*International Civil Aviation Organization*

**The 19th Meeting of the Regional Airspace Safety Monitoring Advisory Group (RASMAG/19)**

Pattaya, Thailand, 26 – 30 May 2014

**Agenda Item 3: Reports from Asia/Pacific RMAs and EMAs**

# PRE-IMPLEMENTATION SAFETY ASSESSMENT FOR RNP4 OPERATIONS IN SOUTH CHINA SEA AIRSPACE

(Presented by Singapore)

**SUMMARY**

This paper presents the pre-implementation horizontal safety assessment for RNP 4 operations (30NM lateral and 30NM longitudinal separation) report from the South East Asia Safety Monitoring Agency (SEASMA) for operations on the six major air traffic service routes within the South China Sea for the period 1 Jan 2013 through 31 Dec 2013. The assessment concludes that the Asia and Pacific Region Target Level of Safety (TLS) values established for 30NM lateral and 30NM longitudinal separation standards were satisfied for the six-route system with high statistical confidence during the 12-month period examined.

This paper relates to –

**Strategic Objectives:**
*A: **Safety** – Enhance global civil aviation safety*

## 1. INTRODUCTION

1.1 This working paper is an assessment to determine if RNP4 flight operations on the six major South China Sea routes comply with APANPIRG-agreed Target Level of Safety (TLS) values for 30NM lateral and 30NM longitudinal separation standards. The examination period covered is from 1 Jan 2013 till 31 Dec 2013. The TSD for Dec 2013 was used for this risk assessment.

## 2. DISCUSSION

<u>Executive Summary</u>

2.1 The current lateral separation standard applied in the six South China Sea routes – L642, M771, N892, L625, N884 and M767 – is 50NM. The longitudinal separation minimum applied is 50NM for pairs of co-altitude aircraft on L642 and M771 and 10 minutes, with Mach number technique applied, and 80NM RNAV for the other four routes. As more aircraft are equipped with RNP4 capabilities and region is continuing to experience traffic growth, there is a push to move to RNP 4 operations to maximize airspace usage without compromising safety.

2.2 **Table 1** presents the lateral and longitudinal collision risk estimate trends for RNP 4 operations (30NM lateral and longitudinal separation) for South China Sea airspace during the period January 2013 to December 2013.

| | | | |
|---|---|---|---|
| **Risk** | **Risk Estimation** | **TLS** | **Remarks** |
| Lateral Risk | **$0.255 \times 10^{-9}$** | $5.0 \times 10^{-9}$ | **Below TLS** |
| Longitudinal Risk | **$0.705 \times 10^{-9}$** | $5.0 \times 10^{-9}$ | **Below TLS** |

**Table 1**: South China Sea Airspace Horizontal Risk Estimates

2.3 **Table 2** contains a summary of Large Lateral Deviations (LLD) and Large Longitudinal Errors (LLE) received by SEASMA for the South China Sea airspace.

| Code | Deviation Description | No. |
|---|---|---|
| E | ATC Coordination errors | 4 |
| Total | | 4 |

**Table 2:** Summary of South China Sea Airspace LLD and LLE Reports

2.4 **Figure 1** presents the 30NM lateral and longitudinal collision risk estimate for South China Sea airspace during the period January 2013 to December 2013.

