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COMMITTEE A

Agenda Item 3: Enhancing the global air navigation system
3.3: Air traffic flow management (ATFM)

A CASE STUDY ON AIRSPACE CAPACITY ESTIMATION APPLYING DIFFERENT MODELS

(Presented by the Republic of Korea)

EXECUTIVE SUMMARY

For successful implementation of the aviation system block upgrades (ASBUs), the accurate estimation of airspace capacity is fundamental, especially in runway sequencing (RSEQ), free-route operation (FRTO) and network operations (NOPS) threads of the ASBUs. This paper presents a case study on airspace capacity estimation which applied two different models, and its results with different capacity. Recognizing the importance of the accurate estimation of airspace capacity for successful implementation of the ASBUs, a globally harmonized method of airspace capacity estimation should be considered.

1. INTRODUCTION

1.1 "Optimum capacity and flexible flights" is one of the four core performance improvement areas (PIA) of aviation system block upgrades (ASBUs). For successful implementation of the ASBUs, the accurate estimation of airspace capacity is fundamental, especially in runway sequencing (RSEQ), free-route operation (FRTO) and network operations (NOPS) in key featured areas of the air navigation system (ASBU threads).

1.2 ICAO provided the guidance material on air traffic services (ATS) sector/position capacity estimation in *Air Traffic Services Planning Manual* (Doc 9426), Appendix C. In addition, recently, the example of a simplified methodology for determining sector capacity to assist ATFM implementation was also provided in the *Manual on Collaborative Air Traffic Flow Management* (Doc 9971), Appendix D.

1.3 The Republic of Korea (ROK) conducted a case study that made an estimate of an airspace capacity on one of the busiest en-route sector in the Incheon flight information region (FIR) which applied two different models: Schmidt model (macroscopic analysis); and Total Airspace and Airport Modeller (TAAM) model (microscopic analysis). This paper provides the result of a case study and highlights the importance of the accurate estimation of airspace capacity for successful implementation of ASBUs.

2. DISCUSSION

2.1 In Doc 9426, two different methods for the estimation of airspace capacity were introduced: Directorate of Operation Research and Analysis (DORATASK Methodology for the assessment of ATC en-route sectors capacity) and Messerschmidt, Bölkow und Blohm (MBB). Moreover, other various models for the estimation of capacity have been developed by States and research institutes.

2.2 Under the concept that the airspace capacity is directly related to the controller's workload, various methods for workload-based airspace capacity estimation were suggested. The methods can be classified into three groups: a) perceived measure that is normally declared by acting controllers; b) analytical approach that addresses the controller workload using mathematical equations; and c) fast-time simulation approach that attempts to measure the controlling time.

2.3 The analytical approach methods include Schmidt model (1973), MBB method (1979), Welch model (2010), etc. The fast-time simulation models, including Re-organized ATC Mathematical Simulator (RAMS Plus), TAAM, Air Traffic Optimization (AirTOp), measure total time spent for controlling activities by identifying controlling events, corresponding activities/tasks and time spent.

2.4 However, the estimation of capacity with different models may give a rise to different results, and imprecise application may cause attenuate the globally harmonization of air traffic management (ATM).

2.5 This case study, having applied aforementioned models: Schmidt model and TAAM estimated the capacity on one of the busiest en-route sector that encompasses Incheon and Gimpo International Airports. Figure A depicts a simplified version of the en-route sector applied for this case study: light grey area (above 1,000 feet AGL); upper portion of dark grey area (above 18,500 feet); and its relevant ATS routes.

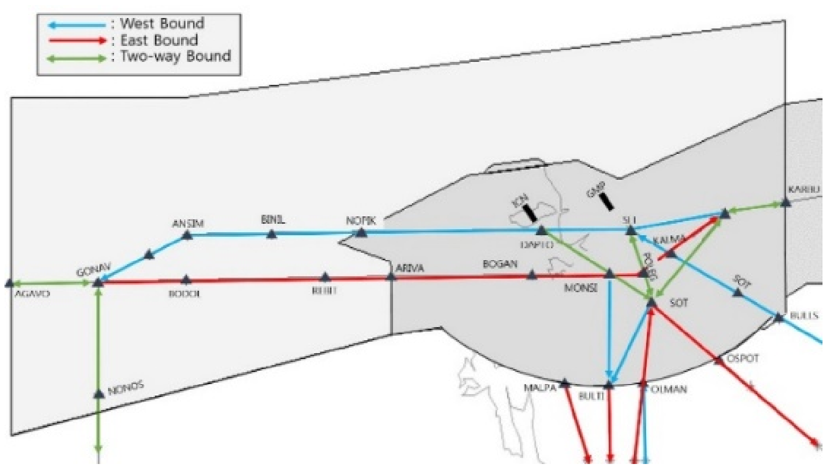

Figure 1. En-route configuration of North Sector in Incheon Area Control Center (ACC)

Airspace Capacity Estimation applying Schmidt Model

2.6 The Schmidt model is an empirical and deterministic model that evaluates the en-route sector capacity based on flight track data. The model based on traffic variables, ATS route and sector geometry, and air traffic control (ATC) procedures to an index that quantifies the controller's workload required for controlling the flights.

