Safety Analysis for Reduction of Longitudinal Time Separation Minima on Oceanic Routes

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Background (1)

- More efficient use of airspace is expected with the growth of air demand.
- Vertical separation
  - RVSM (Reduced Vertical Separation Minima)
    - Separation of the altitude is changed from 2000 ft to 1000 ft.
- Longitudinal separation
  - Distance based separation (50 NM/ 30NM)
    - An aircraft pair (ADS system and RNP/RNAV authorization required) can apply the distance based separation.

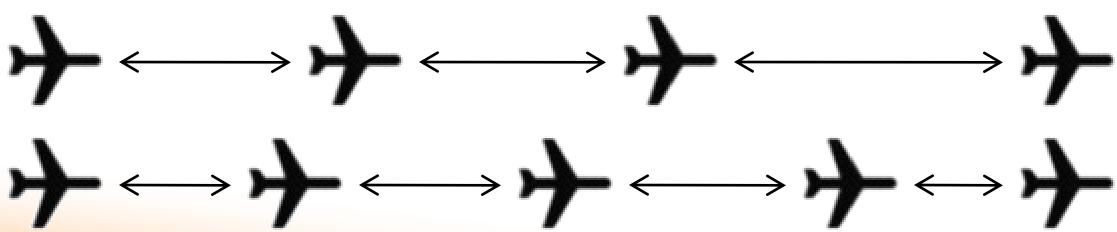
Background (2)

- The time based separation (15 minutes) is still widely used.
  - There are still many aircraft without ADS system.
    - It costs more or less money to introduce and use ADS system.

➔ Reduced time based separation to 10 minutes is expected.

Minimum 15 min.

Minimum 10 min.



Safety analysis

- When a new system is introduced, a safety analysis is required.
  - The target level of safety (TLS) in the en-route phase is set to 5.0×10^{-9} per flight hour in each dimension by ICAO.
  - Qualitative analysis is also required.

➔ This time, the risk of collision between two aircraft is calculated based on the aircraft navigation performance.

