International Civil Aviation Organization

The Thirteenth Meeting of the FANS Implementation Team for the Bay of Bengal (FIT-BOB/13) and the Fifth Meeting of the Bay of Bengal Reduced Horizontal Separation Implementation Task Force (BOB-RHS/TF/5)

Bangkok, Thailand, 07 – 11 February 2011

Agenda Item 4: Safety Analysis and Airspace Monitoring Issues

Assessment of the Safety of continued use of 50-NM Lateral and the Implementation of 50-NM Longitudinal Separation Standards on ATS Routes P628 and L510, N571 and P762

(Presented by Singapore)

SUMMARY

This working paper presents the results of an assessment of the risk associated with the continued safe use of 50NM lateral and the introduction of 50NM longitudinal separation standards on Bay of Bengal routes L510, N571, P628 and P762. The safety assessment was conducted using internationally applied ICAO collision risk methodology, making use of relevant results developed in other portions of the Asia and Pacific Region where appropriate. The main sources of data used in the safety assessment are information extracted from the December 2009 Traffic Sample Data (TSD) collection, radar-based measurements of position obtained from the Kuala Lumpur Air Traffic Control Centre and Yangon Air Traffic Control Centre and the result of monitoring navigational performance on the routes – a process which has been underway on a continuous basis since July 2010. The risk associated with the 50NM lateral separation standard is estimated to be in compliance with the Regional Target Level of Safety (TLS). Examination of the risk associated with the 50NM longitudinal separation standard also indicates that the TLS is satisfied with high confidence. In light of favorable risk estimates and the ongoing program for monitoring navigational performance, the safety assessment supports the continued used of 50NM lateral and the introduction of 50NM longitudinal separation standards on L510, N571, P628 and P762.

Action by BOB/RHS/TF5 is at Paragraph 5.

1 INTRODUCTION

1.1 In November 2009, the First Meeting of the ICAO Bay of Bengal Reduced Horizontal Separation Implementation Task Force, BOB/RHS/TF-1, agreed to a step-by-step or phased implementation of reduced horizontal separation. At the BOB/RHS/TF3 and BOB/RHS/TF4 meetings, the ATS routes L510, N571, P628 and P762 were identified for Phase 1 implementation. For Phase 2, the ATS routes affected are L301, L759, M300, M770, N563, N877, P570 and P574. The meeting agreed, further, that any introduction of reduced separation minima would be subject to the satisfactory outcome of a safety assessment of proposed changes. India advised the meeting that, they are prepared to establish an Enroute Monitoring Agency (EMA) in accordance with ICAO provisions.

1.2 At the BOB/RHS/TF4, held in Bangkok from 18 – 22 October 2010, India requested for South East Asia Safety Monitoring Agency (SEASMA) to support and assist in the conduct of the initial safety assessment of Phase 1 implementation of reduced horizontal separation in the Bay of Bengal region, as well as to provide continued safety monitoring services until such time when India is endorsed by Regional Airspace Safety Monitoring Advisory Group (RASMAG) as a competent EMA.

1.3 The ATS routes affected for Phase 1 and 2 were considered in the conduct of the initial safety assessment for Phase 1 implementation. The purpose of this working paper is to present the assessment on the safety of continued used of 50NM lateral and the introduction of 50NM longitudinal separation minima on L510, N571, P628 and P762.

2 Background

2.1 Description of Bay of Bengal Airspace

2.1.1 Twelve FIRs – Bangkok, Chennai, Colombo, Delhi, Karachi, Kathmandu, Kolkata, Kuala Lumpur, Lahore, Male, Mumbai and Yangon – have air traffic control responsibility for L301, L510, L759, M300, M770, N563, N571, N877, P570, P574, P628 and P762. Figure 1 shows the routes affected in Phase 1, (L510, N571, P628 and P762), and Phase 2, (L301, L759, M300, M770, N563, N877, P570 and P574), of the implementation of 50NM longitudinal separation minima.

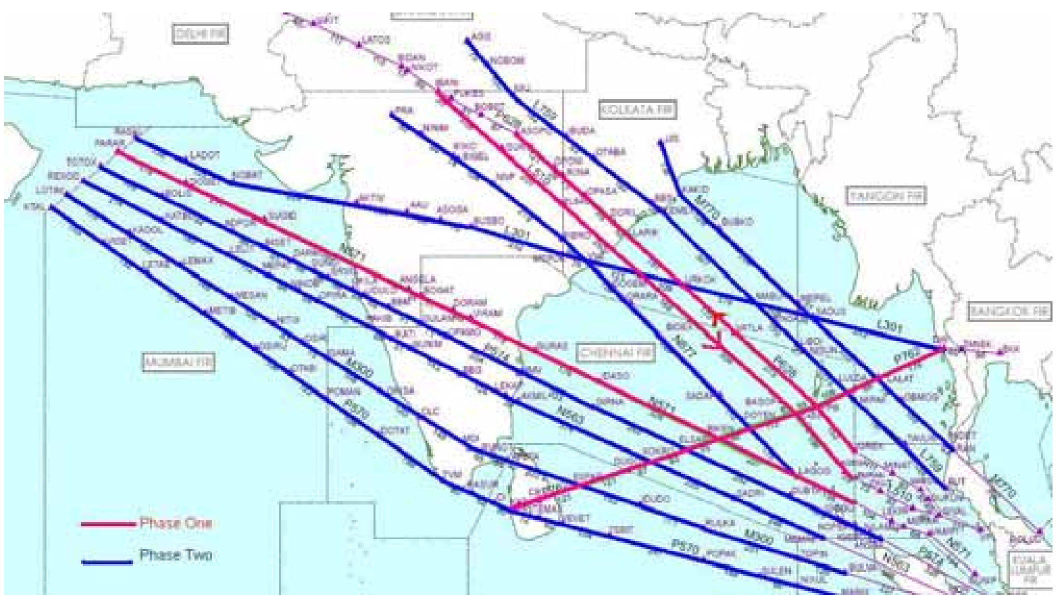

Figure 1: Bay of Bengal Airspace

3 Results of Data Collection

3.1 The December 2009 TSDs were obtained through Monitoring Agency for the Asia Region (MAAR) as agreed during BOB/RHS/TF-4 with the concurrence from the Regional Airspace Safety Monitoring Advisory Group (RASMAG). Table 1 shows the summary of TSD received.

State	FIR	Status
Bangladesh	Dhaka	No
India	Chennai	Yes
	Delhi	Yes
	Kolkata	Yes
	Mumbai	Yes
Malaysia	Kuala Lumpur	Yes
Maldives	Male	Yes
Myanmar	Yangon	Yes
Nepal	Katmandu	Yes
Pakistan	Karachi	Yes
	Lahore	Yes
Sri Lankan	Colombo	Yes
Thailand	Bangkok	Yes

Table 1: Summary of December 2009 TSD received

3.2 The Navigational Error reports submitted for the period July 2010 through December 2010 is shown in Table 2.

Month	Report Received from:					
	Bangkok	Chennai	Kolkata	Kuala Lumpur	Male	Mumbai
July 2010	Yes	Yes	Yes	Yes		Yes
August 2010	Yes	Yes	Yes	Yes		Yes
September 2010	Yes	Yes	Yes	Yes		Yes
October 2010	Yes	Yes	Yes	Yes		Yes
November 2010	Yes	Yes	Yes	Yes		Yes
December 2010	Yes			Yes	Yes	

Table 2: Record of Navigational Error reports for the period July 2010 through December 2010

3.3 The traffic-count reports submitted for the period July 2010 through December 2010 is shown in table 3.

Month	Report Received from:					
	Bangkok	Chennai	Kolkata	Kuala Lumpur	Mumbai	Yangon
July 2010	Yes	Yes	Yes	Yes	Yes	
August 2010	Yes	Yes	Yes	Yes	Yes	
September 2010	Yes	Yes	Yes	Yes	Yes	Yes

October 2010	Yes	Yes	Yes	Yes	Yes	Yes
November 2010	Yes	Yes	Yes	Yes	Yes	Yes
December 2010	Yes	Yes		Yes		Yes

Table 3: Record of Traffic-count reports for the period July 2010through December 2010

3.4 Table 4 presents the total traffic counts reported by month transiting all Bay of Bengal monitoring fixes for the period July 2010 through December 2010.