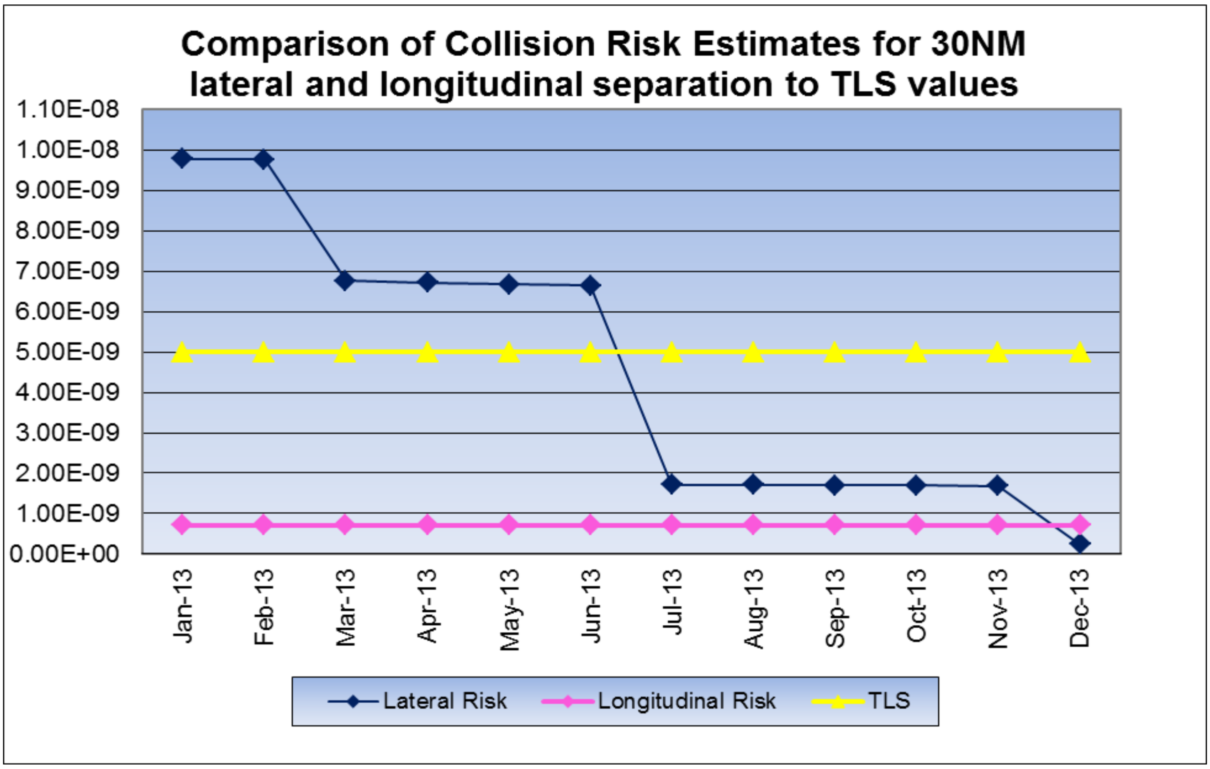


**Figure 1:** Collision risk estimates for 30M Lateral and Longitudinal

## 3. ACTION BY THE MEETING

3.1 The meeting is invited to:

a) note the information contained in this paper;

b) note the RNP 4 performance on the South China Sea RNAV routes is compliant with the APANPIRG-agreed lateral and longitudinal TLS to allow for such operations in South China Sea airspace; and

c) discuss any relevant matters as appropriate.

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## Appendix: SEASMA Safety Report for the South China Sea

Background

1.1 The lateral separation standard applied in the six South China Sea routes – L642, M771, N892, L625, N884 and M767 – is 50NM. The longitudinal separation minimum applied is 50NM for pairs of co-altitude aircraft on L642 and M771 and 10 minutes, with Mach number technique applied, or 80NM RNAV for the rest of the four routes. As more aircraft are equipped with RNP4 capabilities and region could proceed to RNP 4 operations.

Results of Data Collection

1.2 The fidelity of large-error and traffic-count reporting by each responsible air navigation service provider (ANSP) for the period Jan 2013 through Dec 2013 is shown in **Table 1**.

| **Month** | **Report Received from:** | | |
|---|---|---|---|
| | **Hong Kong, China** | **Philippines** | **Singapore** |
| Jan 2013 | Yes | Yes | Yes |
| February 2013 | Yes | Yes | Yes |
| March 2013 | Yes | Yes | Yes |
| April 2013 | Yes | Yes | Yes |
| May 2013 | Yes | Yes | Yes |
| June 2013 | Yes | Yes | Yes |
| July 2013 | Yes | Yes | Yes |
| August 2013 | Yes | Yes | Yes |
| September 2013 | Yes | Yes | Yes |
| October 2013 | Yes | Yes | Yes |
| November 2013 | Yes | Yes | Yes |
| December 2013 | Yes | Yes | Yes |