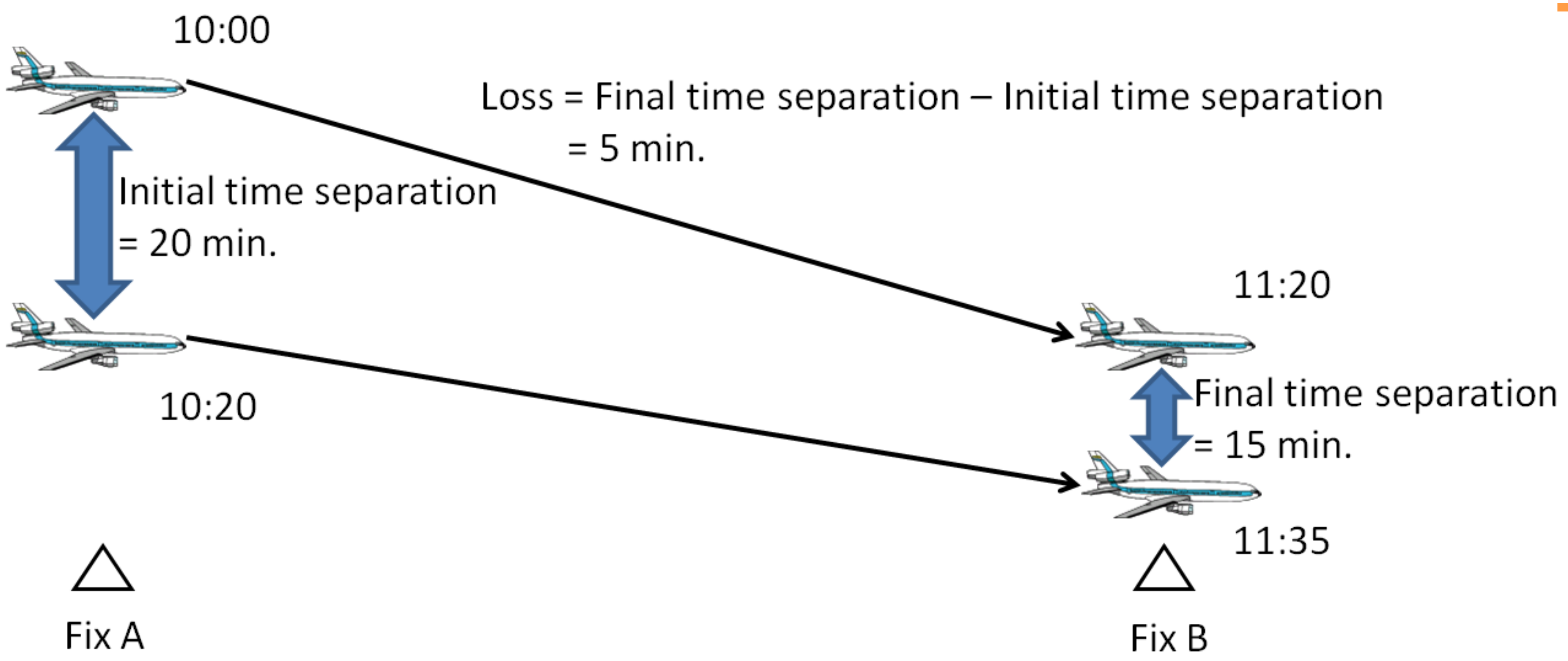
How to calculate the risk of collision

$$N_{ax} = P_y(0)P_z(0)\frac{2\lambda_x}{\overline{|\dot{x}|}T}\left[\frac{\overline{|\dot{x}|}}{2\lambda_x} + \frac{\overline{|\dot{y}(0)|}}{2\lambda_y} + \frac{\overline{|\dot{z}(0)|}}{2\lambda_z}\right]\sum E_x(t)Q_x(t)$$

$$= \underbrace{P_y(0)}_{\text{lateral}} \cdot \underbrace{P_z(0)}_{\text{vertical}} \cdot \underbrace{P_x(0)}_{\text{longitudinal}}$$

- A collision happens when a pair of aircraft is superposed vertically, laterally, and longitudinally.
  - $P_y(0) = 0.20$
  - $P_z(0) = 0.5380$
  - How to estimate $P_x(0)$?

Conventional loss distribution



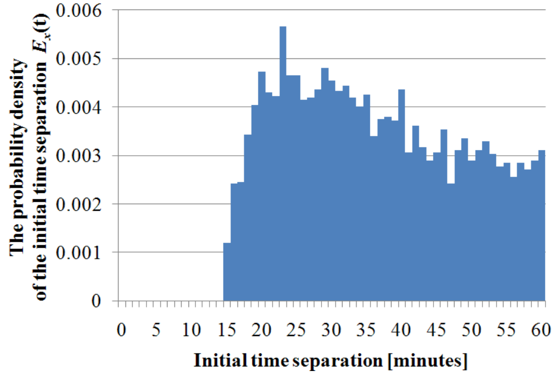
- Loss time > Initial time separation

  ➔Infringed longitudinal separation.

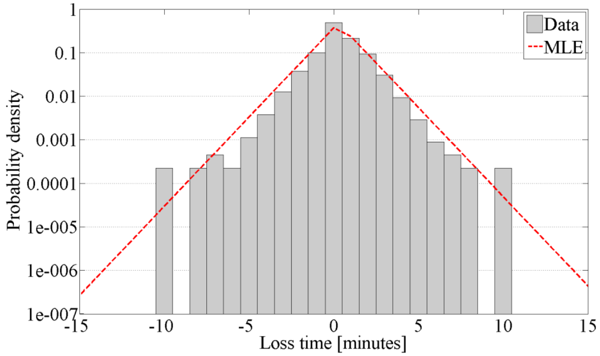
How to calculate Px(0)