2.7 Control difficulty index (CDI) measures the controller's difficulty in controlling the flights within its sector. The index is a weighted sum of frequencies of three types of control events as follows: conflict event; aircraft-overtake event; and routine control event, which are further divided into five sub-events including handoff, point-out, coordination, pilot request, and traffic structuring. Weighting factors are proportional to the time required for each event (Appendix A refers).

2.8 The major results of capacity estimation using Schmidt model are as follows:

a) Prior to applying the Schmidt model, actual ATC radar track data and ATC communication data are intensively analysed to measure the control event processing time and weighting factors. The measured value are identified in Table 1;

<table>
<tr><th colspan="2">Type of Control Event</th><th>Time(sec)</th><th>Weight factor(W)</th></tr>
<tr><td colspan="2">Crossing conflict</td><td>30</td><td>1.14</td></tr>
<tr><td colspan="2">Overtake conflict</td><td>30</td><td>1.14</td></tr>
<tr><td rowspan="5">Routine Control</td><td>Hand off</td><td rowspan="5">7.69</td><td rowspan="5">0.29</td></tr>
<tr><td>Point out</td></tr>
<tr><td>Coordination</td></tr>
<tr><td>Pilot request</td></tr>
<tr><td>Traffic structuring</td></tr>
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Table 1. Event Processing Times and Weighting Factors measured in this Case Study

b) Reflecting the above measured value, the frequency of conflict events (E_c) at ATS route intersection, the expected frequency of aircraft overtake events (E_o) and the frequency of routine control events (E_r) have been calculated as follows: a) E_o = 2.66; b) E_c = 0; and c) E_r = 3.89; and

c) The weighted sum of routine events, calculated with the routine event processing time, and its weight factor and frequency of routine control events, is 1.14. In result, the en-route sector capacity (N_c) of this case study is 68 flights per hour.

Airspace Capacity Estimation applying TAAM Model

2.9 The TAAM, a microscopic fast-time simulation model, represents each aircraft movement in 4-dimension (x, y, z and time) domain. Based on heading and speed of each aircraft along with its performance, the simulation model tracks the aircraft position at every interval (i.e., 1 sec). The model also triggers the ATC activities/tasks for routine work and/or needed for resolving potential conflicts. The estimation process of TAAM is described in Appendix B.

2.10 This TAAM analysis was carried out using the same traffic data which were used in the aforementioned Schmidt model analysis. At every interval (e.g., every 5 minute), the TAAM provides information on different types of traffic flow (i.e., numbers of arriving, departing and over-flying aircraft during each interval) and total amount of time that ATC spent to control the traffic during each interval.

2.11 Employing the different types of traffic flow as dependent variables and the total time spent for ATC activities as the dependent variable, a multiple regression equation for time duration spent for ATC control is obtained. The resulting equation was "Time spent for air traffic control (in minutes) = 1.3(No. of Arrivals per hr) + 0.63(No. of Over-flights per hr) + 0.05(No. of Arrivals per hr)(No. of Departures per hr) + 0.01(No. of Departures per hr)(No. of Over-flights per hr)."

2.12 The average ATC workload at capacity must be less than eighty per cent. Therefore, in this capacity analysis, it is assumed that a sector reaches its capacity when ATC controller(s) spends 48 minutes (i.e., 80% of an hour) to handle its traffic. Applying the 48 minutes to the regression equation, the equation for capacity is "48 minutes = 1.3(No. of Arrivals per hr) + 0.63(No. of Over-flights per hr) + 0.05(No. of Arrivals per hr)(No. of Departures per hr) + 0.01(No. of Departures per hr)(No. of Over-flights per hr)."

2.13 Figure 2 depicts the capacity surface given by the equation. Any point on the surface shows a capacity of the sector studied. In other words, the simulation approach provides multiple capacity values for different traffic patterns.

