International Civil Aviation Organization

The Fifteenth Meeting of the Regional Airspace Safety Monitoring Advisory Group (RASMAG/16)

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Agenda Item 5: Airspace Safety Monitoring Activities/Requirements in the Asia/Pacific Region

PRELIMINARY ANALYSIS OF ATS ROUTE B576 FOR SAFETY ASSESSMENT

(Presented by Republic of Korea)
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SUMMARY

This paper presents the methodology, process and preliminary result on the quantitative safety assessment on the pre-implemented parallel route B576 performed by the Korea Transport Institute. The quantitative safety assessment for the lateral collision risk has been carried out using Reich Collision Risk Model. The traffic sample data used in this study is from the radar surveillance data at Incheon ACC for the month of June 2010. This study is about the first quantitative safety assessment of an ATS route conducted in the Republic of Korea. The safety assessment of the other routes will be performed with the air traffic data to be accumulated in the future.

I. Introduction

1.1 In 2007, the 36th ICAO Assembly resolution (A36-23) urges all member States to implement Performance Based Navigation (PBN) for En-route and terminal areas, and PBN approach procedures with vertical guidance (APV) for all international airports by 2016. According to ICAO's plan, the Republic of Korea has established the PBN implementation roadmap. PBN based on the instrument flight procedures will be implemented to all airports and ATS routes in Incheon FIR by 2016. The implementation of PBN will be applied firstly in the most congested route in Incheon FIR, B576 connecting Seoul-Jeju, and instrument departure / arrival procedures for Incheon and Gimpo international airports.

1.2 Before the implementation of PBN, the safety assessment for the new and changed routes is required. The Korea Transport Institute (KOTI), an independent institute funded by the government, was asked by the MLTM (Ministry of Land, Transport and Maritime Affairs) to carry out the pre-implementation safety assessment for domestic airspace. The research team of KOTI is performing study on airspace safety assessment.

1.3 Based on this background, KOTI has evaluated the collision risk between two aircrafts flying on simulated parallel routes in Incheon FIR. The safety level of B576 route has been evaluated assuming parallel routes condition which are currently operated as a single route (sometime operated by off-set routes). Using CRM (Collision Risk Model), this study shows that the estimate of the collision risk for the simulated parallel routes B576 satisfy the Target Level of Safety (TSL) value of no more than 5×10^{-9} fatal accidents per flight hour.

1.4 The methodology, process and preliminary results of the quantitative safety assessment on the pre-implemented parallel routes B576 are presented in this paper. KOTI is planning to continuously conduct airspace safety assessment on post-implemented PBN routes, and to set up an En-route Monitoring Agency (EMA) to play a leading role in making a contribution to the global air safety.

II. Status of Object Route

2.1 Flight environment of B576 Route

B576 Route is composed of 15 fixes across Incheon FIR north-south. Its distance is 458.3NM (the longest route in Incheon FIR). Especially, OLMEN-ATOTI segment is operated with off-set procedure.

Item		Details
Target	Period of Traffic Sample Data	2010.6.1.~2010.6.29.
	Altitude	Traffic on FL290~FL410 (total 5103 flights)
	Basic Analysis	Aircraft types, Number of flight, Aircraft characteristics, traffic distribution (distribution over direction, day, time and altitude)
Analysis Result	Type of Aircraft	Total 44 types of aircraft; A333, B744, A320, B772, A321 and B738. The percentage of major 6 types is about 71.2%
	Average Traffic	170.1 flights per day. Standard deviation 14.0
	Maximum Traffic	193 flights per day on June 3^{rd}, 2010
	Maximum cumulative number of flights	868 flights on Wednesdays
	Peak Traffic	Traffic concentrated in : SB - 10:30~12:00 and 00:00~00:30, : NB - 20:00~21:00
	Altitude	Most traffic on FL360