$$P_x(0) \propto \int E_x(t) Q_x(t) dt$$

$$Q_x(t) = \int_t^{\infty} l(\tau) d\tau$$

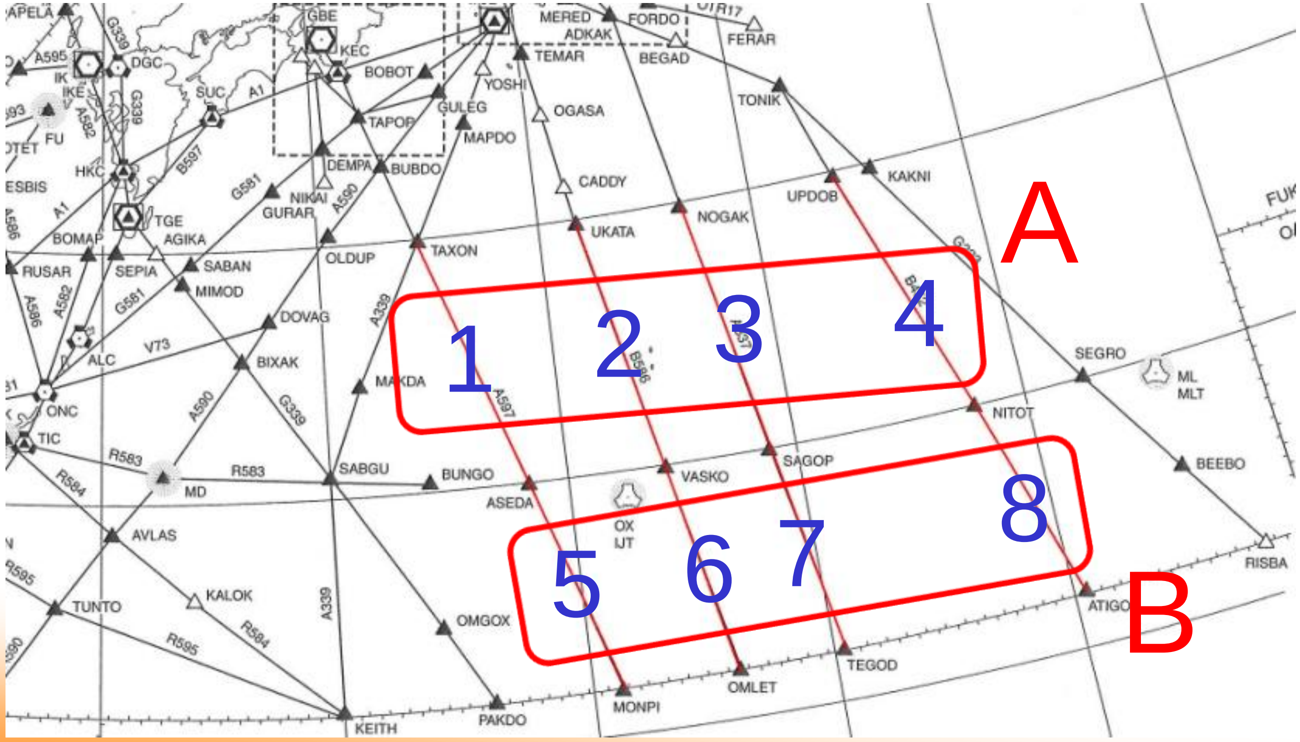


- Ex(t): The proportion of the initial time separation equal to t.
- Qx(t): The probability of the loss time greater than t.
- L(t): The probability density function of the loss time.

