain if the methodology could be revised to reflect the type of lateral error in various error categories. A new analysis was proposed, involving averaging the risk contributed by waypoint errors over distance between waypoints. Using this analysis, methods were presented for indexing or "weighting" observed lateral errors, categorized as to cause, prior to testing for MNPS compliance.

If changes to the model are thought appropriate, due consideration should be given to the impact which they might have on the NAT decision making process. The remainder of this section examines some of the implications of the changes proposed to date.

Several criticisms have been raised regarding the continued application of the Reich Model and the MNPS to the NAT. Specifically, the assumptions of position-invariant navigational performance and the use of a DDE distribution have been challenged. Evidence has been cited of a secondary peak in the distribution of observed NAT lateral errors in the neighborhood of 60 nm from assigned route during recent years. Further, the occurrence of certain types of errors such as waypoint errors, observed near the end of the track, are thought to make the observed distribution substantially different than might be observed at other points across the ocean. Substantial modifications to the decision making process for determination of lateral route spacing have consequently been proposed, and it is the intent of this section to consider what effects such modifications might have

on the basic collision risk model, navigation performance specifications and system monitoring.

Previous sections have carefully reviewed the development of the TLS, MNPS criteria and monitoring procedures. It is important to keep this historical perspective in mind when examining proposed modifications. Figure 4.1 illustrates in general terms the relationship of model risk to system risk. The original model is based upon a set of assumptions which were never claimed to be exact. However, it was structured in a mathematically consistent fashion so that model risk would vary in a consistent and roughly proportional manner to system risk. When the NAT/SPG employed the TLS together with this model, they were implicitly accepting a level of system risk equal to R . The decision makers were satisfied that, if the model produced a risk value below the TLS, then actual system risk would be acceptable.

Now various modifications involving the averaging of risk have been proposed to this original model which tend to make it less conservative. This has the general effect of shifting the model-system risk relationship to the right. Consequently, if the modified model yields a risk value equal to the original TLS, then system risk will be equal to R' , which would be larger than originally intended. To achieve a level of actual system risk equal to R , which would have been achieved had the original model met the TLS, a new value of model-estimated risk, M^* , below the original TLS is required for the modified model.

The first essential point here is that previous decisions regarding acceptable levels of risk, including the decision not to reduce separation in 1968, have been made in the context of the Reich Model. Acceptance of the TLS value has historically been supported at least partially on the fact that, when applied in the context of the Reich Model, it ensures that reduction in separation to 60 nm will