Monitoring Month	Total Monthly Traffic Count Reported over Monitored Fixes	Cumulative 6-Month Count of Traffic reported Over Monitored Fixes Through Monitoring Month
July 2010	5546	5546
August 2010	6057	11603
September 2010	5996	17599
October 2010	6297	23896
November 2010	5958	29854
December 2010	5514	35368

Table 4: Monthly Count of Monitored Flights Operating on Bay of Bengal ATS Routes for the period July 2010 through December 2010

3.5 Table 5 presents the cumulative totals of Large Lateral Deviations (LLDs) and Large Longitudinal Errors (LLEs) for the Monitoring Period July 2010 through December 2010.

Monitoring Month	Cumulative 6-Month Count of LLDs Reported Over Monitored Fixes Through Monitoring Month	Cumulative 6-Month Count of LLEs Reported Over Monitored Fixes Through Monitoring Month
July 2010	0	0
August 2010	0	0
September 2010	0	0
October 2010	0	0
November 2010	0	0
December 2010	0	0

Table 5: Monthly Count of LLDs and LLEs Reported on Bay of Bengal RNAV Routes for the period July 2010 through December 2010

3.6 It is of the utmost importance that relevant information be provided so that the safety assessment will be correct and effective. States are strongly urged to provide accurate data to facilitate the conduct of the safety assessment and to identify trends.

4 Risk Assessment and Safety Oversight

4.1 The safety assessment has been conducted using the internationally applied collision risk methodology which has supported airspace separation changes in several ICAO regions. As applied to a proposed separation change, the methodology consists of using a mathematical model to estimate the risk of midair collision for the proposed standard and comparing the estimated risk to a safety goal, the Target Level of Safety (TLS), which is a value of risk, agreed as tolerable by decision makers. If the estimated risk is less than the TLS, the outcome of applying the methodology is to support the proposed change.

4.2 The APANPIRG has adopted the value 5 x 10^{-9} fatal accidents per flight hour as the TLS for each separation dimension – lateral, longitudinal and vertical – in the Asia and Pacific Region.

4.3 <u>Factors Affecting the Risk of Collision in the Bay of Bengal Airspace</u>

4.3.1 One of the assumptions made in developing the collision risk model is that there is no independent surveillance of aircraft position. As a result, there is no allowance made for the value of air traffic control intervention to reduce the risk that a pair of aircraft loses planned separation. As a result, the risk estimates presented in this working paper should be considered conservative, that is, higher than is likely the case in the airspace.

4.3.2 As shown in Table 5, no 15NM or greater magnitude lateral errors and no longitudinal-error events have been reported on L301, L510, L759, M300, M770, N563, N571, N877, P570, P574, P628 and P762. India had also confirmed that that was no report of large lateral deviations since the implementation of 50NM lateral separation minima.

4.3.3 Operators and aircraft flying at or above FL280 on the Bay of Bengal routes require State RNP 10 approval. Compliance with this requirement is equivalent to stating that 95 percent of lateral deviations from route centerline are 10NM or less. In turn, under the assumptions made in the development of the RNP 10 standard, this containment percentage is equivalent to requiring that the standard deviation of lateral errors is roughly 5NM. Radar-based measurements of the positions of aircraft indicate that the standard deviation of lateral errors is on the order of 0.5 NM. As a result, decision makers should have high confidence that RNP 10 requirements for lateral navigational performance are being met. This estimate of standard deviation would seem to support the reported results of monitoring lateral errors: there has been no report of a 15NM or greater magnitude lateral error since 2002 in the Bay of Bengal Routes. Based on the radar-based evidence, it would seem that, if a 15NM or greater magnitude error would occur in the future, it would not be the result of typical navigational performance in the airspace.

4.4 <u>Estimate of the Collision Risk Model Parameters</u>

4.4.1 The lateral separation standard between ATS routes Phase 1: P628, L510, N571 and P762 and Phase 2: L301, L759, M300, M770, N563, N877, P570 and P574 are 50NM. The form of the lateral collision risk model used in assessing the safety of operations on these routes is:

$$N_{ay} = P_y(S_y)P_z(0)\frac{\lambda_x}{S_x}\left\{E_y(same)\left[\frac{\overline{|\dot{x}|}}{2\lambda_x}+\frac{\overline{|\dot{y}(S_y)|}}{2\lambda_y}+\frac{\overline{|\dot{z}|}}{2\lambda_z}\right]+E_y(opp)\left[\frac{\overline{V}}{\lambda_x}+\frac{\overline{|\dot{y}(S_y)|}}{2\lambda_y}+\frac{\overline{|\dot{z}|}}{2\lambda_z}\right]\right\}$$

4.4.2 The longitudinal separation standard for co-altitude aircraft on ATS routes P628, L510, N571 and P762 to be implemented is 50NM; the current longitudinal separation standard is either 10 minutes with Mach Number Technique (MNT) or 80NM otherwise for the routes.

4.4.3 The form of the longitudinal collision risk model used in assessing the safety of operations on the Bay of Bengal RNAV routes is:

$$N_{ax} = P_y(0)P_z(0)\frac{2\lambda_x}{\overline{|\dot{x}|}}\left[\frac{\overline{|\dot{x}|}}{2\lambda_x} + \frac{\overline{|\dot{y}(0)|}}{2\lambda_y} + \frac{\overline{|\dot{z}|}}{2\lambda_z}\right] \times \sum_{k=m}^{N}\sum_{K=k}^{M} Q(k) \times P(K > k)$$

4.4.4 Table 6 summarizes the value and source material for estimating the values for each of the inherent parameters of the internationally accepted Collision Risk Model (CRM). Appendix A provides the details in deriving the parameters used in the lateral and longitudinal collision risk model.

Model Parameter	**Description**	**Value Used in Preliminary Safety Assessment**	**Source for Value**
For Lateral Collision Risk Model			
N_{ay}	Risk of collision between two aircraft with planned 50-NM lateral separation	5.0 x 10^{-9} fatal accidents per flight hour	TLS adopted by APANPIRG as safety goal for changes in separation minima
S_y	Lateral separation minimum	50 NM	Current established lateral separation on EMARSSH routes
$P_y(50)$	Probability that two aircraft assigned to parallel routes with 50-NM lateral separation will lose all planned lateral separation	1.60 x 10^{-7}	Value required to meet exactly the TLS value of 5 x 10^{-9} fatal accidents per flight hour, given other parameters used in the preliminary safety assessment.
$P_z(0)$	Probability that two aircraft assigned to same flight level are at same geometric height	0.538	Commonly used in safety assessments
λ_x	Aircraft length	0.0399 NM	Merged December 2009 TSDs
λ_y	Aircraft wingspan	0.0349 NM	
λ_z	Aircraft height	0.0099 NM	

Model Parameter	Description	Value Used in Preliminary Safety Assessment	Source for Value
S_x	Length of the interval, in NM, used to count proximate aircraft at adjacent fix for occupancy estimates	+120 NM to -120 NM, equivalent to the +15-minute to -15-minute pairing criterion used in the preliminary safety assessment, for aircraft operating at 480 kts.	Arbitrary criterion which does not affect the value of risk
E_y(same)	Same-direction lateral occupancy	0.1	Using TSD 2009 of route parallel routes in the BOB region
E_y(opp)	Opposite-direction lateral occupancy	0.0	
$\overline{V}$	Aircraft along-track speed	490.2 kts.	December 2009 TSDs
$\left\|\overline{\dot{y}}\right\|$	Average relative speed of a pair of aircraft as they lose all planned 50-NM lateral separation	75 kts.	Reference 2
$\left\|\overline{\dot{z}}\right\|$	Average relative vertical speed of a co altitude aircraft pair assigned to the same route	1.5 kts.	Conservative value commonly used in safety assessments
For Longitudinal Collision Risk Model			
N_{ax}	Risk of collision between two co-altitude aircraft with planned longitudinal separation equal to at least the applicable minimum longitudinal separation standard	5.0×10^{-9} fatal accidents per flight hour	TLS adopted by APANPIRG for changes in separation minima
$P_y(0)$	Probability that two aircraft assigned to same route will be at same across-track position	0.2	Reference 5
$\overline{\left\|\dot{x}(m)\right\|}$	Minimum relative along-track speed necessary for following aircraft in a pair separated by m at a reporting point to overtake lead aircraft at next reporting point	75 knots	December 2009 TSDs
$\overline{\left\|\dot{y}(0)\right\|}$	Relative across-track speed of same-route aircraft pair	1 knot	Reference 5

Model Parameter	Description	Value Used in Preliminary Safety Assessment	Source for Value
M	Longitudinal separation minimum in NM	50NM	Goal to implement longitudinal separation minimum on ATS routes L510, N571, P628 and P762; used for all ATS routes in TLS compliance assessment
N	Maximum initial longitudinal separation in NM between aircraft pair which will be monitored by air traffic control in order to prevent loss of longitudinal separation standard	150NM	Arbitrary value of actual initial separation beyond which there is negligible chance that actual longitudinal separation will erode completely before next air traffic control check of longitudinal separation based on position reports
M	Maximum longitudinal separation loss in NM observed over all pairs of co-altitude aircraft	Dependent on initial longitudinal separation distance	December 2009 TSDs
$Q(k)$	Proportion of aircraft pairs with initial longitudinal separation k	Initial distribution of longitudinal separation for RNAV routes L642 and M771 used in RASMAG/9 safety assessment	December 2009 TSDs
$P(\ K > k)$	Probability that a pair of same-route, co-altitude aircraft with initial longitudinal separation of k NM will lose at least as much as k NM longitudinal separation before correction by air traffic control	Values derived to satisfy TLS of 50NM longitudinal separation minimum	December 2009 TSDs

Table 6: Summary of Risk Model Parameters Used in the CRM

4.5 Safety Oversight - Lateral

4.5.1 For the lateral safety assessment, all twelve routes were considered and the parameters used for the lateral collision risk model were calculated based on these twelve routes.