**Table 1**: Record of ANSP Reporting by Month for Period Jan 2013 through Dec 2013

Reported Traffic Counts for Jan 2013 through Dec 2013 Monitoring Period

1.3 **Table 2** presents the total traffic counts reported by month transiting all South China Sea monitoring fixes for the period Jan 2013 through Dec 2013.

| **Monitoring Month** | **Total Monthly Traffic Count Reported Over Monitored Fixes** | **Cumulative 12-Month Count of Traffic Reported Over Monitored Fixes Through Monitoring Month** |
|---|---|---|
| January 2013 | 9983 | 119637 |
| February 2013 | 9666 | 119916 |
| March 2013 | 10733 | 120590 |
| April 2013 | 10711 | 121297 |
| May 2013 | 11147 | 122159 |
| June 2013 | 10744 | 122891 |
| July 2013 | 10767 | 123458 |
| August 2013 | 10824 | 124060 |
| September 2013 | 10272 | 124350 |
| October 2013 | 11139 | 125190 |
| November 2013 | 10689 | 125633 |
| December 2013 | 11484 | 126358 |

**Table 2**: Monthly Count of Monitored Flights Operating on South China Sea RNAV Routes for the period Jan 2013 through Dec 2013

Monitoring Reports

1.4 **Table 3** presents the cumulative totals of Large Lateral Deviations (LLDs) and Large Longitudinal Errors (LLEs) LLDs and LLEs for the period January 2013 until December 2013.

| Monitoring Month | Monthly Count of LLDs Reported Over | Cumulative 12-Month Count of LLDs Reported Over Monitored Fixes | Monthly Count of LLEs Reported Over Monitored Fixes | Cumulative 12-Month Count of LLEs Reported Over Monitored Fixes |
|---|---|---|---|---|
| January 2013 | 0 | 4 | 0 | 0 |
| February 2013 | 0 | 4 | 0 | 0 |
| March 2013 | 0 | 3 | 0 | 0 |
| April 2013 | 0 | 3 | 0 | 0 |
| May 2013 | 0 | 3 | 0 | 0 |
| June 2013 | 0 | 3 | 0 | 0 |
| July 2013 | 0 | 1 | 1 | 1 |
| August 2013 | 0 | 1 | 0 | 1 |
| September 2013 | 0 | 1 | 2 | 3 |
| October 2013 | 0 | 1 | 1 | 4 |
| November 2013 | 0 | 1 | 0 | 4 |
| December 2013 | 0 | 0 | 0 | 4 |

**Table 3**: Monthly Count of LLDs and LLEs Reported on South China Sea RNAV Routes for the period Jan 2013 through Dec 2013

Risk Assessment and Safety Oversight

1.5 This section presents the results of safety oversight to the lateral and longitudinal separations standards applied in the South China Sea RNAV route structure. Analysis techniques used are in conformance with the internationally applied collision risk methodology.

Estimate of the CRM Parameters

1.6 The lateral separation standard between the six RNAV routes is 50NM. The form of the lateral collision risk model used in assessing the safety of operations on the South China Sea RNAV routes is:

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

1.7 The longitudinal separation standard for co-altitude aircraft on RNAV routes L642 and M771 is 50NM; for the other four RNAV routes, the longitudinal separation standard is either 10 minutes with Mach Number Technique (MNT) or 80NM RNAV.

Longitudinal risk assessment using Hsu Model

1.8 The Hsu model is used as on trial basis as an ongoing improvement to longitudinal risk assessment. The generalized model states the collision risk [Reference 1] as

$$CR(t_0,t_1) = 2NP \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{t_0}^{t_1} HOP(t|V_1,V_2) P_z(h_z) \left( \frac{2V_{rel}}{\pi \lambda_{xy}} + \frac{\overline{|\dot{z}|}}{2\lambda_z} \right) f_1(V_1) f_2(V_2) dt dV_1 dV_2$$

1.9 The component HOP(t) represents the probability of the pair of aircraft having a horizontal overlap during a given time interval given the speeds of the pair of aircraft. It is based on reliability theory and is evaluated in terms of multiple integrals of the probability density functions for the along and cross track position errors of each aircraft and is stated in [Reference 1] as

$$HOP(t|V_1 V_2) = \frac{\pi \lambda_{xy}^2}{16\lambda^2} e^{-|D_x(t)|/\lambda} \left( \frac{|D_x(t)|}{\lambda} + 1 \right)$$

1.10 The South China Sea route system comprises of 6 unidirectional non intersecting parallel routes. Thus this risk assessment will only consider the case of same identical track.