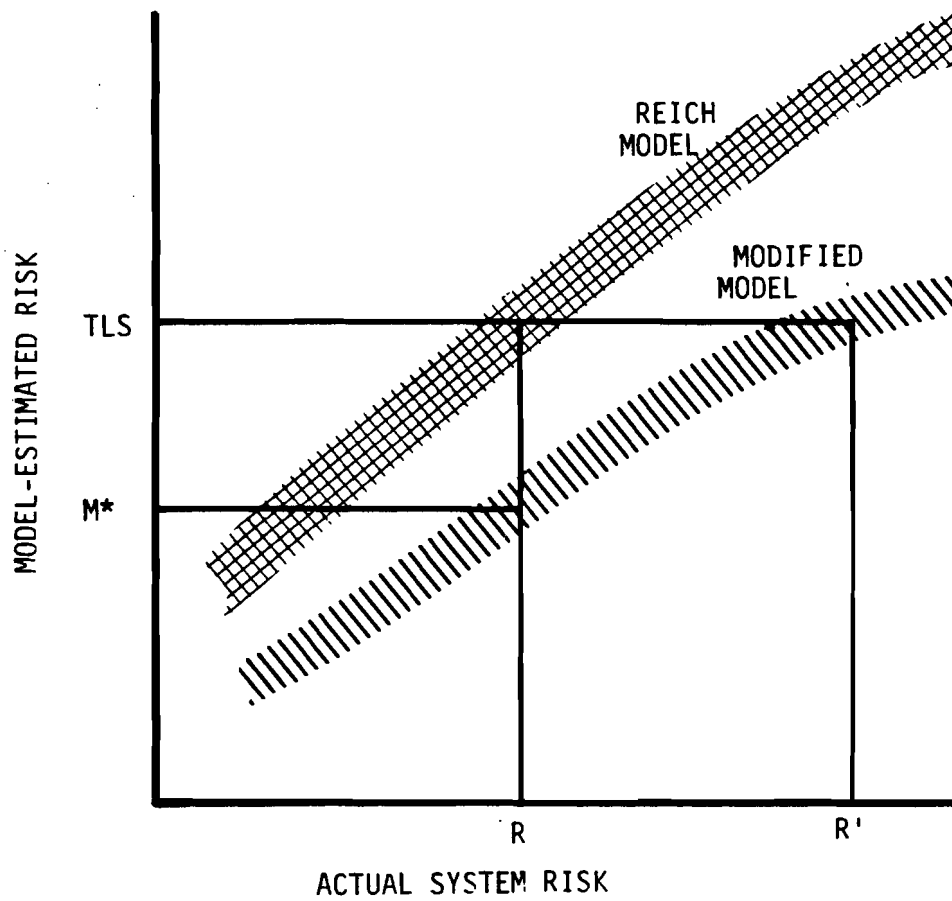


Figure 4.1 Model-System Risk Relationships

not increase system risk beyond levels historically achieved. Modifications of the model, without recalibration of the TLS, may allow for a substantially higher value of system risk than originally intended.

The second essential point is that the MNPS criteria are directly linked to both the assumption of a position-invariant distribution for lateral errors and to characterization of those errors by a specific distribution: DDE distribution. This distribution was arrived at based upon examination of historical data. The MNPS criteria were set up to insure that, given that lateral deviations continued to follow a DDE distribution, systems meeting the criteria would also satisfy, in the context of the model, the TLS. Further, the ζ criteria was meant to ensure that the DDE assumption was reasonable. The MNPS criteria do not provide assurance of system safety if the DDE distribution is not appropriate.

A third essential point concerns the specific statistical testing procedures proposed to determine whether the system as operating achieved the MNPS criteria. These testing procedures relied specifically on the assumption that the distribution of lateral deviations from track observed when aircraft came under radar surveillance was representative of performance everywhere in the system. This time-invariant or position-invariant property allowed the tests to be based on a simple count of large deviators through a Poisson distribution. Relaxation of the position-invariant assumption requires substantial changes in the necessary statistical testing procedures, and a possible reexamination of the type of data required to verify adherence with MNPS criteria will be needed.

To make specific some of the changes in criteria and decision making procedures which would be necessary if the assumptions of position-invariant performance and the DDE distribution were to be relaxed, it is useful to consider

certain typical modifications. The original model assumed for lateral deviations was that of a DDE distribution with density function:

$$f(Y) = \frac{1-\alpha}{2\lambda_1} e^{-|Y|/\lambda_1} + \frac{\alpha}{2\lambda_2} e^{-|Y|/\lambda_2} \quad (1)$$

This distribution consists of two exponential terms, often interpreted as representing normal performance and "blunders." The self-convolution at a route spacing of S nautical miles is:

$$\begin{aligned} C(S) &= \int_{-\infty}^{\infty} f(Y)f(Y-S)dY \\ &= \frac{(1-\alpha)^2}{4\lambda_1^2} (\lambda_1+S)e^{-S/\lambda_1} + \frac{\alpha^2}{4\lambda_2^2} (\lambda_2+S)e^{-S/\lambda_2} \\ &\quad + \frac{\alpha(1-\alpha)}{2} \left[\frac{1}{\lambda_2-\lambda_1} \left(e^{-S/\lambda_2} - e^{-S/\lambda_1} \right) + \frac{1}{\lambda_1+\lambda_2} \left(e^{-S/\lambda_1} + e^{-S/\lambda_2} \right) \right] \quad (2) \end{aligned}$$

Now for concurred values of occupancy and other model parameters, assuming position-invariant navigational performance, collision risk as calculated by the original Reich Model will be less than .2 accidents per 10^7 track system flying hours if $C(S) \leq 6.45 \times 10^{-6}$. The MNPS criteria, specifically η and ζ , were formulated to ensure that, if lateral errors were characterized by the DDE and the criteria were achieved, then the above condition on C(S) would be met. In deriving the η criterion, various DDE distributions exactly satisfying the condition were examined and from these a value of η selected, 5.3×10^{-4} .