4.5.2 As the monitoring program for Bay of Bengal only commenced in July 2010, there were only six month of traffic being monitored. Therefore the risk assessment employs 2 method of analysis.

a) Sequential Sampling

As can be seen in figure 2, the number of large lateral deviations is plotted against the number of traffic being monitored. In order to have a high statistical confidence that the TLS is met, it would require at least 35000 monitored flights for the plot to be within the green zone. If there are no large lateral deviations reported after roughly 35000 flights, the plot enters the “green zone” which indicates that it meet the TLS. The cumulative total of flights monitored since July 2010 through December 2010 is 35368 (Please refer to Table 4). During this period, no large lateral deviations were reported for all twelve routes. The location of this plot fall within the “green zone’ which indicates that it meet the TLS.

4.5.3 In addition, since implementation of EMARSSH routes in Bay of Bengal in 2002, there had not been any report of incidents of large lateral deviations as mention in paragraph 4.3.2. If the traffic count is extrapolated to include the past years data, the plot will be well within the “green zone”.

4.5.4 As a result, it can be concluded with 95 percent statistical confidence that the continued use of 50NM lateral separation standard for all the twelve routes meet the TLS.

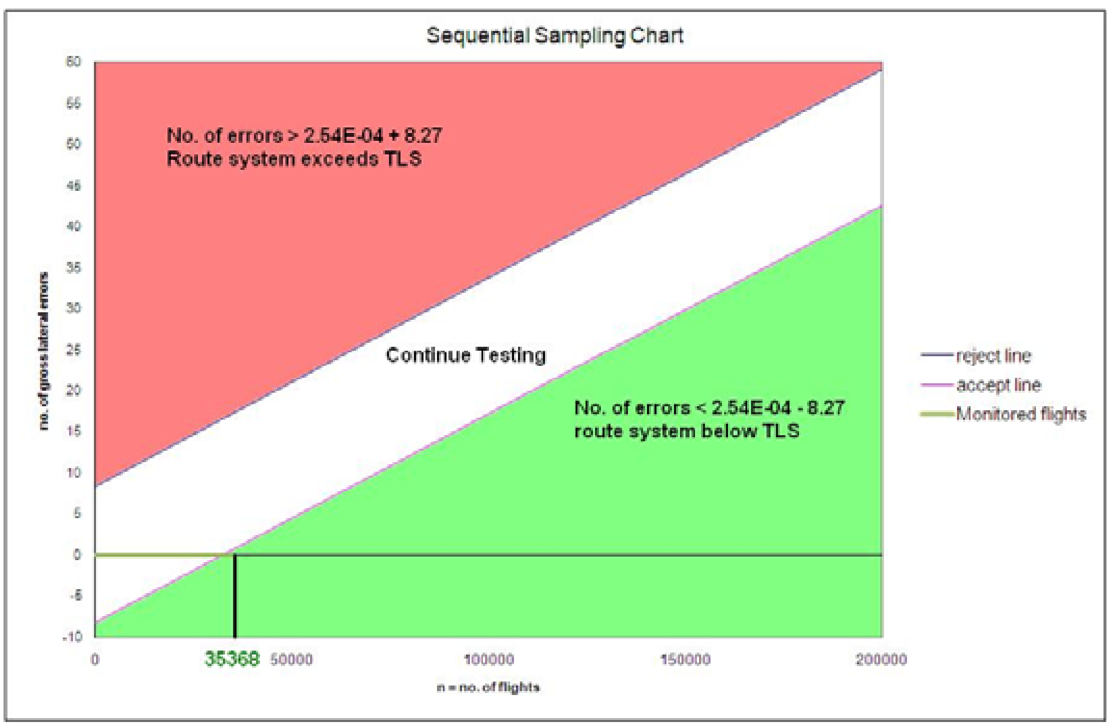

Figure 2: Sequential Sampling Approach to Demonstrate That Lateral Collision Risk for 50-NM Lateral Separation Standard Applied to the twelve routes

b) Direct Estimation

This approach was used as a confirmation that the lateral risk can meet the TLS. The lateral risk was estimated based on the number of navigation error reports received. Using this method, the lateral collision risk is estimated to be 1.95×10^{-10} which met the TLS.

4.6 Safety Oversight – Longitudinal

4.6.1 Given the values of $P_y(0)$, $P_z(0)$ and other risk model parameters, the value of the summation of $[Q(s) \cdot P(S \geq s)]$ in paragraph 4.4.3 for all values of s needed to meet the TLS is 4.24×10^{-8} for a value of T equal to 30 minutes, the interval between position updates allowing air traffic control to intervene, if necessary, to increase separation.

4.6.2 The resulting value for summation of $[Q(s) \cdot P(S \geq s)]$ for all values of s, 3.22×10^{-9}, is less than the required value of 4.24×10^{-8} required to meet the TLS. The longitudinal collision risk is then estimated to be 3.80×10^{-10}.

4.7 Table 7 summarises the result of the airspace oversight.

Type of risk	Risk estimation	TLS	Remarks
Lateral Risk	1.95×10^{-10}	5×10^{-9}	Below TLS
Longitudinal Risk	3.80×10^{-10}	5×10^{-9}	Below TLS

4.8 Figure 3 presents the results of the collision risk estimate for each month using the cumulative six month LLDs and LLEs report since July 2010.

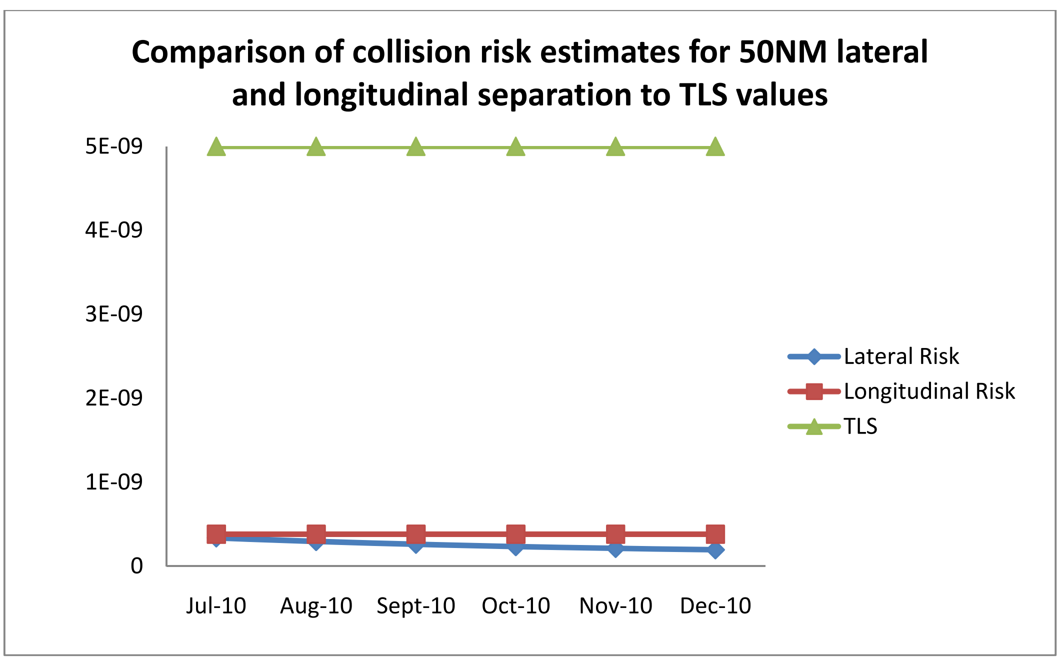

Figure 3: Assessment of Compliance with Lateral and Longitudinal TLS

4.9 Conclusions and Recommendations from the Safety Assessment concerning continued use of the 50-NM Lateral and the implementation of 50NM Longitudinal Separation Standard on four routes of Phase One Bay of Bengal

4.9.1 As can be seen, both the estimates of lateral and longitudinal risk shows compliance with the corresponding TLS values during the months of the monitoring period.