1.11 **Table 4** summarizes the value and source material for estimating the values for each of the inherent parameters of the internationally accepted Collision Risk Model (CRM).

| **Model Parameter** | **Definition** | **Value Used in TLS Compliance Assessment** | **Source for Value** |
|---|---|---|---|
| **For Lateral Collision Risk Model** | | | |
| $N_{ay}$ | Risk of collision between two aircraft with planned 50NM lateral separation | 5.0 x $10^{-9}$ fatal accidents per flight hour | TLS adopted by APANPIRG for changes in separation minima |
| $S_y$ | Lateral separation minimum | 30NM | Lateral separation minimum for RNP 4 operations in the South China Sea |
| $P_y(50)$ | Probability that two aircraft assigned to parallel routes with 50NM lateral separation will lose all planned lateral separation | 2.10 x $10^{-9}$ | Value required to meet exactly the APANPIRG-agreed TLS value using equation (1), given other parameter values shown in this table. |
| $\lambda_x$ | Aircraft length | 0.0399NM | Based on December 2013 TSD operations on L642/M771 |
| $\lambda_y$ | Aircraft wingspan | 0.0350NM | |
| $\lambda_z$ | Aircraft height | 0.0099NM | |
| $P_z(0)$ | Probability of vertical overlap for airplanes assigned to the same flight level | 0.538 | Commonly used in safety assessments |
| $S_x$ | Length of half the interval, in NM, used to count proximate aircraft at adjacent fix for occupancy estimates | 120NM, equivalent to the +/- 15-minute pairing criterion | Arbitrary criterion which does not affect the estimated value of lateral collision risk |
| $E_y(same)$ | Same-direction lateral occupancy | 0.0 | Result of direction of traffic flows on each pair of RNAV routes |
| $E_y(opp)$ | Opposite-direction lateral occupancy | 0.255 | Based on December 2013 TSD |
| $\overline{V}$ | Individual-aircraft along-track speed | 507 knots | Based on December 2013 TSD |
| $\left\lvert \overline{\dot{y}(S_y)} \right\rvert$ | Average relative lateral speed of aircraft pair at loss of planned lateral separation of $S_y$ | 35.9 knots | Conservative value based on assumption of waypoint insertion error [Reference 3] |
| $\lvert \dot{z} \rvert$ | Average relative vertical speed of a co altitude aircraft pair assigned to the same route | 1.5 knots | Conservative value commonly used in safety assessments |

**Table 4**: Summary of Risk Model Parameters Used in the CRM

Longitudinal risk assessment using Hsu Model

1.12 The Hsu model is used as on trial basis as an ongoing improvement to longitudinal risk assessment. The generalized model states the collision risk [Reference 1] as

$$CR(t_0,t_1) = 2NP \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{t_0}^{t_1} HOP(t|V_1,V_2)P_z(h_z)\left(\frac{2V_{rel}}{\pi\lambda_{xy}}+\frac{\overline{|\dot{z}|}}{2\lambda_z}\right)f_1(V_1)f_2(V_2)dtdV_1dV_2$$

1.13 The component HOP(t) represents the probability of the pair of aircraft having a horizontal overlap during a given time interval given the speeds of the pair of aircraft. It is based on reliability theory and is evaluated in terms of multiple integrals of the probability density functions for the along and cross track position errors of each aircraft and is stated in [Reference 1] as

$$HOP(t|V_1V_2) = \frac{\pi\lambda_{xy}^2}{16\lambda^2}e^{-|D_x(t)|/\lambda}\left(\frac{|D_x(t)|}{\lambda}+1\right)$$

1.14 The South China Sea route system comprises of 6 unidirectional non intersecting parallel routes. Thus this risk assessment will only consider the case of same identical track.