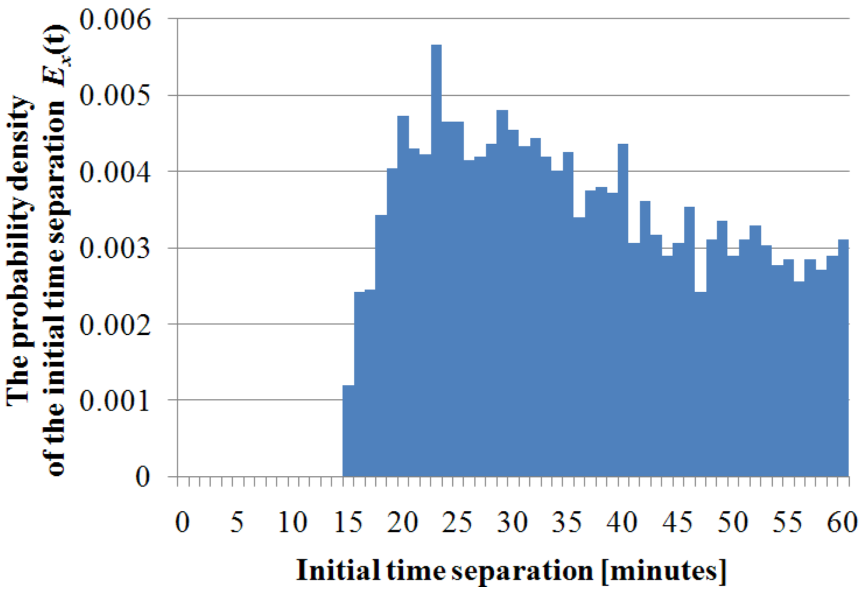


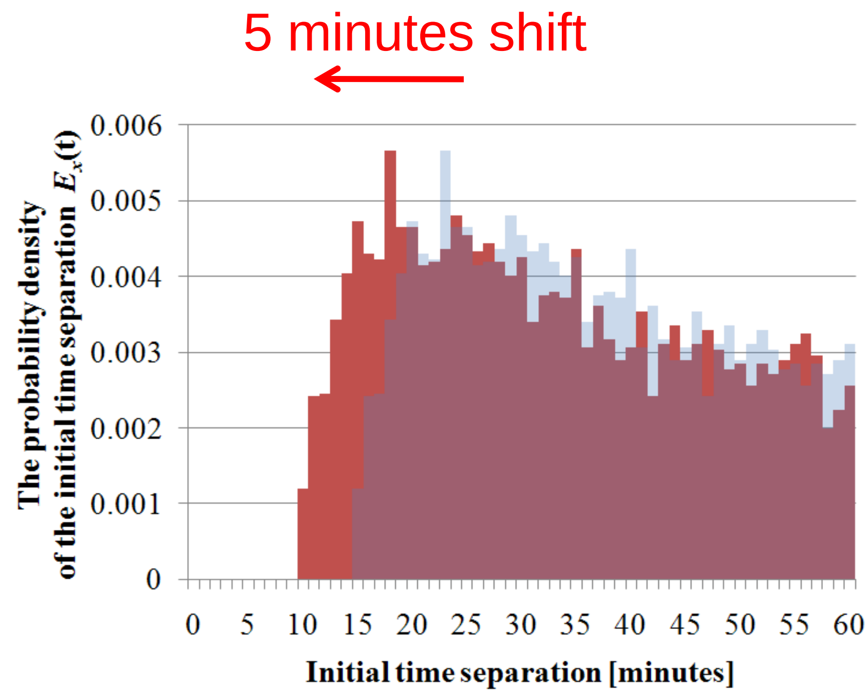
The target routes of the study

- Oceanic routes bound south in Fukuoka FIR.
  - Airspace A: segment 1, 2, 3, 4: 306~318 NM
  - Airspace B: segment 5, 6, 7, 8: 245~253 NM
- Data obtained between May 2008 and May 2010.
  - About 28,000 pairs of aircraft data in each airspace are used.



Initial time separation (Ext)