4.9.2 Since the assessment for the lateral TLS used traffic counts and LLDs reported for all twelve routes, it can be concluded that a 50NM lateral separation between any of the two routes would satisfy the lateral TLS.

5. Action by the Meeting

5.1 The Meeting is invited to:

a) Note that the safety assessment supports the continued use of 50NM RNP10 50NM lateral separation on L301, L510, L759, M300, M770, N563, N571, N877, P570, P574, P628 and P762.

b) Note that the safety assessment supports the implementation of RNP10 50NM longitudinal separation minima on L510, N571, P628 and P762.

Appendix A

1 Introduction

1.1 This appendix describes the methodology of the collision risk model applied in the safety assessment of the Bay of Bengal routes structure.

1.2 ICAO Collision Risk Methodology

1.2.1 In the context of a change in a separation standard, "safety assessment" means the application of the internationally accepted ICAO collision risk methodology. This methodology consists of using a general mathematical model to estimate the risk of midair collision due to loss of the planned separation standard and comparing the estimated risk to a level of risk which has been agreed as tolerable.

1.2.2 This tolerable level of risk is referred to as the "Target Level of Safety." The APANPIRG has adopted the value of 5×10^{-9} fatal accidents per flight hour as the Asia Region TLS for each separation dimension.

1.2.3 The safety assessment reported in this paper employs this TLS value.

2 Overview of Collision Risk Models

2.1 Detailed descriptions of the assumptions underlying the lateral and longitudinal risk models, as well as their mathematical derivations, may be found in reference 1. Statement of a few principal assumptions and definition of a few key concepts, however, will assist in understanding the safety assessment

2.2 One simplifying assumption used in development of the risk models is that aircraft shapes can be represented as rectangular parallelepipeds (that is, as blocks or slabs) with length, width and height equal, respectively, to a typical aircraft's metallic length, wingspan and height from the underside of the fuselage – with landing gear retracted – to the top of the vertical tail. Loss of separation in a dimension (longitudinal, lateral or vertical) is then equivalent to the centers of mass of two slabs (representing two aircraft under the simplifying assumption) being closer together than the corresponding size of the slab in that dimension (length, width or height).

2.3 When two aircraft are closer together than the size of the slab in a dimension, they are said to be in ***overlap*** in that dimension. Overlap corresponds to the loss of all planned separation in a dimension, but not necessarily to a collision (two aircraft could be 100 miles apart along a common route, and have lost all planned lateral separation). Thus, from the standpoint of collision risk modeling, two aircraft collide only when they are, at the same time, closer together by less than the size of the slab in each dimension. Two aircraft in such a condition is said to be in ***simultaneous overlap***

2.4 If P is the proportion of time that an aircraft pair is in simultaneous overlap in airspace and if t is the average time for a simultaneous overlap, then the rate of collisions, CR, between a typical pair of aircraft is:

$$CR = P/t$$

2.5 Another assumption used in the modeling is that navigational errors are independent in each dimension (that, the occurrence of a lateral error is not influenced by the occurrence of a longitudinal or vertical error). Under this assumption of independence, if P_x, P_y and P_z are the proportions of time that a typical pair of aircraft is in overlap in the longitudinal, lateral and vertical dimensions, then

$$P = P_x \bullet P_y \bullet P_z$$

2.6 That is, the proportion of time that a typical pair of aircraft is in simultaneous overlap is the product of the probabilities that the pair is in overlap in the longitudinal, lateral and vertical dimensions.

2.7 If t_x, t_y and t_z are, respectively, the average duration of a longitudinal, lateral and vertical overlap, the effect of other initiating assumptions is that:

$$t = t_x + t_y + t_z$$

2.8 That is, the average of duration of a simultaneous overlap is the sum of the average durations of longitudinal, lateral and vertical overlap.

2.9 It is then possible to express CR, the rate of collisions between a typical pair of aircraft in the airspace, as

$$CR = P_x \bullet P_y \bullet P_z / (t_x + t_y + t_z)$$

2.10 Multiplication of the collision rate, CR, which represents the rate of collision of pairs of aircraft, by a factor of 2 results in the rate of aircraft accidents, which are assumed to be always fatal. This multiplication then permits comparison of model-estimated risk expressed in fatal accidents per flight hour to the TLS, which was derived originally from worldwide fatal accident data reported to ICAO annually, and, as was noted in the previous section in citing the APANPIRG adoption of a TLS value, is also expressed in fatal accidents per flight hour.

2.11 Another of the assumptions underlying risk modeling is that, in a collision, one aircraft slab passes through the other completely. Although not consistent with the actual mechanism of a collision, this assumption simplifies the mathematics of deriving a risk model and has been shown to be an adequate means of estimating collision risk. If, for example, $\left|\dot{x}\right|$ represents the average speed of a pair of aircraft as they lose all planned longitudinal separation and λ_x is the length of the slab representing the aircraft in the longitudinal dimension, then t_x in the expression for the collision rate, CR, becomes $\lambda_x/\left|\dot{x}\right|$ (recall that distance = speed • time, or time = distance/speed).

2.12 The separation planned for an aircraft in a dimension, r, is represented by the symbol S_r in risk model expressions. Thus, for example, S_y represents planned lateral separation. Depending upon the separation standard being examined, there may or may not be ATC-planned separation in a dimension. For example, in the case of lateral separation, there is no planned longitudinal separation between two aircraft on laterally adjacent tracks. Likewise, in the application of vertical separation, there is no planned longitudinal separation between pairs of aircraft at adjacent flight levels on the same route.

2.13 It is important to note that there is a significant difference between no planned separation and planned separation of 0 nm or 0 ft. Thus, two aircraft on the same route at the same flight level are separated longitudinally by at least the minimum longitudinal separation standard, but have planned separation of 0 ft vertically and 0 NM laterally (which may be considered to be another way of saying "on the same route, at the same flight level). Using the symbols presented here, $P_y(0)$ and $P_z(0)$ are the mathematical representations of the probabilities of vertical and lateral overlap for two co altitude aircraft on the same route, with planned longitudinal separation at least equal to the longitudinal separation standard.

2.14 Having provided this general explanation of assumptions and terms, the mathematical form of the collision risk model applicable to the assessment of the safety a lateral separation standard is:

$$N_{ay} = P_y(S_y)P_z(0)\frac{\lambda_x}{S_x}\left\{E_y(same)\left[\frac{\overline{|\dot{x}|}}{2\lambda_x}+\frac{\overline{|\dot{y}|}}{2\lambda_y}+\frac{\overline{|\dot{z}|}}{2\lambda_z}\right]+E_y(opp)\left[\frac{\overline{V}}{2\lambda_x}+\frac{\overline{|\dot{y}|}}{2\lambda_y}+\frac{\overline{|\dot{z}|}}{2\lambda_z}\right]\right\}$$

(1)

and the form of the longitudinal risk model is:

(2)

The terms on the left side of these two equations, N_{ay} and N_{ax}, are the estimated lateral and longitudinal collision risks, respectively.

2.15 It is possible to see evidence of the "$P_x \bullet P_y \bullet P_z$" term in the collision rate expression above in each of the model forms, although some explanation below should make the three proportions, or probabilities, more evident. The term in "[ ]" in each model form is actually the "1/ (t_x + t_y + t_z)" term in the expression for the collision rate, CR, above. The specifics of the derivation which results in the sum of the three terms, each of which is the ratio of a relative speed to an aircraft dimension, are found in reference 1.

3. Parameters Common to the Lateral and Longitudinal Risk Models

3.1 Aircraft Length, Wingspan and Height: λ_x, λ_y and λ_z

3.1.1 These are the dimensions of the slab discussed above. Although not immediately obvious from the model forms shown above, it is a well established result that model-estimated risk increases in proportion to the increase in the size of the aircraft dimensions chosen for λ_x, λ_y and λ_z.