Table 1. Basic Analysis of B576

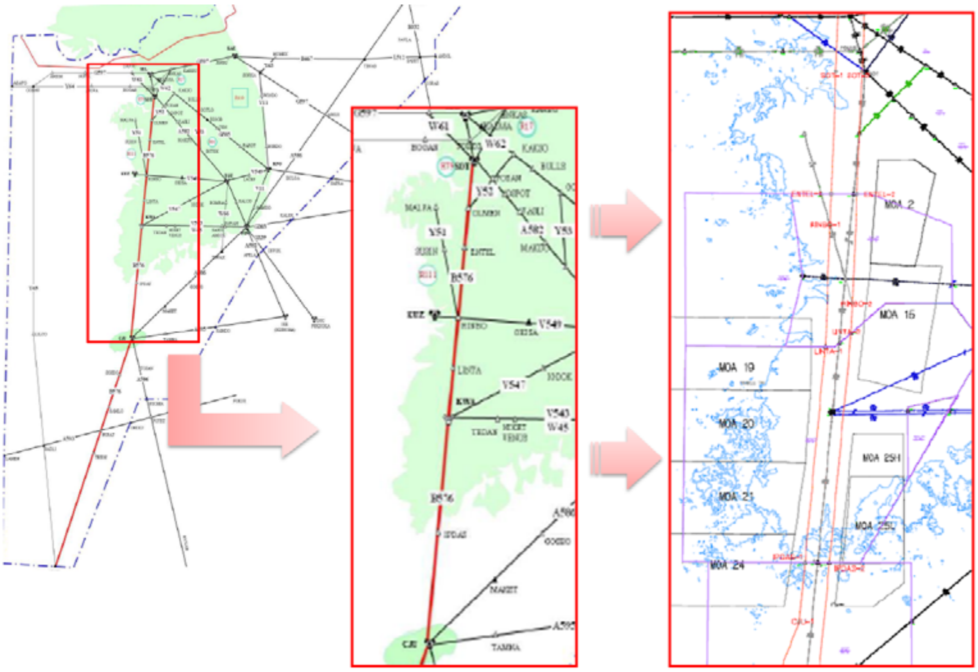

Figure 1. Concept of parallel routes of B576

2.2 Air Traffic in B576 (in 2010)

Since 41% of total traffic is concentrated on B576 route, it causes traffic congestion. Thus, the parallel routes are required. The most congested segment is RINBO-KWA, which is 35% of total flights.

There is a plan to increase capacity of airspace in B576 with followings

- ✓ Suggest parallel routes in B576
- ✓ Need safety assessment on parallel routes
- ✓ Design B576 route according to RNAV 2

III. Traffic Sample Data (TSD)

3.1 Traffic sample data from Incheon FIR for the month of June 2010 was used. The data set contained 75,003 records[1]. Form of the data is Excel (CSV format), and time period of data is from June 1st to 29th in 2010.

The following conditions were used

[Common conditions]

- Only records for route B576
- Consider only opposite direction traffics
- Current geometric route will be used for future PBN operation
- All aircrafts operation with PBN navigation equipments
- Large deviation data from defined route have been filtered
- Safety assessment performed for linear segment. (excluded the terminal area)
  - ✓ Upper section (RINBO-LINTA-KWA-IPDAS) : Domestic & International flights
- Current B576 route is not RNAV route but conventional one with large lateral deviation
- B576 was operated with off-set procedure due to air traffic congestion
- Lateral separation with 10NM

IV. Lateral Collision Risk Assessment

4.1 Lateral Collision Risk Model (Reich Collision Risk Model)[2]

The Reich Collision Risk Model has been used to evaluate the level of safety on each route. The lateral collision risk has been estimated due to the loss of lateral separation between aircraft on adjacent parallel routes, flying at the same altitude (flight level)[3]. The Reich model has already been used in many ICAO member states.

As for these two simulated parallel routes of B576, it is possible to use the 'Reich Collision Risk Model' to compute lateral collision risk.