Obtained distribution in Airspace A

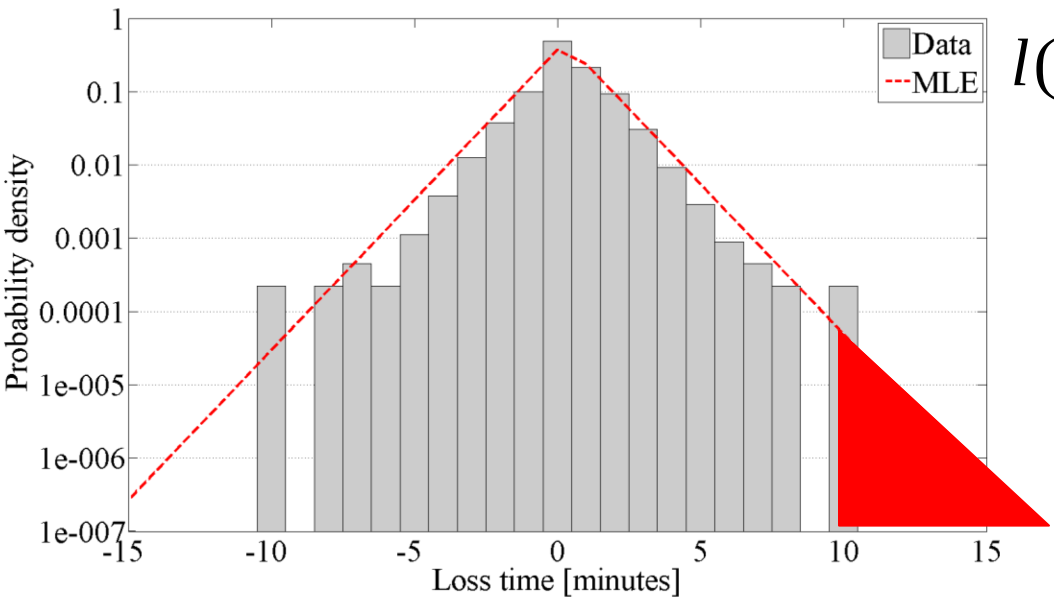
(The minimum is 15 min.)

Estimated distribution in Airspace A

(The minimum is 10 min.)

Loss distribution (Lt)

- Loss distribution is modeled by double exponential (Laplace) distribution.
  - The loss distribution is obtained only when the Initial time separation is less than 60 minutes.
  - The loss time is discretized by 1 minute.



$$l(t;\mu,\lambda)=\frac{1}{2\lambda}\exp\left(\frac{-|t-\mu|}{\lambda}\right)$$

$$Q_x(t)=\int_t^{\infty} l(\tau)d\tau$$

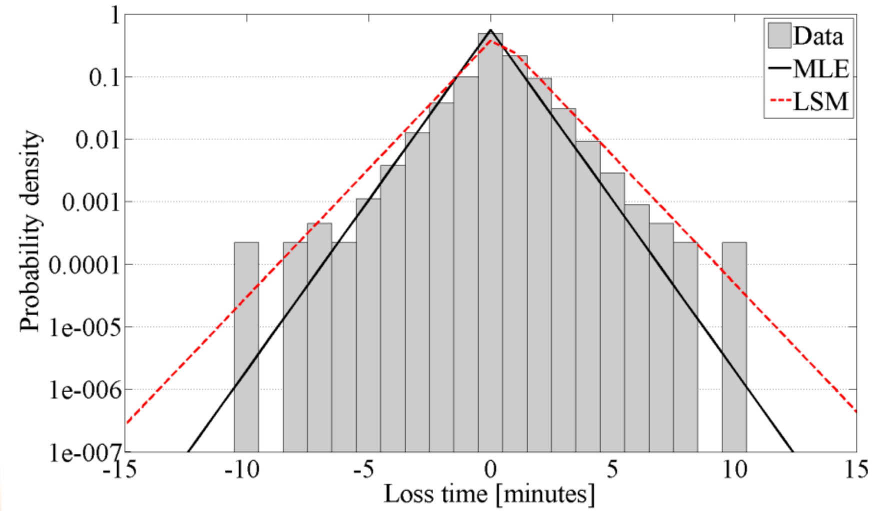
Parameter estimation

- MLE (Maximum Likelihood Estimation)

$$lik = \prod_{i=1}^{n} \frac{1}{2\lambda} \exp\left(\frac{-|t_i - \mu|}{\lambda} \right)$$ is maximized.

- LSM (Least Square Method)

$$F = \sum_{t}^{p_{act}(t)\neq 0} \left[\log(p_{act}(t)) - \log(p_{est}(t)) \right]^2$$ is minimized.