1.15 Assumptions

a. This assessment takes a conservative approach and does not account for controllers' intervention or system alerts to mitigate collision.

b. The estimates are made using the RNP Type required for the application of the separation.

1.16 **Table 6** shows the parameters used.

| Parameters | Description | Value | Source |
|---|---|---|---|
| $V_1$ | Assumed average ground speed of a/c 1 | 480knots | Reference 1 |
| $V_2$ | Assumed average ground speed of a/c 2 | 480knots | Reference 1 |
| $\lambda_{xy}$ | Average aircraft wingspan or length (whichever is greater) | 0.0363NM | December 2013 TSD |
| $\lambda_z$ | Aircraft height | 0.0101NM | December 2013 TSD |
| $\lambda_v$ | scale factor for speed error distribution | 5.82 | Reference 1 |
| T | ADS periodic report | 10 min | Singapore FIR |
| NP | No. of a/c per hour | 1 | Reference 1 |
| $P_z(0)$ | Probability of vertical overlap for airplanes assigned to the same flight level | 0.538 | Commonly used in safety assessments |

| | | | |
|---|---|---|---|
| $\overline{\lvert\dot{z}\rvert}$ | Average relative vertical speed of a co altitude aircraft pair assigned to the same route | 1.5knots | Commonly used in safety assessments |
| τ | controller intervention buffer | 3 cases | Reference 1 |
| RNP | Required Navigation Performance | 4NM | Reference 1 |

**Table 6**: Parameters used in the Hsu's model

1.17 **Table 7** shows the summary of the 3 cases of Controllers intervention buffer (τ) [Reference 1] used in the computation of the horizontal risk. **Tables 8 -10** presents the detailed component of each of the cases. The final collision risk is also stated as

$$0.95\times(0.95\times CR(\tau=4)+0.05\times CR(\tau=10.5))+0.05\times CR(\tau=13.5)$$

| τ | Minutes |
|---|---|
| Case 1: normal ADS ops | 4 |
| Case 2: ADS report received & response to CPDLC uplink NOT received in 3 mins | 10.5 |
| Case 3: ADS periodic reports takes more than 3 mins | 13.5 |

**Table 7**: 3 cases of τ

| Case 1: normal ADS ops | Seconds |
|---|---|
| Screen update time/controller conflict recognition | 30 |
| Controller message composition | 15 |
| CPDLC uplink | 90 |
| Pilot reaction | 30 |
| Aircraft inertia plus climb | 75 |
| Total | 240 |

**Table 8**: Case 1

| Case 2: ADS report received & response to CPDLC uplink NOT received in 3 mins | Seconds |
|---|---|
| Screen update time/controller conflict recognition | 30 |
| Controller message composition | 15 |
| CPDLC uplink | 90 |
| HF communication | 300 |
| Pilot reaction | 30 |
| Aircraft inertia plus climb | 75 |
| Total | 630 |

**Table 9**: Case 2

| Case 3: ADS periodic reports takes more than 3 mins | Seconds |
|---|---|
| Controller wait for ADS report | 180 |
| Controller message composition | 15 |
| CPDLC uplink & wait for response | 180 |
| HF communication | 300 |
| Pilot reaction | 30 |
| Aircraft inertia plus climb | 75 |
| Extra allowance | 30 |
| Total | 810 |

**Table 10**: Parameters used in the Hsu's model

1.18 Reference 2 has presented that GNSS aircraft are navigating very well along the route centerline. There are significant differences in the results when observed navigation performance is used in longitudinal risk estimates. It was recommended that a reporting interval of 10 min to be used for RNP 4 operations.

1.19 For the South China Sea Airspace, **Figure 1** shows the comparison of longitudinal risk due to RNP using various reporting period from 14 minutes to 9 minutess. It can be seen that the risk decrease with a more frequent reporting interval. In Singapore FIR, the current reporting rate is 10 minutes. However, aircraft navigating with RNP1 displays a higher risk compared to aircraft navigating RNP4. The Observed Navigation performance in the South China Sea airspace would need to be analysed further before tweaking of the parameters used for risk assessment.