The model is as follows:

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

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1 B576 route : RINBO-IPDAS = 75,003 records

2 STAMA(2009), 「EUR/SAM: "Double Unidirectionality" Post-Implementation Risk Assessment」, pp.26-29.

3 ARINC(2001), 'Risk Assessment of RNP 10 and RVSM in the South Atlantic Flight Identification Regions'

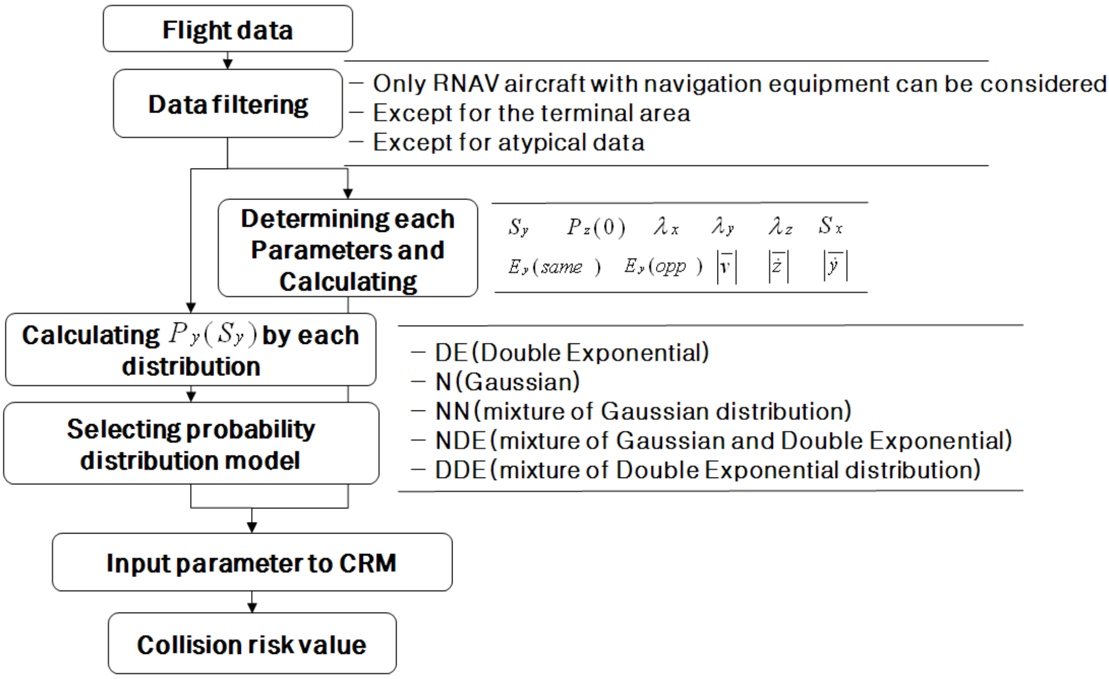

Figure 2. Process of CRM application

The safety assessment is based on the following hypothesis:[4]

- All routes are parallel.
- All collision normally occurs between aircrafts on adjacent routes, although, if the probability of overlap is significantly large, they may also occur on non-adjacent routes.
- The aircraft are replaced by rectangular boxes.
- There is no corrective action by pilots or ATC when two aircrafts are about to collide.

It is assumed that the nature of the events making up the lateral collision risk is completely random. It implies that any location within the system can be used to collect a representative sample data on the performance of the system.