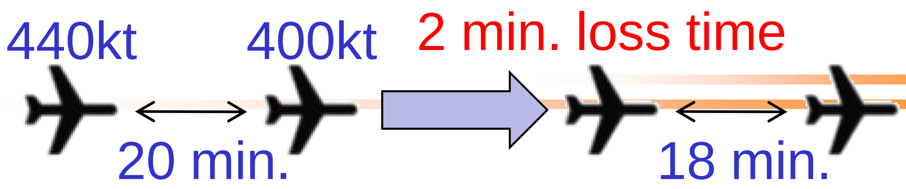


The expected risk of collision

- The expected risk of collision is calculated assuming that the minimum initial time separation is set to 10 minutes.
  - Airspace A: 4.977×10^{-8}
  - Airspace B: 2.688×10^{-8}
  - TLS: 5.0×10^{-9}
- The risk of collision is greater than the TLS. Is it risky to introduce 10 min. time separation?

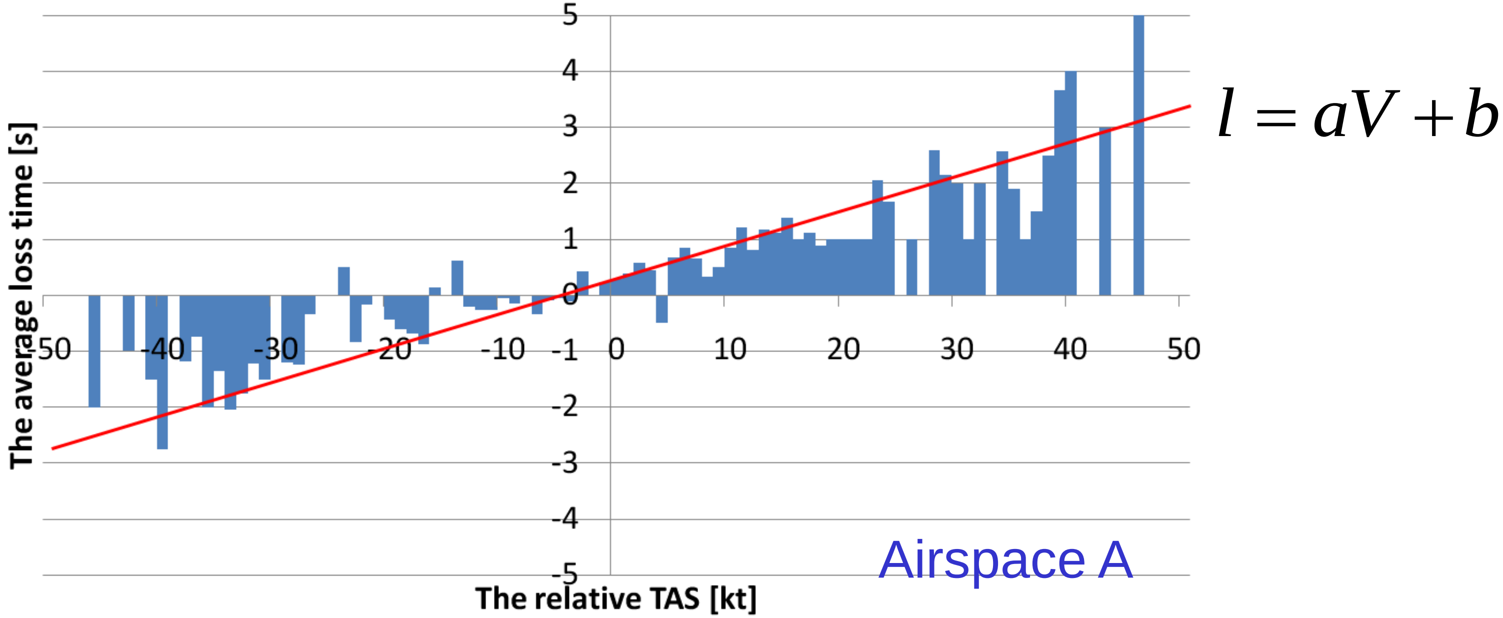
  ➔ The conventional calculation method causes an over-estimation.