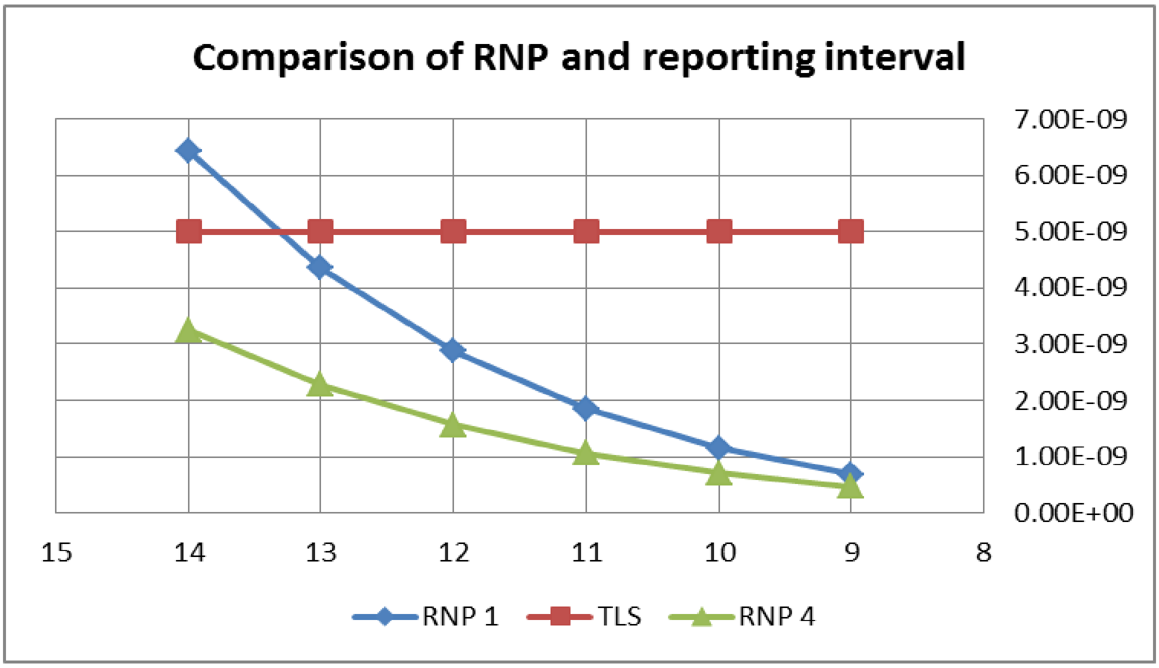


**Figure 1**: Comparison of Longitudinal Risk due to RNP and reporting interval

<u>ADS data collection</u>

1.20 In the model, the value for CPDLC uplink in τ (for case 1) is stated as 90 sec [Reference1]. For future risk assessment to better model the actual Communication Navigation and Surveillance (CNS) component, an operational value of CPDLC uplink delivery time could be derived from the actual uplink delivery time database shown in **Table 11**.

| Uplink Message Delivery Time | 30 s | 40 s | 60 s | 120 s | 180 s | 360 s | >360 s | Total No. of CPDLC Uplink Messages |
|---|---|---|---|---|---|---|---|---|
| Jan-13 | 87.88% | 89.72% | 92.91% | 98.45% | 99.39% | 99.91% | 100.00% | 19,878 |
| Feb-13 | 87.21% | 89.53% | 93.18% | 98.30% | 99.23% | 99.90% | 100.00% | 20,594 |
| Mar-13 | 84.81% | 87.50% | 91.71% | 97.62% | 98.92% | 99.81% | 100.00% | 21,409 |
| Apr-13 | 85.21% | 87.74% | 92.06% | 97.54% | 98.77% | 99.71% | 100.00% | 23,435 |
| May-13 | 86.12% | 88.45% | 92.54% | 97.89% | 99.09% | 99.83% | 100.00% | 24,398 |
| Jun-13 | 86.00% | 88.37% | 92.59% | 97.78% | 99.01% | 99.85% | 100.00% | 23,750 |
| Jul-13 | 86.08% | 88.37% | 92.56% | 97.94% | 99.00% | 99.76% | 100.00% | 25,632 |
| Aug-13 | 86.50% | 89.06% | 93.12% | 98.00% | 98.99% | 99.83% | 100.00% | 26,108 |
| Sep-13 | 86.30% | 88.83% | 92.87% | 98.01% | 99.20% | 99.84% | 100.00% | 25,485 |
| Oct-13 | 88.01% | 89.91% | 93.40% | 98.10% | 99.23% | 99.84% | 100.00% | 20,552 |
| Average % | 86.41% | 88.75% | 92.69% | 97.96% | 99.08% | 99.83% | 100.00% | 23,124 |