4.2 Estimated Values of Parameters and Lateral Collision Risk

Parameter	Value		Unit
	Note	POLEG-CJU	
S_y	Lateral separation distance	10	NM
$P_y(S_y)$	Probability of lateral overlap of aircraft nominally flying on laterally adjacent paths	3.33E-16 (NN distribution)	-
$P_z(0)$	Probability of vertical overlap of aircraft nominally flying at the same flight level	0.538	-
λ_x	Average length of an aircraft	0.0301	NM
λ_y	Average width of an aircraft	0.0275	NM
λ_z	Average height of an aircraft	0.0085	NM

4 STAMA(2009), 「EUR/SAM: "Double Unidirectionality" Post-Implementation Risk Assessment」

S_x	Length of longitudinal window used in the calculation of occupancies	80	NM
$E_y(same)$	Same direction lateral occupancy, i.e. average number of same direction aircrafts flying on laterally adjacent routes at same flight level within segments of length 2Sx centered on the typical aircraft	-	-
$E_y(opp)$	Opposite direction lateral occupancy, i.e. average number of opposite direction aircrafts flying on laterally adjacent tracks at same flight level within segments of length 2Sx centered on the typical aircraft	0.2710	-
$\overline{V}$	Average speed of an aircraft	464.88	Knot
$\overline{\lvert\dot{z}\rvert}$	Average relative vertical speed of aircraft flying at the same flight level	75	Knot
$\overline{\lvert\dot{y}\rvert}$	Average lateral cross-track speed between aircraft that have lost their lateral separation	1.5	Knot
N_{ay}	Expected number of accidents (two per each aircraft collision) per flight hour due to the loss of lateral separation between aircraft flying on routes with nominal spacing Sy	**3.09E-16**	

Table 2. Risk Estimates for Simulated Parallel Routes B576

V. Future Plan

5.1 In this study, the safety risk has been estimated for the simulated parallel routes B576 in Incheon FIR. It is first quantitative safety assessment in the Republic of Korea and the first step toward setting up an evaluation process for the safety assessment. Korean government is planning to continuously conduct airspace safety assessment on post-implemented PBN and RVSM routes.

5.2 For these activities, KOTI and Incheon ACC have signed on the MoU to accumulate the radar surveillance data. The working paper on the results of the safety assessment of the other routes will be presented in next meeting of RASMAG.

VI. Action by the Meeting

6.1 The meeting is invited to:

a) present the information contained in this paper; and

b) discuss any relevant matters as appropriate.

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References

1. 「Asia/Pacific EMA Handbook」 - Version 2.0, August 2010
2. 「EUR/SAM: "Double Unidirectionality" Post-Implementation Risk Assessment」
3. 「Air Traffic Management」, Doc 4444, ATM/501, Fifteenth Edition, 2007, ICAO
4. The 15th Meeting of the Regional Airspace Safety Monitoring Advisory Group (RASMAG /15) Bangkok, Thailand, 1-5 August 2011
5. 「Collision Risk Model」, ENRI, Japan
6. PBN Korea Website (http://pbn.mir9.co.kr/en/)
7. 「Preliminary Analysis of Airspace Characteristics in the Incheon FIR and of ATS route B576 for Safety Assessment」, RASMAG/15−IP/02, 2011.8

Appendix

1. Estimating Probability of Lateral Overlap : $P_y(S_y)$

- Basic concept[5]

The probability of lateral overlap of aircrafts nominally flying on adjacent flight paths, separated by S_y, is denoted by $P_y(S_y)$ and it is defined by:

$$P_y(S_y) = \int_{-\lambda_y}^{\lambda_y} f^{y_{12}}(y)dy$$

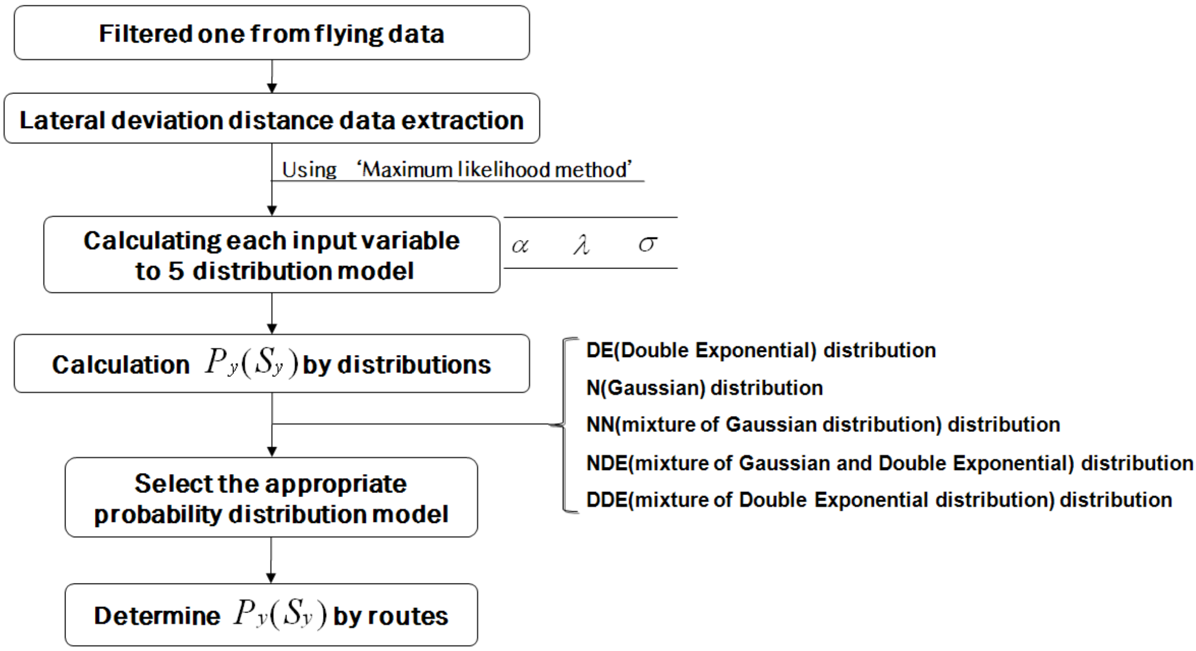
Where f_{y12} denotes the probability density of the lateral distance y_{12} between two aircrafts with lateral deviations y_1 and y_2, nominally separated by S_y, i.e.

$$y_{12} = S_y + y_1 - y_2$$

and

$$f^{y_{12}}(y) = \int_{-\infty}^{\infty} f^{y}(y_1) f^{y}(S_y + y_1 - y)dy_1$$

- Process of estimate $P_y(S_y)$



Appendix Figure 1. Py(Sy) estimate process

<u>Step 1</u> <u>of Py(Sy) calculation</u> : Input data (α,λ,σ) which are used to 5 distribution models is calculated by 'Maximum likelihood method' using lateral loss deviation distance data.

The followings[6] are the probability density functions of lateral deviations of a single aircraft.

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5 STAMA(2009), 「EUR/SAM: "Double Unidirectionality" Post-Implementation Risk Assessment」, pp.37-38.

DE(double exponential distribution). Here, λ denotes the positive scale parameter.

$$f(x) = \frac{\exp(-|x|/\lambda)}{2\lambda}$$

N (Gaussian distribution). Here, σ denotes the positive standard deviation parameter.

$$f(x) = \frac{\exp(-x^2/2\sigma^2)}{\sqrt{2\pi}\sigma}$$

NN (mixture of Gaussian distributions). Here, σ_1 and σ_2 denote the positive standard deviation parameters, and α denotes the weight parameter satisfying $0 \le \alpha \le 1$.

$$f(x) = (1-\alpha)\frac{\exp(-x^2/2\sigma_1{}^2)}{\sqrt{2\pi}\sigma_1} + \alpha\frac{\exp(-x^2/2\sigma_2{}^2)}{\sqrt{2\pi}\sigma_2}$$

NDE (mixture of Gaussian distribution and double exponential distribution). Here, σ denotes the positive standard deviation parameter, λ denotes the positive scale parameter, and α denotes the weight parameter satisfying $0 \le \alpha \le 1$.