Reasons for over-estimation



- The relative speed
  - The distribution model is usually used to model the uncertainty of the system.
  - Assuming that the following aircraft flies faster than the preceding aircraft, a positive loss time is to be expected.
- The range of the initial time separation consisting of the loss distribution
  - Why does the loss distribution consist of the data which have less than **60 minutes** initial time separation?
  - The loss distribution by 60 minutes initial time separation and 15 minutes initial time separation can be different according to some factors (wind conditions..).

The relationship between loss time & relative speed



- A positive relative TAS (true air speed) is defined in the case when the following aircraft flies faster than the preceding aircraft.
- There seems to be a relationship between the relative TAS & the average loss time.

Refined loss time

- Refined loss time: $t_i^{new} = t_i - (a\Delta V_i + b)$
- Refined loss distribution: $l_m^{new}(t)$
- The probability that the loss time is greater than t: $Q_x^{new}(t) = \sum_{\Delta V} e(\Delta V) \int_t^{\infty} l_m^{new}(\tau - (a\Delta V + b)) d\tau$

The relative TAS * the refined loss time
Original loss time distribution
} can be different.

- The distribution of the convolution of the two dependent parameters can be different from the original distribution.

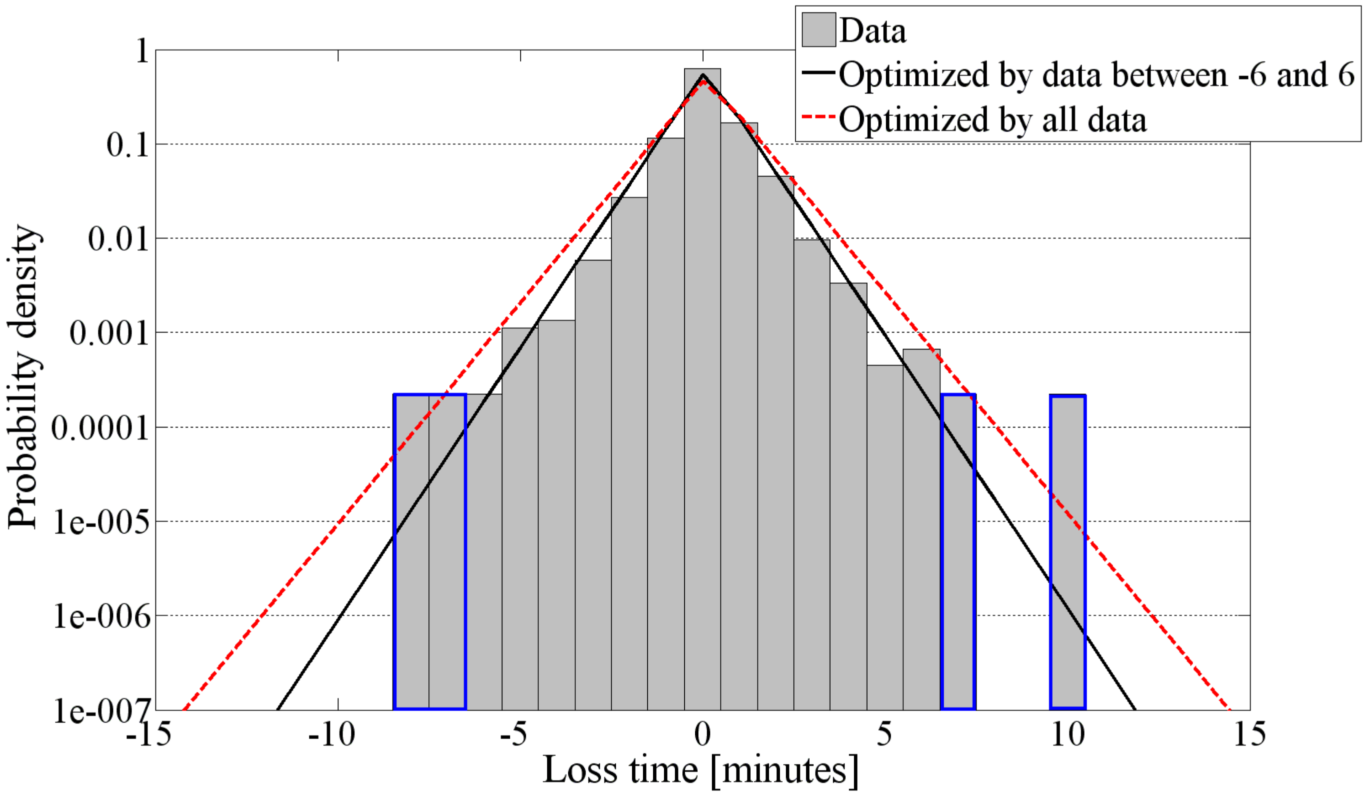
Refined risk of collision (1)