3.1.2 Table 2 of reference 2 presents the 15 aircraft types observed most frequently in the December 2009 TSDs. The most frequently occurring type is the B777 combined, accounting for 20 percent of the observations. The second most frequently observed type is the B738 at 15 percent. And in the category of B777s, the B77W (B777-300ER) ranks the second highest. Based on the results concerning aircraft types presented in reference 2, the safety assessment used the B-77W as the typical aircraft. The length, wingspan and height of this aircraft type are 0.0399 NM, 0.0349NM and 0.0099 NM, respectively.

3.2 Probability That Two Aircraft Assigned to the Same Flight Level Are at The Same Geometric Height: $P_z(0)$

3.2.1 The value of this parameter depends on the accuracy of the height-keeping in the airspace under analysis and, also, on the height of the aircraft type chosen to represent the typical aircraft. Since a value for $P_z(0)$ using the B-777-300 as the typical aircraft was not readily available, the safety assessment proceeded with the commonly used value of this parameter associated B-747-400. The value used in this safety assessment, 0.538, has been used previously for other Asia and Pacific Region risk assessments and reflects the positive effect of compliance with RVSM performance requirements on height-keeping accuracy.

3.3 The Average Relative Vertical Speed of Two Aircraft Assigned to the Same Flight Level: $|\bar{\dot{z}}|$

3.3.1 As in the case of all recent safety assessments conducted to support separation changes in the Asia and Pacific, the value used in this document is 1.5 knots. This value also reflects the effect of compliance with RVSM requirements on height-keeping performance.

4 Parameters Used Only in Estimation of Lateral Risk

4.1 Same- and Opposite-Direction Lateral Occupancies: E_y(same) and E_y(opp)

4.1.1 There is no planned longitudinal separation between two aircraft operating on parallel routes at the same flight level. As a result, the proportion of time spent in longitudinal overlap, P_x, for such aircraft pairs is the result of the relative aircraft density at the available flight levels on the routes, as opposed to loss or maintenance of a separation standard. A measure of this relative density is termed "occupancy," and provides quantitative insight into the likelihood that two co altitude aircraft on laterally adjacent routes will be in the same relative along-track position.

4.1.2 Since these parameters measure the density of aircraft pairs in the airspace, they are the means whereby risk modeling reflects differences in risk as the result of traffic-flow differences among different portions of airspace. It should be noted that occupancy is not expressed in a unit of traffic flow, such as the number of aircraft per year using a route. Rather, occupancy is a dimensionless number, like a probability, and increases with an increase in the number of pairs of aircraft on laterally adjacent routes which are at or near the same along-track positions. Insofar as an increase in airspace traffic volume results in an increase in these proximate aircraft pairs, occupancy increases with increasing flights using the airspace.

4.1.3 In the general airspace system, it is possible to have two co altitude aircraft on parallel tracks flying identical or reciprocal headings. These two possibilities for the headings of an aircraft pair operating on adjacent tracks are referred to as "same- and opposite and opposite-direction flight" in documentation on collision risk modeling. In the expression of the lateral risk model (equation (1), above), there are two parameters, representing the relative density of same- and opposite-direction pairs on adjacent routes, E_y(same) and E_y(opp), to account for these differences in headings.

4.1.4 From the December 2009 TSD, it can be seen that for all aircrafts on the twelve routes, uses similar flight level in the same direction. Therefore, E_y(opp) has the value zero. So in a conservative approach, this report will take the occupancy of the rest of the routes in the Bay of Bengal region has bi-directional traffic flow. Because of this, the expression for lateral risk reduces to:

$$N_{ay} = P(S_y) \bullet P_z(0) \bullet (\lambda_x/S_x) \bullet E_y(\text{same}) \bullet [\ ]$$

where the "[ ]" refers to the sum of ratios of relative speeds to aircraft dimensions in equation (1).

4.1.5 Availability of traffic movement data containing times reported by flights at fixes allows estimation of occupancy values for a volume of airspace. In the case of a pair of parallel routes, the basic estimation process is to:

a) count the number of proximate co altitude aircraft pairs on the routes at each pair of laterally adjacent fixes on the two routes, where "proximate" means that the reported times of a pair over the adjacent fixes are within some interval (usually, -15 minutes to +15 minutes) of each other,

b) for each pair of adjacent fixes, multiply the count of pairs by 2 to produce the number of proximate aircraft,

c) divide the number of proximate of aircraft by the total number of aircraft reporting times over the adjacent fixes, producing an estimate of occupancy for each fix-pair in the traffic movement data and

d) averaging the occupancy estimates for each fix-pair to produce overall occupancy estimates for the airspace which are, based on reported times over adjacent fixes on the two routes. The number of such pairs at each fix is multiplied by 2 to obtain a count of proximate aircraft, and then divided by the total number of aircraft on the two routes reporting times

4.2 Speed of the Typical Aircraft in the System: $\overline{V}$

4.2.1 This parameter represents the relative speed of two aircraft as they lose all planned separation while operating on parallel tracks at the same flight level on reciprocal headings. As noted earlier, there is no planned separation between co altitude aircraft on adjacent parallel tracks. Thus, aircraft operations on parallel tracks are independent of application of Mach number technique or any other actions by ATC to regulate the relative speed between aircraft. As a result, the relative speed between a typical pair of co-altitude aircraft on adjacent tracks reflects the range of speeds of individual aircraft in the airspace.

4.2.2 The Combined TSDs provided information to estimate the value of this parameter. All flights on the routes considered were used to produce separate estimates of the parameter. The results are shown in table 1.

Route	Fix-Pair	Distance Between Fix-Pair (NM)	Estimate of $\overline{V}$ (kts.)
L510	ELBAB – EMRAN	1005	490.2
N571	PARAR – IGOGU	2019	482.5
P628	OPASA - IGREX	930	481.3
P762	DUGOS –LULDA	606	472.0
M300	LOTAV - CLC	1035	483.9
Route	**Fix-Pair**	**Distance Between Fix-Pair (NM)**	**Estimate of $\overline{V}$ (kts.)**
P574	TOTOX – GULAM	874	481.1
P570	POMAN – KITAL	842	485.8
M770	PADET – MEPEL	514	482.9
N563	MEMAK – GUNIM	1145	482.4
L301	RINDA – MEPOK	594	444.4
L759	IBUDA – TAVUN	1139	471.7
N877	IGOGU – RIBRO	999	482.4

Table 1. Average Aircraft Speeds based on December 2009 TSD

4.3 Relative Across-Track Speed of Two Aircraft on Parallel Tracks As They Lose All Planned Lateral Separation: $|\bar{\dot{y}}|$

4.3.1 This parameter describes the relative speed of two aircraft as they lose all planned lateral separation. Since global experience has shown that the basic track-keeping accuracy of aircraft approved for RNP-10, as is required for operation, precludes the loss of 50-NM lateral separation due to normal navigational performance, the most reasonable circumstance associated with such a separation-loss event is a waypoint insertion error.

4.3.2 Nevertheless, a cautious approach to lateral risk estimation should include use of a value for $|\bar{y}|$ which corresponds to the loss of 50-NM lateral separation. Reference 3 contains such a value, 75 kts which has been used in the preliminary safety assessment.

4.4 Probability of Lateral Overlap: $P_y(50)$

4.4.1 This parameter describes the chance that two aircraft assigned to laterally adjacent routes which are separated by 50 NM will lose all planned lateral separation. Two approaches to treating $P_y(50)$ are possible in lateral collision risk assessment:

a) Collecting sufficient lateral navigational performance to estimate the value of $P_y(50)$ directly and then using this value in equation (1) with the other necessary parameter values to estimate lateral risk and then comparing the risk estimate to the TLS in order to demonstrate that the safety goal is satisfied, and

b) Using all the other necessary parameters in risk model, determining that value of $P_y(50)$ which will satisfy exactly the TLS and then demonstrating that this value is satisfied

4.4.2 The first approach requires, typically, many years of recording lateral errors in a parallel-track system in order to demonstrate with high statistical confidence that the TLS is satisfied.

4.4.3 The second approach takes advantage of the fact that there is a well-established relationship between the probability that two aircraft with planned 50-NM separation will lose all planned separation, $P_y(50)$, and the probability that an individual aircraft will commit a lateral error of 25 NM or more in magnitude. Table B-1 of Attachment B to reference 4 is an example of this approach for the case of planned 30-NM lateral separation between parallel routes.