The ζ criterion, which relates to the proportion of lateral errors in the vicinity of the adjacent track, relies on the approximation

$$C(S) \doteq 2f(S) \quad (3)$$

This approximation is valid only if the distribution of lateral errors is symmetric, unimodal and slowly varying in the neighborhood of 60 nm, with the bulk of the

distribution inside 30 nm. For the DDE distribution, this requires that λ_2 be much greater than λ_1 and α be very small, under which conditions the convolution can be approximated by

$$C(S) \doteq \frac{\alpha}{\lambda_2} e^{-S/\lambda_2} \quad (4)$$

which is indeed approximately $2f(S)$, twice the density function for large S , including $S = 60$ nm.

The ζ requirement has been consciously or unconsciously reinterpreted over the years. In particular, it has been noted that if the approximation in (3) holds, then the condition on $C(S)$ is equivalent to requiring that $f(S) \leq 3.225 \times 10^{-6}$. Moreover, if $f(Y)$ is relatively flat in the neighborhood of $Y = S = 60$ nm, then

$$f(60) \doteq \frac{1}{40} P(50 \leq |Y| \leq 70) \quad (5)$$

so that the condition on $f(S)$ is equivalent to requiring that $\zeta = P(50 \leq |Y| \leq 70) \leq 1.3 \times 10^{-4}$.

It must be recognized that the ζ requirement ensures that the TLS is met only if the approximation in (3) holds. Under the original DDE assumption, it does hold. A simple example under which it does not hold is if lateral errors follow a single double exponential distribution with density function

$$f(Y) = \frac{1}{2\lambda} e^{-|Y|/\lambda} \quad (6)$$

Then

$$C(S) = \frac{1}{4\lambda^2} (\lambda+S)e^{-S/\lambda} = \frac{1}{2} \left(1 + \frac{S}{\lambda}\right) f(S) \quad (7)$$

For route spacings S and parameter values λ likely to occur, $C(S) > 2f(S)$, meaning

that meeting the ζ requirement as currently specified would not by itself guarantee that the TLS was met. In such a case, different values for the present type of MNPS criteria would be required.

One modification of the lateral error distribution which has been proposed to represent aircraft inadvertently occupying the track adjacent to the assigned track is placement of a secondary peak at $Y = 60$ nm. Such a peak, if similar to the main peak, would require a density function of the form

$$f(Y) = \frac{1-\alpha_1-\alpha_2}{2\lambda_1} e^{-|Y|/\lambda_1} + \frac{\alpha_1}{2\lambda_2} e^{-|Y|/\lambda_2} + \frac{\alpha_2}{4\lambda_1} e^{-|Y-S|/\lambda_1} + \frac{\alpha_2}{4\lambda_1} e^{-|Y+S|/\lambda_1} \quad (8)$$

For small α_1 and α_2 , this density function yields a convolution value

$$C(S) \doteq \frac{1}{4\lambda_1^2} (\lambda_1+S)e^{-S/\lambda_1} + \frac{\alpha_1}{\lambda_2} e^{-S/\lambda_2} + \frac{\alpha_2}{4\lambda_1} \quad (9)$$

The approximation $C(S) \doteq 2f(S)$ is no longer valid, but more seriously $f(Y)$ is not relatively flat in the neighborhood of $Y = S$. For small λ_1 , $(1/40)P(50 \leq |Y| \leq 70)$ may very seriously underestimate $f(60)$. In fact, ζ is no longer proportional to risk, and the η and ζ requirements are not sufficient to ensure that the TLS is being met. Thus, a different type of MNPS specification is required, including a specification insuring that λ_1 is not too small.

The above example demonstrates that the MNPS criteria are specific to the distributional form assumed for lateral deviations. A more radical modification of the basic collision risk model occurs when terms are added to the distribution which vary with along-track position. For example, suppose the secondary peak in (8) was not always located on the adjacent track but varied in some manner with the distance X from a waypoint on the main route. Such behavior has been suggested for waypoint errors. Now at any given X , suppose the secondary peak is

centered at a distance D ($0 \leq D \leq S$) from the main route. Then the density function for lateral deviations would take the form

$$f(Y|X) = \frac{1-\alpha_1-\alpha_2}{2\lambda_1} e^{-|Y|/\lambda_1} + \frac{\alpha_1}{2\lambda_2} e^{-|Y|/\lambda_2} + \frac{\alpha_2}{4\lambda_1} e^{-|Y-S+D(X)|/\lambda_1} + \frac{\alpha_2}{4\lambda_1} e^{-|Y+S-D(X)|/\lambda_1} \quad (10)$$