$$f(x) = (1-\alpha)\frac{\exp(-x^2/2\sigma^2)}{\sqrt{2\pi}\sigma} + \alpha\frac{\exp(-|x|/\lambda)}{2\lambda}$$

DDE (mixture of double exponential distributions, it is sometimes called double double exponential distribution). Here, λ_1 and λ_2 denote the positive scale parameters, and α denotes the weight parameter satisfying $0 \le \alpha \le 1$.

$$f(x) = (1-\alpha)\frac{\exp(-|x|/\lambda_1)}{2\lambda_1} + \alpha\frac{\exp(-|x|/\lambda_2)}{2\lambda_2}$$

<u>**Step 2** of Py(Sy) calculation</u> : Selecting the distribution model that best describe the observed data(loss deviation distance) after make a fitting graph.

<u>**Step 3** of Py(Sy) calculation</u> : The value of $P_y(S_y)$ is calculated by using input data $(\alpha, \lambda, \sigma)$ of which is selected model

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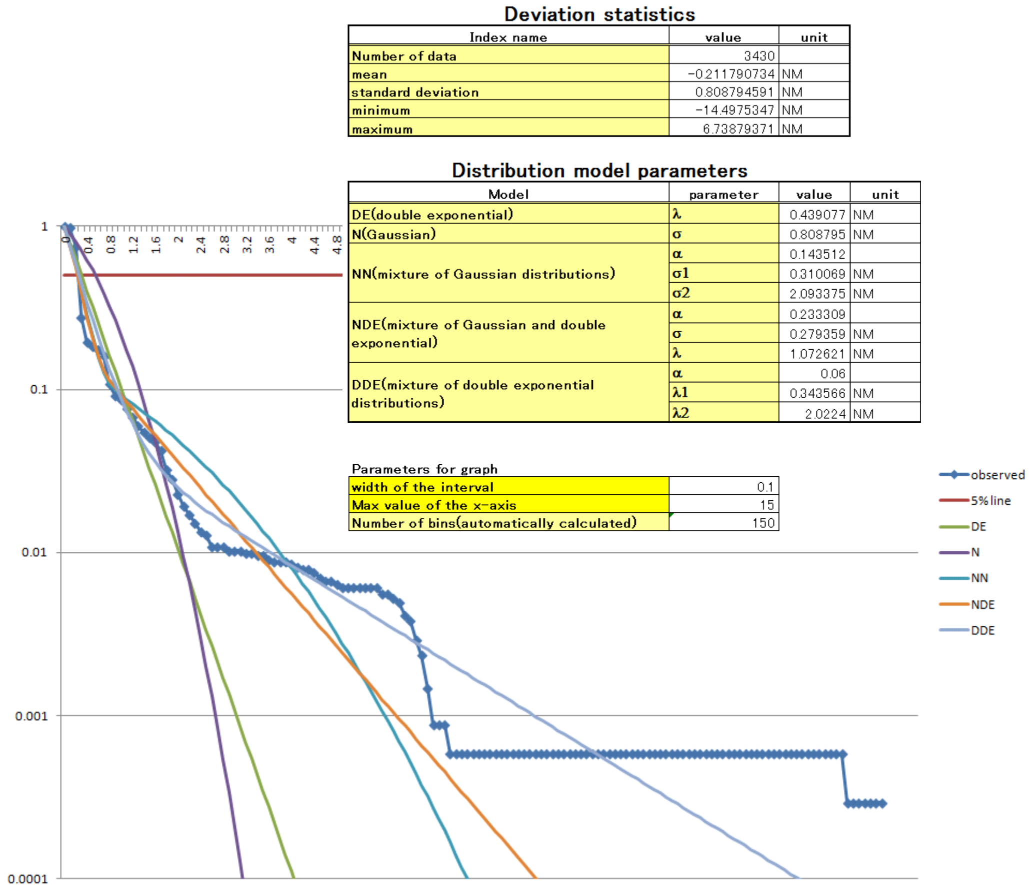
[6] One of the safety assessment methodology in ENRI(Electronic Navigation Research Institute in Japan)