4.4.4 In applying this second approach, a competent authority organizes a program to monitor lateral errors and employs a statistical decision-making process to evaluate the monitoring results. The decision-making process incorporates a predetermined level of statistical confidence that the TLS is met and uses the observed frequency of 25-NM or greater lateral errors to signal, at any time in the monitoring program, one of three decisions:

a) the TLS is satisfied,

b) lateral navigational performance is not at the level required to meet the TLS, or

c) there is not yet sufficient monitoring data available to conclude that the TLS has been satisfied

4.4.5 This approach to demonstrating compliance with the lateral TLS has been applied successfully in parallel-track systems in several portions of worldwide airspace and has been adopted in the preliminary safety assessment. Details will be provided after review of the lateral risk model parameter values used in the preliminary safety assessment.

5. Lateral Safety Assessment – Sequential Sampling

5.1 Assuming that December 2009 is a month representative of the traffic counts on the twelve routes, it is reasonable to conclude that there will be, in a year, about 50000 flights available for monitoring on the twelve routes. The required value of $P_y(50)$ shown in table 6 of the main working paper, 1.60×10^{-7}, implies that it would be necessary to have many years of navigational performance observations from the monitoring program in order to show with high confidence that the TLS is being met.

5.2 Taking the approach outlined in the section of this paper, which addresses the demonstration of compliance with the TLS through analysis of GNEs, can shorten the process considerably. The approach is based on a statistical technique known as sequential sampling and employs a control chart. As proposed for application in the case of continued safe use of the 50-NM lateral separation standard on the twelve routes demonstrated by compliance of risk with the TLS, and the standard for quality is an acceptably low rate of occurrence of GNEs.

5.3 Figure 1 shows a control chart which mechanizes the sequential sampling process using the parameter values shown in Table 6 of the main working paper, with the assumption that decision-makers requires a 95 percent statistical confidence that the TLS is met. The chart permits plotting of GNEs on the vertical axis against numbers of observations from the monitoring program on the horizontal axis.

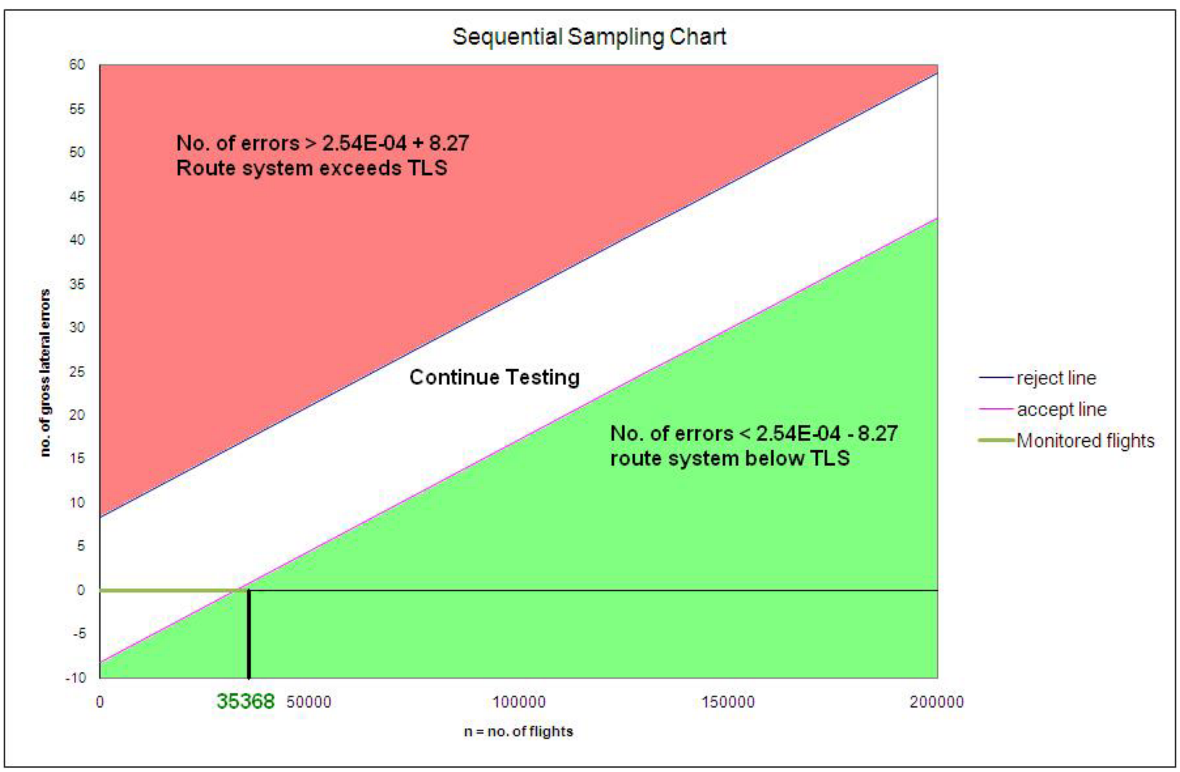

Figure 1. Sequential Sampling Approach to Demonstrating That Lateral Collision Risk for 50-NM Lateral Separation Standard Applied to the four routes

5.4 The two straight lines of identical slope in the figure divide the chart into three regions, corresponding to the three decisions possible after entering each monitoring observation onto the chart:

a) the number of GNEs recorded during observation of the total number of flights monitored lead to the conclusion that the TLS is met (the plot of GNEs versus number of monitored flights enters the region below the lower sloped line),

b) the total number of flights monitored is not yet sufficient to conclude that the TLS is met (the plot of GNEs versus number of monitored flights is between the two sloped lines), or

c) navigational performance, as measured by the number of GNEs recorded for the number of flights monitored, is not adequate to meet the TLS and, therefore, investigations must be done to look for any sources of systematic error which, if found, must be eliminated (the plot of GNEs versus number of monitored flights enters the region above the upper sloped line).

5.5 In the interim, unless the plot of GNEs versus monitored flights enters the uppermost region of the chart, use of the 50-NM lateral separation standard is justified, in the sense that system operation has not yet produced enough monitoring observations to conclude that the TLS is met – but there is no indication that the TLS will not be satisfied eventually.

6. Parameters Used Only In Estimation of Longitudinal Risk

6.1 <u>Background Information from the Merged December 2009 TSDs Useful for the Estimation of Longitudinal Collision Risk</u>

6.1.1 All flights on the four routes of Phase 1 were examined between a specific segment, given that these segments begins and ends with fixes that the aircraft are required to report. A pair of aircraft was included in the examination of relative along-track speed if the two aircraft were at the same flight level and passed over the entry fix within 60 minutes of each other. The same-altitude/close-in-time criteria were intended to minimize the effects of wind on the estimation of relative speeds. Application of these criteria resulted in 35 L510 pairs, 232 N571 pairs, 344 P628 pairs and 49 P672 pairs available for the examination of relative speed.

6.1.2 All flights on the four routes were used to estimate the average transit time between the fix-pairs. Table 2 shows the results of this investigation.

Route	Fix-Pair	Average Speed (kts.)	Average transit Time (mins.)
N571	OPASA – IGREX	482.5	251.6
L510	ELBAB – EMRAN	490.2	123.1
P628	PARAR - IGOGU	481.3	116.2
P762	DUGOS - LULDA	472.0	77.1

Table 2: Average Speeds and Transit Times on the four routes

6.2 Probability That Two Aircraft Assigned to the Same Route and Flight Level Are in Lateral Overlap: $P_y(0)$

6.2.1 As can be seen from inspection of the longitudinal collision risk model presented in equation (2) above, risk is directly proportional to the value of this parameter. That is, as the value of this parameter increases, longitudinal risk increases.

6.2.2 Experience has shown that use of the Global Positioning System (GPS) in determining aircraft position produces highly accurate results. In turn, these accurate position estimates produce smaller lateral errors from course. Smaller lateral errors produce higher values of $P_y(0)$, thus increasing the risk of losing longitudinal separation, all other things being equal. This "navigation paradox" – improvements in navigation in one dimension increase collision risk in another – is well known.

6.2.3 The ICAO Reduced Vertical Separation Minima Implementation Task Force initiated work to introduce the RVSM into Pacific FIRs in November 1998. At its Third Meeting, the Task Force was presented with reference 5 which described analysis of cross track errors exhibited by B-747-400 aircraft known to be using GPS for position-determination. Based on analysis of these errors, reference 10 reported that, if all Pacific operations were conducted by B-747-400 aircraft equipped with GPS, the estimated value of $P_y(0)$ would be 0.3868. In contrast, if there were no GPS-equipped aircraft in the airspace, the value would be only 0.019. Reference 5 provided evidence that about 27 percent of Pacific operations at the time of the RVSM/TF/3 meeting were conducted by GPS-equipped aircraft. The corresponding value of $P_y(0)$ adopted by the Task Force was 0.052.