**Table 11**: ADS CPDLC uplink message delivery time

Use of RNAV Routes

1.21 **Table 12 and 13** was presented in Reference 4 and these tables show the proportion of flights equipped with RNP4 based on TSD Dec 2010 and 2011. One of the factors for RNP4 implementation would depend on the percentage of aircraft using the 6 RNAV routes with RNP4 equipage.

1.22 **Table 12** shows the traffic count on L642, M771, N892, L625, N884 and M767 and the percentage of filed RNP4 in December 2010. A total of 11033 flights operated on the six RNAV routes. 28% of the total flight filed RNP4 and 20% of the total flight did not indicate any PBN approval in their flight plan. None of the flights on N884 filed RNP4.

| 2010 | | | | | |
|---|---|---|---|---|---|
| Routes | Traffic Count | Filed RNP4 | No Data on PBN Approval | % Filed RNP4 | % No Data on PBN Approval |
| L642 | 3662 | 999 | 69 | 27.3% | 1.9% |
| M771 | 2742 | 1148 | 66 | 41.9% | 2.4% |
| N892 | 1582 | 278 | 580 | 17.6% | 36.7% |
| L625 | 1157 | 585 | 133 | 50.6% | 11.5% |
| N884 | 1271 | 0 | 1127 | 0.0% | 88.7% |
| M767 | 619 | 87 | 230 | 14.1% | 37.2% |

**Table 12**: Usage on L642, M771, N892, L625, N884 and M767 in December 2010

1.23 13798 flights took place in December 2011 which amount to a 25% increase compared to December 2010. The proportion of filed RNP4 and No data on PBN approval in the flight plan remain generally the same as December 2010. Table 2 presents the used on L642, M771, N892, L625, N884 and M767 and the percentage of filed RNP4 in December 2011

| 2011 | | | | | |
|---|---|---|---|---|---|
| Routes | Traffic Count | Filed RNP4 | No Data on PBN Approval | % Filed RNP4 | % No Data on PBN Approval |
| L642 | 4317 | 1182 | 163 | 27.4% | 3.8% |
| M771 | 3740 | 1328 | 119 | 35.5% | 3.2% |
| N892 | 1935 | 330 | 732 | 17.1% | 37.8% |
| L625 | 1376 | 600 | 215 | 43.6% | 15.6% |
| N884 | 1176 | 2 | 1141 | 0.2% | 97.0% |
| M767 | 1254 | 340 | 471 | 27.1% | 37.6% |

**Table 13**: Usage on L642, M771, N892, L625, N884 and M767 in December 2011

Safety Oversight

1.24 **Table 14** summarizes the results of the airspace oversight for RNP 4 operations, as of Dec 2013.

| Type of Risk | Risk Estimation | TLS | Remarks |
|---|---|---|---|
| Lateral Risk | **$0.255 \times 10^{-9}$** | $5 \times 10^{-9}$ | Below TLS |
| Longitudinal Risk | **$0.705 \times 10^{-9}$** | $5 \times 10^{-9}$ | Below TLS |

**Table 14**: Lateral and Longitudinal Risk Estimation

1.25 **Figure 2** presents the results of the collision risk estimates for each month using the cumulative 12-month LLD and LLE reports since Jan 2013.