The convolution value is specific to X and can be approximated by

$$C(S|X) \doteq \frac{1}{4\lambda_1^2} (\lambda_1+S) e^{-S/\lambda_1} + \frac{\alpha_1}{\lambda_2} e^{-S/\lambda_2} + \frac{\alpha_2}{4\lambda_1^2} (\lambda_1+S-D(X)) e^{-(S-D(X))/\lambda_1} \quad (11)$$

Again, the approximation of $C(S) \doteq 2f(S)$ is poor and the distribution is not, in general, flat near $Y = S$.

Relaxation of the position-invariant navigational performance assumption represents a radical change in the basic collision risk model. No longer is the collision rate constant across the ocean but varies with the along-track position X . An important decision must now be made: what should be controlled? Is the intent of the TLS to control the maximum risk while flying across the ocean, or is it intended that low levels of risk at some points be allowed to offset high risk at others? The waypoint weighting proposal averages risk along the interval between waypoints $[0 \leq X \leq W]$ according to

$$\bar{C}(S) = \frac{\int_0^W C(S|X) dX}{W}$$

Requiring the average risk to meet the TLS allows risk at certain points across the ocean to be substantially higher than the established level of safety. This is in contrast to the original use of the Reich Model and the TLS, which employed the

available data in a worst-case mode to ensure that risk at all points across the ocean was below the TLS. The decision makers should be aware that acceptance of a model with position-varying navigational performance implies a redefinition of what is meant by system safety.

The point of the above examples is that, if the model for lateral deviations is modified, potential revisions to both the TLS and the MNPS criteria must be examined. Under the original model, a definition of system safety had been established and a distribution assumed which made it sufficient to examine three factors: the standard deviation of lateral errors, deviations beyond one half a separation standard and deviations within 10 nm of the separation standard. With a different distribution and changed assumptions, the TLS must be reexamined and new MNPS criteria potentially devised. It is important during this investigation to hold open the possibility that any of the three current MNPS criteria may be impacted by revisions to model or distributional assumptions. To date, proposed revisions to the Reich Model have sought to accommodate new modeled risk contributions with the present ζ criterion alone while ignoring any relevance of these changes to the η and σ criteria. As the above examples indicate, these revisions would require development of a new form of MNPS. During this development, it would be necessary to be attentive to the necessary changes to all the current criteria. It would also be necessary to keep in mind the availability of data sufficient to test whether the changed criteria are being met in the NAT system.

Modifications in the model assumptions and the MNPS criteria will also have substantial impact on the statistical testing procedures required to ensure that the system satisfies those criteria. For example, consider the ζ requirement. For the original model, where the distribution of lateral errors is assumed to be constant

everywhere across the ocean, the proportion of flight time spent between 50 and 70 nm off track is directly proportional to the number of aircraft observed at that distance when they come under radar control near the end of their journey. Consequently, a simple count of such deviations is sufficient to test a hypothesis regarding the ζ criterion. Given some of the model modifications proposed, a simple count is inadequate.

In the case of the original model the following hypotheses were proposed:

$$H_0: \zeta = 1.3 \times 10^{-4}$$

$$H_1: \zeta = 2.6 \times 10^{-4}$$

Having observed n total flights of which n_1 were between 50 and 70 nm off track, the likelihood function based upon the Poisson distribution takes the form

$$l(\zeta | n_1) = \frac{(n\zeta)^{n_1} e^{-n\zeta}}{n_1!} \quad \zeta \geq 0 \quad (12)$$

which involves the data only through the count n_1 . Consequently, n_1 is a sufficient statistic for the Poisson distribution, and estimates and tests of ζ can be based upon it. The maximum likelihood estimator is

$$\hat{\zeta} = \frac{n_1}{n} \quad (13)$$

and the likelihood ratio relevant for testing the specified hypothesis is

$$\Lambda = \frac{P_1(n_1)}{P_0(n_1)} = 2^{n_1} e^{-n(1.3 \times 10^{-4})} \quad (14)$$

Note that this is well-specified, involving only the sample size and number of large deviations.