6.2.4 Table 2 of reference 2 presents the 15 aircraft types which, taken together, account for 91 percent of the operations on the twelve Bay of Bengal routes found in the merged December 2009 TSDs. From this table, it is possible to conclude that at least 50 percent of the operations on these routes were conducted by aircraft types known to be equipped with GPS.

6.2.5 Based on this percentage of GPS equipage, the preliminary safety assessment used a value of 0.20 for $P_y(0)$.

6.3 Level - $|\dot{y}|$ Relative Across-Track Speed of Two Aircraft Assigned to the Same Route and Flight

6.3.1 The effect of GPS in the navigation solution is to reduce aircraft cross-track velocity. Reference 5 provides the value of relative cross-track speed, 1 knot, used in the current estimation of longitudinal risk

6.4 Probability of Longitudinal Overlap: P_x

6.4.1 The remaining terms in the longitudinal risk model address the estimation of P_x, the probability of a pair of same-route, co-altitude aircraft loses all planned longitudinal separation.

6.4.2 If Q(s) is the proportion of aircraft pairs separated initially by s in the longitudinal dimension and $P(S \geq s)$ is the probability of losing at least the separation s, then the probability of losing all longitudinal separation between a pair of aircraft, Px , can be represented by:

P_x = (factor dependent on initial separation s) •
summation of $[Q(s) \cdot P(S \geq s)]$ for all values of s.

6.4.3 The term in "( )" (factor dependent on initial separation) is represented in equation (2) above by $(2\lambda_x / |\dot{x}|)$, where the relative speed is that necessary for two aircraft to lose longitudinal separation, S_x within a time T. The value of T is usually taken to be the time between successive waypoint reports, under the assumption that air traffic control will intervene to correct the case of a serious loss of longitudinal separation at the next waypoint. In oceanic airspace such as the Pacific, T is roughly 60 minutes.

6.4.4 Further investigation of the four routes in Phase 1, it can be seen that the longest time between reporting points is on N571 at approximately 40 mins. If two aircraft were separated longitudinally by 50 NM at a required reporting point, the relative speed difference required to lose exactly 50 NM within 40 minutes is 75 kts. The data on relative speeds presented in table 2 suggest that such an overtake speed is highly unlikely.

6.4.5 In longitudinal risk estimation, the term Q(s) is, typically, the distribution of initial separations between co-altitude same-route aircraft pairs on entering the airspace. The term $P(S \geq s)$, the chance of losing all planned longitudinal separation of s or more, is usually is estimated from data on longitudinal separation erosion available from airspace records.

6.4.6 The merged December 2009 TSDs were used to gain insight into both the initial distribution of along-track separation and also separation decrease or increase during operations on the four routes. It will be convenient to use the term "separation loss or gain" to describe the decrease or increase in initial separation, but, in using this term, there should be no misunderstanding that "separation loss" means loss of all initial longitudinal separation between an aircraft pair.

6.4.7 The TSD data were processed to determine pairs of co altitude aircraft on the four routes of Phase 1. Aircraft were considered a pair and counted as they enter the entry point. And as they exit the exit point, the final separation is found. The following Table 3 shows the routes, entry and exit points and no. of pairs identified.

Route	Entry	Exit	No. of pairs
L510	ELBAB	EMRAN	35
N571	PARAR	IGOGU	232
P628	IGREX	OPASA	344
P672	DUGOS	LULDA	49

Table 3 : No. of pairs of aircraft identified

6.4.8 Aircraft were considered a pair when they pass over the entry point within 60 minutes of each other. The numbers were computed and the data summarized as counts of initial-separation/separation-change. The combined total of which contributed to the initial-separation/separation-change analysis is 660 pairs.

6.4.9 Implementation of a 50NM longitudinal separation standard will result in the application of a distance-based separation on L510, N571, P628 and P762. All data describing the results of current longitudinal separation practice which were available for the safety assessment are in units of time. As a result, the safety assessment will examine the likelihood that a 6-minute longitudinal separation standard will meet the TLS.

6.4.10 Collision risk analysis focuses on the loss of all separation, which is equivalent to a collision. Therefore, to meet the TLS, it is necessary to determine whether the summation of $[Q(s) \cdot P(S \geq s)]$ for all values of s is less than 4.24×10^{-8}. From the data in figure 2, initial separation values near the minimum of 10 minutes occur at lower frequencies and increase in frequency up to about 20 minutes. After that point, the frequencies of larger initial separations decrease.

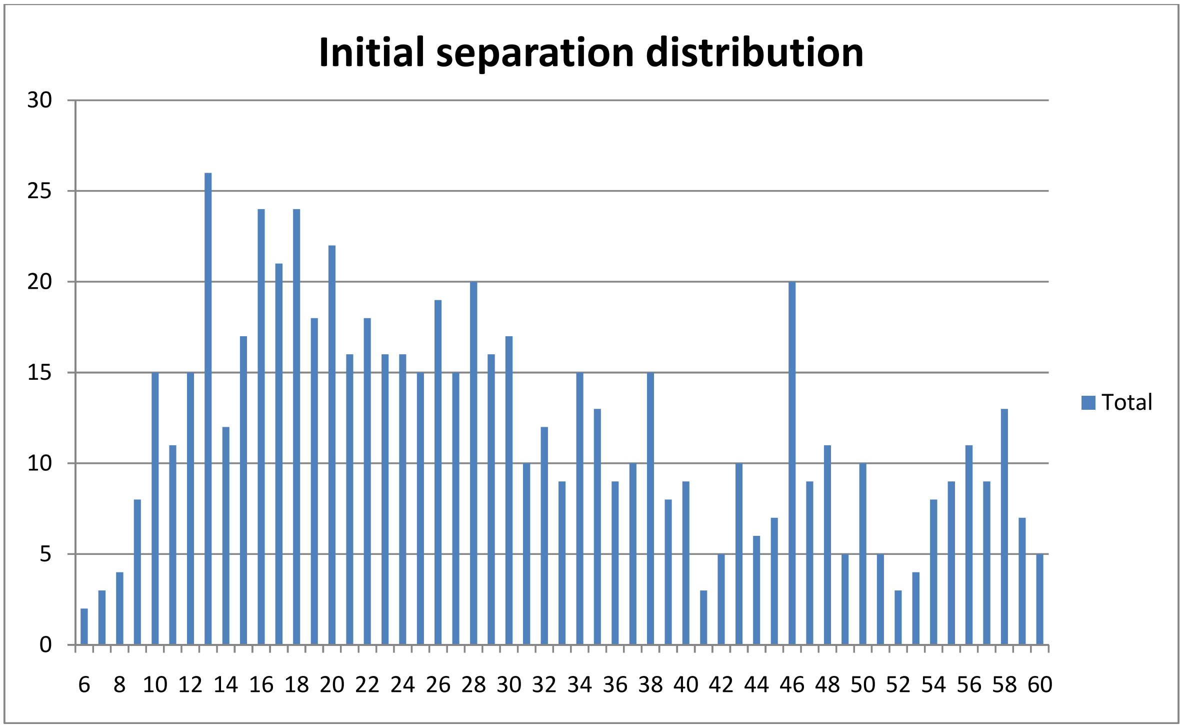

Figure 2: Count of aircraft's initial separation

6.4.11 In the safety assessment, this same characteristic of initial separation values is assumed to pertain when 6 minutes is the minimum longitudinal separation standard with the implementation of 50NM longitudinal separation.

6.4.12 From Figure 2, separation losses for smaller initial separation values were observed to be small relative to the current longitudinal separation standard of 10 minutes. This same characteristic is assumed to apply when the 50NM, or 6-minute, minimum longitudinal separation standard is in effect.

6.4.13 Figure 2 demonstrate the effectiveness of applying the Mach number technique. As a result, a larger separation loss, 6 minutes or more, between the two aircraft of a pair would require that the at least one of the aircraft exhibit an unexpected change in separation of three minutes or more for which Mach number technique did not account. It would seem that such a significant change would have to be the result of substantial wind gusts affecting only one member of the pair, or some aircraft system failure resulting in a major change in true airspeed since the last position update.

6.4.14 Results from the Bay of Bengal monitoring program are that there was no unexpected change in longitudinal separation of three minutes or more observed for pairs of aircraft during the period July 2010 through December 2010. These results indicate, further, that there was no instance of a significant individual-aircraft longitudinal error – defined as a 3-minute or greater unexpected deviation between a pilot forecast of next waypoint and the actual report at that fix – reported for any of the 35368 flights monitored.