	Risk of collision considering relative TAS	Risk of collision by conventional method
Airspace A	1.949×10^{-8}	4.977×10^{-8}
Airspace B	5.462×10^{-9}	2.688×10^{-8}
TLS	5.0×10^{-9}	

- The risk of collision is decreased when the relative TAS is considered, but is still greater than the TLS.

  ➔Next, the range of the initial time separation consisting of the loss distribution is considered.

Abnormal values



- The black line fits better with the data between -6 and 6 minutes.
  - The distribution gets wider wrongly because of a few abnormal values surrounded by blue rectangles.

Number of abnormal values

Initial time separation x	Airspace A	Airspace B
0 < x <= 20	0/526	0/506
20 < x <= 30	0/1358	0/1262
30 < x <= 40	1/1187	4/1115
40 < x <= 50	1/972	2/862
50 < x <= 60	2/761	2/722

The number of abnormal values / The number of all data

- The result implies that the number of abnormal values depends on the initial time separation.

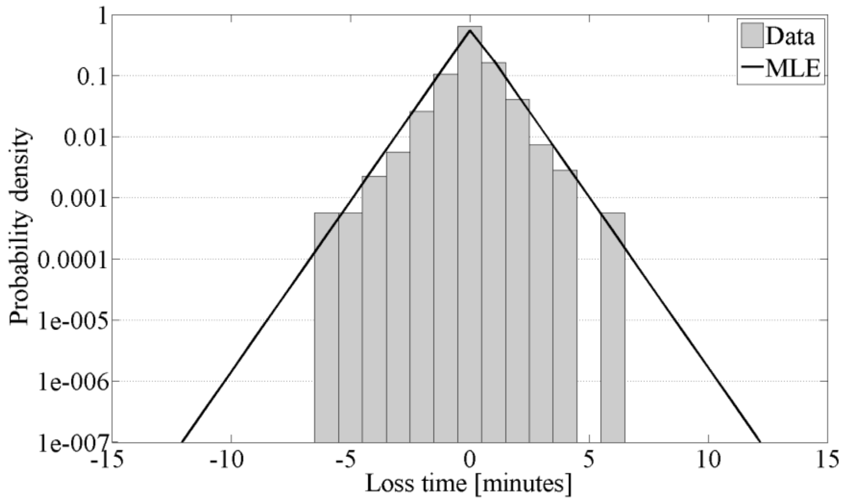
  ➔ Check by binomial test

  – It CANNOT be said that the number of the abnormal values is NOT related to the initial time separation.

The refined risk of collision (2)

	Risk of collision considering relative TAS & 30 min. initial time separation	Risk of collision considering relative TAS	Risk of collision by conventional method
Airspace A	2.394×10^{-9}	1.949×10^{-8}	4.977×10^{-8}
Airspace B	1.425×10^{-10}	5.462×10^{-9}	2.688×10^{-8}
TLS	5.0×10^{-9}		

- The risk of collision is smaller than the TLS in each airspace.



Conclusions

- A safety analysis was conducted under 10 minutes time-based separation in Fukuoka FIR.
  - The conventional safety assessment was likely to cause an over-estimation

  ➔ Two factors were considered:
    - The relative true airspeed
    - The initial time separation
  - Using the refined method, it was proven that the risk of collision was less than the TLS.

This safety analysis was conducted under just one hazardous condition.