Now suppose that the model as modified requires testing not of whether the number of deviations between 50 and 70 nautical miles off track is equal to

1.3×10^{-4} but of whether some linear combination of the proportions of different classes of errors is equal to 1.3×10^{-4} . Let this linear combination be of the form

$$C = W_1 \zeta_1 + W_2 \zeta_2 + \dots + W_K \zeta_K \quad (15)$$

Then two hypotheses can be formed as follows:

$$H_0: C = 1.3 \times 10^{-4}$$

$$H_1: C = 2.6 \times 10^{-4}$$

The relevant distribution in this case is that of the multivariate Poisson distribution, which takes the form

$$p(n_1, n_2, \dots, n_K) = \frac{(n\zeta_1)^{n_1} (n\zeta_2)^{n_2} \dots (n\zeta_K)^{n_K} e^{-n(\zeta_1 + \zeta_2 + \dots + \zeta_K)}}{n_1! n_2! \dots n_K!} \quad (16)$$

where n_1, n_2, \dots, n_K are the number of observed deviations in each class. While it has been proposed to use the estimator

$$\hat{C} = W_1 \frac{n_1}{n} + W_2 \frac{n_2}{n} + \dots + W_K \frac{n_K}{n} \quad (17)$$

to test the hypotheses, \hat{C} is not a sufficient statistic for the multivariate Poisson distribution. Further, even if it is assumed that for each class of errors the proportion in the alternative hypothesis is twice that of the null, the relevant likelihood ratio is

$$\Lambda = \frac{p_1(n_1, n_2, \dots, n_K)}{p_0(n_1, n_2, \dots, n_K)} = 2^{n_1 + n_2 + \dots + n_K} e^{-n(\zeta_1 + \zeta_2 + \dots + \zeta_K)} \quad (18)$$

As part of the null hypothesis, an additional specification regarding the sum of the proportions of the K classes of gross deviations $(\zeta_1 + \zeta_2 + \dots + \zeta_K)_0$ is required to construct a well-framed decision between the hypotheses.

In summary, it should be emphasized that modifications of the oceanic collision risk model, either through changes in the distributional form for lateral errors or by relaxing the assumption of position-invariant navigational performance, require modification of at least the interpretation of the TLS and its corresponding relation to system safety, of the MNPS criteria, and of the decision making procedures for determining whether these criteria are being met. Careful study of any proposed modifications is necessary to ensure that the risks of making incorrect decisions are known and that adequate system safety is maintained.

5. Open Issues

Reduction of NAT lateral separation to 60 nm is now an accomplished fact. During deliberations leading to this action, the NAT/SPG considered changes to its established procedures for both modeling risk and also assessing the inference which observed navigational performance provides concerning risk. Prior to adopting any of these changes and making them a part of the process for setting performance standards, it is necessary to consider their impact on the basic decision making process.

The discussions and developments of the above sections make it clear that there are indeed choices to be taken with respect to the selection of a decision making process for the NAT region. The selection of a decision using or not using mathematical models and criteria is, in the final analysis, a social/political process, not a mathematical process. But despite the freedoms of choice which do exist, the framework of any particular quantitative decision making process chosen for application in the NAT region must be mathematically rigorous. Failure to maintain mathematical rigor throughout the process can result in system decisions which are arbitrary and capricious, and, worse, which may in fact not achieve the desired level of system safety.

To be mathematically rigorous and logically consistent, a decision making process must accomplish a predetermined set of goals based upon the application of models, decision criteria, statistical testing procedures, monitoring procedures and operational judgment. These must all be both based on a single, self-consistent set of assumptions and also consistent with the data. Thus, one cannot arbitrarily change, for example, the statistical testing procedure or the monitoring procedures without examining the implications of such a change on the models and criteria. It is observed that the Reich Model for calculation of collision risk, the MNPS as stated in Section 2, and the statistical testing and monitoring procedures as outlined in Section 3 meet the necessary criteria of an acceptable decision making process. Subsequent changes to this decision making procedure suggested to date do not in our view meet the necessary conditions for acceptability.