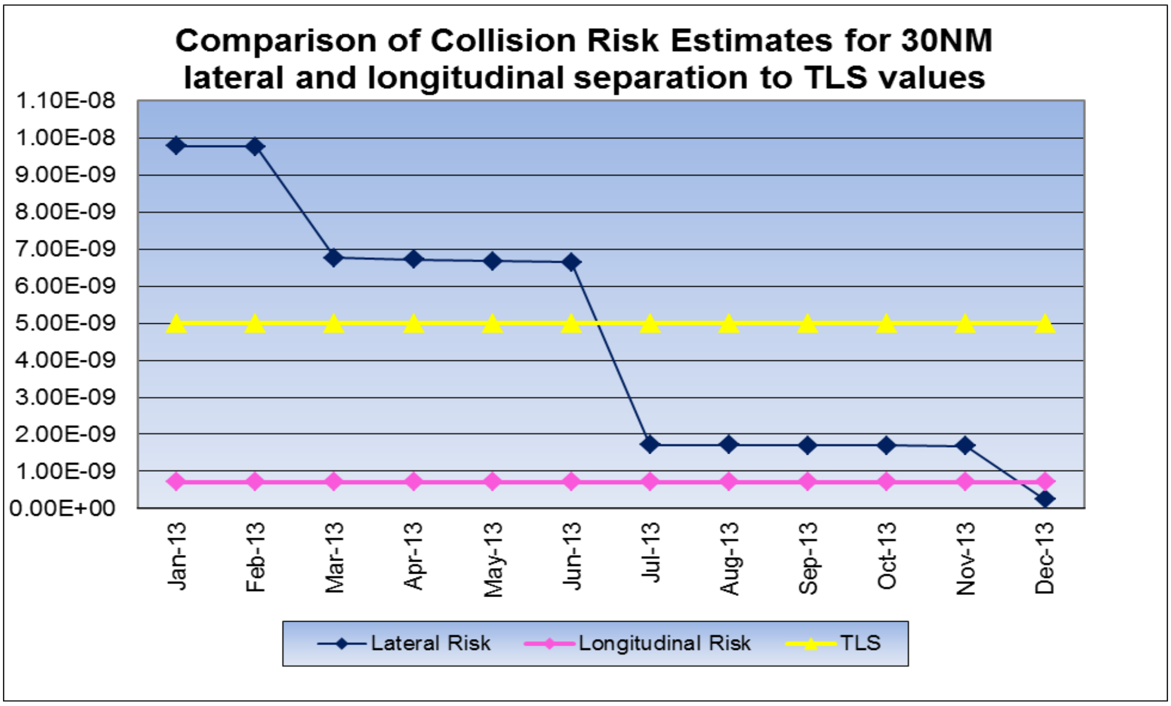


**Figure 2**: Collision risk estimates for 30M Lateral and Longitudinal

1.26 The estimates of lateral and longitudinal risk show compliance with the corresponding respective TLS values during all months of the monitoring period.

Conclusion

1.27 The longitudinal risk assessment used the 10 minute ADS reporting interval which is present reporting interval used in Singapore FIR. Taking a conservative approach, the ADS reporting interval of 10 minutes could be used for implementation of RNP4 operations for all the 6 RNAV routes of the South China Sea airspace to reduce the risk and provides some buffer to the TLS.

1.28 SEASMA will continue to improve the process of horizontal and analyse the use of various parameters to accurately model the risk in the South China Sea airspace.

1.29 References

1. Anderson, D., "A collision risk model based on reliability theory that allows for unequal RNP navigational accuracy" ICAO SASP-WG/WHL/7-WP/20, Montreal, Canada, May 2005.

2. PARMO, "Safety Assessment to support use of the 50-NM Longitudinal, 30-NM Lateral and 30-NM Longitudinal Separation Standards in New York Oceanic Airspace." Attachment to MAWG/1 WP/2, Honolulu, USA, Dec 2013.

3. PARMO, "PARMO Horizontal Safety Report", RASMAG/18, WP/8, Bangkok, Thailand, April 2012.

4. SEASMA, "Examination of RNP4 equipage on RNAV routes in the South China Sea", RASMAG/17, WP/6, Bangkok, Thailand, August 2012.