Appendix Figure 2. Model selection by fitting graph (source by ENRI, Japan)

2. Estimating Probability of Vertical Overlap : $P_Z(0)$

$P_Z(0)$ is the probability of vertical overlap of aircrafts nominally flying at the same flight level. Generally, the following equation is used to calculate $P_Z(0)$.

$$P_z(0) = 2\lambda_z \int_{-\infty}^{\infty} f^{TVE}(z_1) f^{TVE}(z_1) dz_1$$

The common value of 0.538 has been used.

3. Estimating Average Aircraft Dimensions

<Table 1> summarizes the distribution of aircraft population in the TSD from Incheon FIR for June 2010. The average aircraft dimensions have been evaluated by using the dimensions of each aircraft type weighted by their proportions.

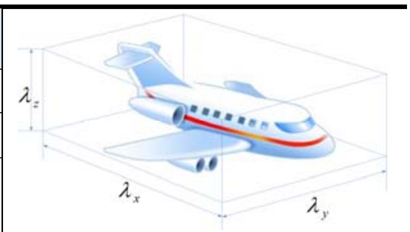
Aircraft	λ_x , length(x)		λ_y , wingspan(y)		λ_z , height(z)	
	M	NM	M	NM	M	NM
A310	46.66	0.025194	43.90	0.023704	15.80	0.008531
A319	33.83	0.018267	33.86	0.018283	12.13	0.006550

A320	37.58	0.020292	33.86	0.018283	12.13	0.006550
A321	44.51	0.024033	33.86	0.018283	11.81	0.006377
A330	59.00	0.031857	60.30	0.032559	16.84	0.009093
A332	59.00	0.031857	60.30	0.032559	17.88	0.009654
A333	63.58	0.034330	60.30	0.032559	16.84	0.009093
A343	63.68	0.034384	60.30	0.032559	16.84	0.009093
B733	33.4	0.018035	31.1	0.016803	11.1	0.006010
B737	33.6	0.018143	35.8	0.019330	12.5	0.006749
B738	39.5	0.021328	35.8	0.019330	12.5	0.006749
B739	42.1	0.022732	35.7	0.019276	12.5	0.006749
B742	70.6	0.038121	59.6	0.032181	19.3	0.010421
B744	70.6	0.038121	64.4	0.034795	19.4	0.010481
B752	47.3	0.025551	38.1	0.020545	13.6	0.007343
B762	48.5	0.026188	47.6	0.025702	15.8	0.008531
B763	54.9	0.029644	47.6	0.025702	15.8	0.008531
B772	63.7	0.034395	60.9	0.032883	18.5	0.009989
B773	73.9	0.039903	60.9	0.032883	18.5	0.009989
B77L	63.7	0.034395	64.8	0.034989	18.6	0.010043
B77W	73.9	0.039903	64.7	0.034935	18.5	0.009989
E190	36.2	0.019519	28.6	0.015421	10.6	0.005713
MD11	58.7	0.031695	52.0	0.028062	17.9	0.009681

Appendix Table 1. Aircraft dimensions on B576 route

The average aircraft dimensions have been calculated using the dimensions of each aircraft type and proportions of flights by type as weighting factors.[7]

		B576 route
λ_x	Average length of aircraft	0.0301
λ_y	Average wingspan of aircraft	0.0275
λ_z	Average height of aircraft	0.0085



Appendix Table 2. Aircraft dimensions on B576 route

4. Estimating the Lateral Occupancy Parameter : $E_y(opp)$

The comparison of crossing times will give the number of proximate pairs. A proximate pair, between aircrafts on adjacent routes and at the same flight level, is defined as the occurrence of two aircrafts passing within a given longitudinal distance $2S_X$. If both aircrafts fly in the same direction it will be a proximate pair in the same direction, whilst it will be an opposite direction proximate pair if they fly in opposite direction. As far as the distance S_X is concerned, it is often given by the time $T0$, being the time it takes an aircraft with an average speed of 480kts to fly that distance. In this study, S_X is 80NM and $T0$, 10 minutes.