This is not to say that the above criteria preclude system decision makers from making further strategic decisions. Indeed the range of potential, strategic decisions is considerable and their impact upon system economics, availability and safety may be profound. These choices include resolution of the following issues:

1. The decision makers may choose the level at which risk can be averaged. It is obvious that the net system collision risk varies substantially both with time of day and position along track. Thus, certain aircraft may be exposed to a collision risk which is substantially higher than other aircraft using the system. Similarly, a route could be safe at all points except one, where there is a very high risk of collision. The issues of average-to-peak risk control have been avoided in the work conducted to date, principally through the assumption of the snapshot principal which looks essentially at the (assumed) worst case by using navigation performance data on aircraft exiting the track system. These issues, however, cannot be skirted if one chooses to adopt more sophisticated risk models which infer a structure to certain navigational errors and hence imply a position-dependent collision risk. Obviously, to be useful, the choices taken must focus on the requirements imposed by the risk model and the degree of resolution which it allows.

2. Decision makers are free to choose the TLS. However, while the TLS is an arbitrary quantity, the choice of a specific value should be compatible both with the risk model, with previous decisions that in essence calibrate the decision making process and with historical performance observed in the track system. It must be recognized that the choice of a TLS value, while arbitrary, has profound social implications and, thus, cannot be taken lightly. It must be the objective of the decision makers here to represent the interests and desires of society at large.
3. The decision makers are free to choose the risk model upon which they will base their assessment of system risk and subsequently strategic decisions impacting the system. This choice, however, must be confined to a set of mathematical models which are both rigorous and mathematically correct. Thus, the choices which can be taken apply mainly to the degree to which the model provides an accurate representation of the real world and, subsequently, to the extent that the model imposes data requirements. Models may be chosen for which the data requirements are relatively simple and for which measurable data are readily obtained. On the other extreme, valid mathematical models could be formulated which would impose severe data requirements, possibly even requiring data that are difficult or impossible to obtain. The decision makers must recognize the tradeoffs between the degree of reality which the model exhibits and the ability to provide valid data for model execution.
4. The decision makers may find it convenient to choose to make certain assumptions which can considerably simplify the subsequent decision making processes. For example, based upon evidence obtained to date, the decision makers may choose to assume that aircraft navigating in the NAT region do so with a navigational performance that can be adequately represented by a DDE distributional form. Acceptance of the assumption that this distributional form is in fact a valid representation of navigational performance subsequently simplifies the development of an MNPS and its associated statistical testing procedure. The choices taken here should, of course, be consistent with historical data obtained to date.
5. The decision makers are free to choose the form of MNPS criteria. The choice of the η , ζ and σ specifications, as given in Section 2, is quite arbitrary. These were chosen for simplicity of statement and interpretation, for their amenability to a statistical testing procedure and monitoring procedure and because, within the context of the assumptions upon which they are based, they assure compliance with the TLS. Whatever MNPS criteria are chosen, they should be such as to provide these characteristics.
6. It must be recognized that decisions resulting from statistical tests of any sort can be in error. Errors are classified according to whether they are Type I or Type II as discussed in Section 3. The decision

makers are free to choose the probability of Type I or Type II errors occurring in the statistical tests used. The choice of these probabilities, however, must be constrained by considerations of system safety and economics. Allowing a high probability of errors could result in compromising system safety. Requiring very low probabilities of errors may impose undue economic burdens.

7. The decision makers are free to choose the data collection procedure by which data are obtained for use in risk modeling and system monitoring. For example, navigational errors might be monitored only at route termini or alternatively, they might be monitored at various regions along specific routes. Both the nature and quantitative aspects of the data obtained are likely to be dependent on the data collection procedure chosen and, thus, influence estimated risk accordingly. The choice of a particular data collection procedure must depend upon the data demands of the chosen risk model, the MNPS and the statistical testing procedure. It must provide data which are, in fact, a valid representation of actual system performance. But it must also take into consideration economic factors such as data collection costs.
8. The decision makers are free to choose the method of assessing continued compliance with MNPS criteria. A variety of valid statistical testing procedures and monitoring practices are available. The choice of a particular method should be consistent with the objectives of the MNPS.
9. The decision makers are free to choose the degree to which their decisions are permanent. For example, they may choose the period of time for which the MNPS will apply.
10. The decision makers are free to choose alternative methods of risk control given that the system fails to meet the TLS. For example, if at some time the system is deemed to be not in compliance with the TLS, the decision makers may choose from a variety of controls to restore system safety to the TLS. Such controls could include enforcement of more stringent navigation performance specifications, provision for surveillance of aircraft on various portions of the track system, or control of collision risk through system occupancy by means of restricting system availability.
11. It is the obligation of the decision makers to take all reasonable steps to improve system safety regardless of whether the TLS is met or not. For example, if system monitoring data identify a class of navigational errors, such as waypoint insertion errors, which are structured in such a way as to permit their easy elimination from the system, it is incumbent upon the decision makers to pursue the appropriate remedial actions. The decision makers are free to choose the form of remedial action to be taken in consonance with the nature of the error identified and the level of risk which it imposes.