6.4.15 The fact that there were no individual-aircraft unexpected changes in longitudinal position reported in 35368 flights does not mean that the rate at which such errors occur is 0.0. Rather, the conclusion to be drawn from the monitoring data is that the true rate of occurrence of significant individual-aircraft longitudinal errors is so small that none were produced in this sample

6.4.16 Given the monitoring program results showing that they are rare events, the probability of occurrence of significant individual-aircraft longitudinal errors can be described by a Poisson distribution, where it is assumed that the rate of significant longitudinal errors decreases as the number of flights increase in a way that keeps the product of the two constant. Assuming that each flight is an independent opportunity for a significant individual-aircraft longitudinal error, no occurrence of this event in 35368 operations is, with 95 percent statistical confidence, consistent with a true rate of occurrence of 8.51×10^{-7} significant longitudinal errors per flight, or less. It is not possible for a pair of aircraft to lose 6 minutes of separation, the equivalent of 50 NM, unless there is an unexpected change in longitudinal position of 3 minutes or more associated with at least one aircraft. As a result, this monitoring-program finding can provide insight into the value of $P(S \geq s)$, the probability that an aircraft pair loses at least as much as longitudinal separation as it has on entering a route.

6.4.17 Given the sparse data on unexpectedly large individual-aircraft longitudinal errors from the monitoring program, it is not possible to propose a probability distribution that characterizes the occurrence of 3-minute or greater individual-aircraft longitudinal errors, that is, the probability of a 3-minute error, 4-minute error, 5-minute error and so on. In attempting to estimate $P(S \geq s)$, it will be assumed that a significant individual-aircraft longitudinal error is equally likely to contribute to an unexpected gain or loss of separation between an aircraft pair. Taking a conservative view, it will be assumed that it is possible to have a significant individual-aircraft longitudinal error as large as 6 minutes, which would require a 100-knot unexpected speed difference from that used by air traffic control to plan separation with other aircraft. Again to be conservative, it will be assumed that 3-minute, 4-minute, 5-minute and 6-minute significant individual-aircraft longitudinal errors are equally likely. As a result:

$$
\begin{aligned}
P(\text{3-minute significant individual-aircraft longitudinal error}) &= 0.25 * 8.51 \times 10^{-7} \\
&= 2.13 \times 10^{-7} \\
&= P(\text{4-minute error}) \\
&= P(\text{5-minute error}) \\
&= P(\text{6-minute error})
\end{aligned}
$$

6.4.18 Again, to be conservative, it will also be assumed that the probability of a zero-minute, 1-minute and 2-minute unexpected losses or gains in separation due to significant individual-aircraft longitudinal error will be identical and equal to $(0.2 - 8.51 \times 10^{-7}) \approx 0.2$.

6.4.19 With these assumptions, 12 minutes is the maximum initial longitudinal separation value which can be lost due to unexpected individual-aircraft longitudinal errors, and would result only when the lead aircraft of a pair loses 6 minutes and the other gains 6 minutes. Because individual-aircraft longitudinal errors are assumed independent between aircraft, the probability that this would happen is the product of the probabilities that each aircraft would have a significant longitudinal error of 6 minutes, or,

$$P(S \geq 12) = P(S = 12) = (2.13 \times 10^{-7}) \bullet (2.13 \times 10^{-7}) = 4.5 \times 10^{-14}$$

This probability is so small that it can be neglected. Likewise, the contribution to summation of [Q(s) · P(S ≥ s)] for all values of s made by initial separation values, s, of 11 minutes, 10 minutes and 9 minutes can be disregarded.

6.4.20 As a result, only 8 minutes, 7 minutes and 6 minutes initial separation values require examination in light of unexpected losses or gains in separation due to significant individual-aircraft longitudinal error. Assuming that Aircraft 1 is following Aircraft 2, the combinations of unexpected losses or gains in separation necessary for two aircraft to lose 8 minutes of initial separation are shown in Table 4:

Aircraft 1 Unexpected Gain (+) or Loss (-) (minutes)	**Aircraft 2 Unexpected Gain (+) or Loss (-) (minutes)**	**Resulting Separation (minutes)**
+6	-2	0
+5	-3	0
+4	-4	0
+3	-5	0
+2	-6	0

Table 4: All Combinations of Unexpected Separation Loss and Gain Resulting in Loss of Exactly 8 Minutes Initial Separation

6.4.21 The value P(S = 8 minutes) is the sum of the products of the probabilities of separation loss and gain in the rows of the table. For example, the contribution to P(S = 8) of the first row is:

$$(2.13 \times 10^{-7}) \bullet (0.2) = 4.26 \times 10^{-8}$$

The contribution of the last row is also 4.26×10^{-8}. The contribution of the products of the probabilities in the other rows is the negligible value 4.5×10^{-14}. Thus, the value of P(S = 8 minutes) is $2 \bullet 4.26 \times 10^{-8}$, or 8.52×10^{-8}.

6.4.22 The value of P(S = 7) can be determined in a similar manner and is $4 \bullet 4.26 \times 10^{-8} = 1.7 \times 10^{-7}$. The value for P(S = 6) is $6 \bullet 4.26 \times 10^{-8} = 2.55 \times 10^{-7}$.

6.4.23 Using the relative frequencies of initial separation values determined from the data shown in figure 5, it is now possible to calculate the quantity summation of [Q(s) · P(S ≥ s)] for all values of s. Table 5 shows the results.

Initial Separation, s (minutes)	Proportion of initial separations, corrected for Mach number, with separation s, Q(s)	P(S ≥ s)	Q(s) • P(S ≥ s)
6	0.0030	5.11×10^{-7}	1.55×10^{-9}
7	0.0045	2.55×10^{-7}	1.16×10^{-9}
8	0.0060	8.51×10^{-8}	5.16×10^{-10}
9 and beyond	0.0	0.0	0.0
Sum Q(s) • P(S ≥ s)			3.22×10^{-9}

Table 5: Computation of the Summation of Q(s) • P(S ≥ s) for All Values of Initial Separation, s

6.4.24 The resulting value for summation of [Q(s) • P(S ≥ s)] for all values of s, 3.22×10^{-9}, is less than the required value of 4.24×10^{-8} required to meet the TLS.

6.4.25 There are various types of data errors observed in the TSD. This could indicate some sort of mach no. technique used, radar monitoring or it could be data integrity issues. There are 3 instances of aircraft pair having initial separation of zero and one instance of aircraft pair having 3 mins initial separation and 4 mins initial separation. There were also instances of succeeding aircraft overtaking preceding traffic. Table 6 shows the count of the various types of data observed in the TSD.

Type	Airways			
	L510	N571	P628	P762
Error	0	18	2	0
Overtake	0	21	6	2
Actual Pairs	35	232	344	49

Table 6: Count of the various types of data errors observed in the TSD

7 Outcome of the Preliminary Longitudinal Safety Assessment

7.1 Examination of the loss or gain in separation in the previous section showed that there is no reason to be concerned about either the current longitudinal separation minimum of 80 NM, or 10 minutes with application of Mach number techniques. That examination also showed that there is no evidence of the loss of 6 minutes or more separation, the equivalent of 50 NM separation given the average speed determined for the flights in the December 2009 TSDs, for aircraft with smaller values of initial longitudinal separation.

7.2 The longitudinal collision risk is estimated to be 3.80×10^{-10} which does not exceed the TLS.

References

1. *Manual on Airspace Planning Methodology for the Determination of Separation Minima*, First Edition, Doc 9689-AN/953, International Civil Aviation Organization, Montréal, 1998.

2. Information Paper on the Examination of Operations Conducted On ATS Routes in the Bay of Bengal Region (BOB/RHS/TF/5)

3. "Safety Assessment for the South China Sea Airspace Where a 60-NM Lateral Separation Minimum Is Applied," The Seventh Meeting of the Regional Airspace Safety Monitoring Advisory Group (RASMAG/7), Bangkok, Thailand, 4 – 8 June 2007, WP/18.

4. Annex 11 of the Convention on International Civil Aviation, *Air Traffic Services*, Thirteenth Edition, International Civil Aviation Organization, Montreal, July 2001.

5. "A Summary of Airspace Characteristics Related to the Operational Trial of 30/30NM lateral and longitudinal separation standards in the Oakland Oceanic Flight Information Region (FIR)," Twenty-fifth meeting of the informal pacific ATC coordinating group (IPACG/25), Tokyo, Japan, 24-27 October 2006, IP-4 Rev.1.