[7] STAMA(2009), 「EUR/SAM: "Double Unidirectionality" Post-Implementation Risk Assessment」, pp.37-38.

If, for each and every flight level, passing times at the reporting point of all aircrafts on one route are compared with the passing times of all aircrafts on another routes at the homologous reporting point, the number of proximate pairs between these two routes will be given by the number of cases in which the absolute value of the difference between both times is less than 10 minutes.

The same procedure must be followed with the remaining pairs of routes. Considering all this, occupancy can be estimated using the following equation: [8]

$$E_y = \frac{2n_y}{n}$$

- Opposite direction lateral occupancy :
  - The average number of opposite direction aircraft flying on laterally adjacent routes at the same flight level within segments
  - Two ways to estimate the lateral occupancy
    - 'Steady state flow model'
    - 'Direct estimation from time at waypoint crossing'
  - Direct estimation is more accurate methods that are commonly used, and this calculations estimated
  - n_y is total number of proximate pairs of aircrafts
  - n is total number of aircrafts in the same route

[B576 route case]

To calculate CRM for B576 conservatively, this study use the heavy-traffic route segments RINBO-LINTA, LINTA-KWA

Segment	Total number	Proximate pairs	Ey(opp)
RINBO-LINTA	271	58	0.2140
LINTA-KWA	275	90	0.3272
Total	546	148	**0.2710**

Appendix Table 3. Heavy-traffic routes RINBO-LINTA, LINTA-KWA and $E_y(opp)$ value

5. Estimating the Average ground speed of an aircraft : $\overline{V}$

The average relative velocity in the opposite direction ($\left|\overline{V}\right|$) is calculated by multiplying with the average flight speed ($\overline{V}$) of the aircraft flying the B576. All flight speed unit of flying data has been converted to NM unit

	B576 route
Object route	RINBO-IPDAS
Average Flying Speed (knots)	464.88

Appendix Table 3. Average flying speed

[8] STAMA(2009), 「EUR/SAM: "Double Unidirectionality" Post-Implementation Risk Assessment」, pp.150-151.

6. Estimating the Average ground speed of an aircraft : $|\bar{\dot{y}}|$

In this study, 75 knots have been used, which have been used in Asia/Pacific EMA Handbook (ver. 2.0) and this is conservative value.

Safety Assessment Implement Organization(or Nation)	Used Value (unit : knots)	Note
ARINC (U.S.A)	42	Average aircraft speed (475-480 knots) from about 5 ° deviation angle calculated the value
NAT(North Atlantic)	80	-
EMA (Asia/Pacific EMA handbook, ver. 2.0)	**75**	Conservative value based on assumption of waypoint insertion error
India(RASMAG/15)	**75**	Used EMA handbook(Asia/Pacific, ver. 2.0) value

Appendix Table 3. $|\bar{\dot{y}}|$ values by safety assessment implement organization

7. Estimating the Average relative vertical speed: $|\bar{\dot{z}}|$

For $|\bar{\dot{z}}|$, the value of 1.5 knots has been used since it has commonly been used in ARINC, EMA and India case.

Safety Assessment Implement Organization(or Nation)	Used Value (unit : knots)	Note
ARINC (U.S.A)	**1.5**	- More conservative value than NAT′s estimation
NAT(North Atlantic)	1	-
EMA (Asia/Pacific EMA handbook, ver. 2.0)	**1.5**	- Conservative value commonly used in safety assessment
India(RASMAG/15)	**1.5**	- Used EMA handbook(Asia/Pacific, ver. 2.0) value

Appendix Table 4. $|\bar{\dot{z}}|$ values