There are obviously many choices to be made in the development and operation of the NAT system. These choices, however, must be made in a manner which fosters economic operation of the system, which provides an acceptable level of system availability and, above all, assures an acceptable level of system safety. These decisions must be made within a rigorous mathematical framework that assures that they are self consistent and that they achieve the desired system objectives.

6. Conclusions

This paper has treated a number of issues relevant to the process of decision making in the NAT region. Throughout this treatment, it has been emphasized that the decision making process has many elements, including the TLS, collision risk analysis methodology, an MNPS, a monitoring procedure, a certification procedure and decision criteria. Each of these elements is linked to all the other elements through a set of assumptions and objectives which dictate their form. Thus, for example, the form of the MNPS, that is, the choice of parameters η , ζ and σ , is dependent upon assumptions made in the collision risk analysis methodology and upon the monitoring and certification procedures. In this case, the efficacy of η and ζ is dependent upon the assumption of the distributional form for navigational errors. One cannot assume new distributional forms as implied by weighting and continue to use η and ζ for risk control. These parameters may simply be inappropriate for other distributions, regardless of their numerical values.

The proposed weighting procedure for decision making is flawed in many respects:

1. It alludes to position-dependent risk in the system, but fails to identify an appropriate TLS. The existing TLS has been applied largely as an upper bound on risk; the weighting procedure seeks to change this to position-averaged risk.

2. The form of the MNPS, that is, the use of η , ζ and σ to control risk is inappropriate. These parameters alone, under the assumptions of the weighting procedure, do not assure risk control. It may be necessary to add a maximum navigation performance specification on σ to assure risk control.
3. The statistical testing procedure and associated decision criteria are inappropriate. Multivariate testing procedures must be used, even to test the ζ criterion as proposed. These procedures are vastly more complex than those currently in use.
4. It is not supported by mid-ocean data to assure that mid-ocean frequencies of certain large errors are well represented by their corresponding end-of-track frequencies or to assure that the nature of course deviations is as assumed.
5. The certification procedure is inappropriate. Control of frequencies of certain large error types must also be verified.

Because the very concept of the weighting procedure proposed is in question, the choice of specific values for weights or for decision criteria is irrelevant. A more fundamental review of the choice of assumptions and parameters is first necessary.

The objective of any risk modeling effort is to be predictive. Historical events cannot be altered by any decision process. They are of value only insofar as they contain information from which inferences may be drawn regarding future events. For example, historical data can provide estimates on the frequencies of occurrence of specific events which can then be used to forecast the future occurrence of similar events. The more detailed one gets in the categorization of events, however, the less information a given set of data contains relative to the expected future occurrence of each type of event. Thus, the more detailed one wishes to be in one's prediction of future events, the more historical data one requires in order to preserve a desired level of confidence in a prediction. Large navigational errors are rare events. Categorization of large navigational errors leads to a set of error types each of which is an even rarer event. The fundamental premise of the proposed weighting procedure is that not all error types have equal consequence (that is, risk). Thus it is important to control each error type

independently to assure total system safety. But even with only a few error categories, this becomes a monumental task. Simply put, the desire to categorize navigational errors quickly leads to vastly increased monitoring requirements which in turn may negate any benefits otherwise obtained. Despite these objections, categorization of errors is useful for identifying effective remedial actions and for assessing the efficacy of the decision making process as used by the decision makers.

In summary, the NAT decision making process consists of a TLS, a risk model with attendant data and assumptions, an MNPS, a monitoring procedure, certification procedures and operational judgement. A change to any constituent of this total decision making process should not be made without an examination of the impact of such a change on all constituents of the total process. Mathematical models are appropriate and useful for guidance in the decision making process, but they must be formulated in accordance with accepted mathematical practice and within the framework of the assumptions imposed by the other elements of the decision making process.