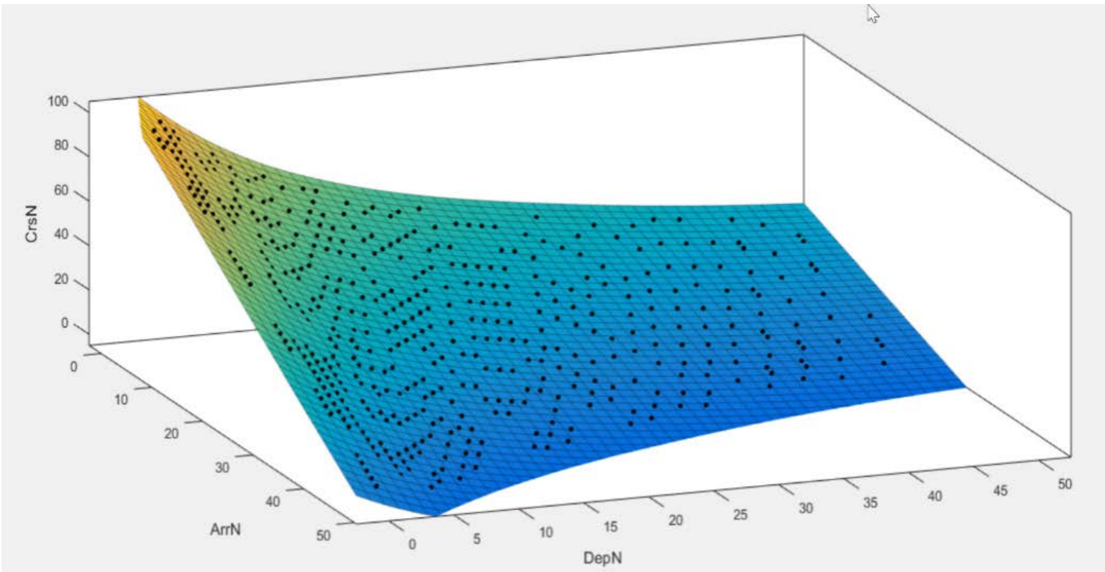

Figure 2. Capacity Surface from TAAM Analysis

2.14 Table 2 illustrates sector capacities estimated in different traffic patterns. As seen in the table, capacity values ranges from 59 to 66 flights per hour depending on the traffic pattern.

Patterns	**Arrivals /hr**	**Departures /hr**	**Over-Flights /hr**	**Capacity Estimated** (Flights/hr)
Arrival Dominated (50:25:25)	29	15	15	59
Departure Dominated (25:50:25)	16	32	18	66
Over-flight Dominated (25:25:50)	15	16	34	65
Equally Distributed (33:33:33)	21	21	20	62

Table 2. Sector capacities for four traffic patterns

2.15 In conclusion, the major results from the simulation approach are as follows:

a) the average number of routine controls per flight is 2.3, and average time taken per routine control is 23.04 sec. It should be noted that time durations for activities used in the analysis are the default values imbedded in the simulation model;

b) compared to Schmidt model, the time required for each routine control is considerably high. This might be the explanation why the capacities estimated from the two methods are noticeably different; and

c) it should be also pointed out that an advantage of using simulation analysis is that it can be applied to a newly designed route whereas the track-based mathematical model cannot be applied.

3. CONCLUSION

3.1 With the case study on estimation of airspace capacity, it is assumed that the different capacity models and methods might cause divergent results. The point is that the accurate method with international standard guidance is essential component to estimate the optimized airspace capacity. Recognizing the importance of accurate estimation of airspace capacity for successful implementation of the ASBUs, a globally harmonized method of airspace capacity estimation should be considered.

3.2 The Conference is invited to take note of the information contained in this paper.

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APPENDIX A

THE FORMULA OF SCHMIDT MODEL

1. $CDI = \sum_i W_i E_i$, Control Difficulty Index (CDI) measures the controller's difficulty in controlling the flights within its sector. The index is a weighted sum of frequencies of three types of control events: i) conflict event (E_c); ii) aircraft-overtake event (E_o); and iii) routine control event (E_r), which are further divided into five sub-events including handoff, point-out, coordination, pilot request, and traffic structuring. Weighting factors (W_i) are proportional to the time required for each event.

Type of Control Event		Time(sec)	Weight factor(W)
Crossing conflict		60	2.28
Overtake conflict		60	2.28
Routine Control	Hand off	6	0.23
	Point out	12	0.46
	Coordination	6	0.23
	Pilot request	5	0.19
	Traffic structuring	5	0.19

Table 1. Event processing times and weighting factors

2. $E_c = \sum_i \frac{2 f_{i1} f_{i2} X (V_{i1}^2 + V_{i2}^2 - 2V_{i1}^2 V_{i12}^2 cos\alpha)^{1/2}}{V_{i1}^2 V_{i2}^2 sin\alpha}$ The frequency of conflict events (E_c) at ATS route intersection is a function of aircraft flow rate (f_{i1}, f_{i2}), velocity of each route (v_{i1}, v_{i2}), minimum separation requirement (X), the angle of intersection between the routes (α) and number of flight levels (i).

3. $E_0 = \sum_{i=1}^{n-1} \frac{(l+2X) f_i}{v_i} \cdot \sum_{k=i+1}^{n} \frac{f_k}{v_k} |v_i - v_k|$, The expected frequency of aircraft-overtake events (E_o) is a function of length of air route (l), flow rate of aircraft (f_i), difference of two average speeds ($|v_i - v_k|$), minimum separation requirement (X).

4. $E_r = k_i N_H$, The frequency of routine control events is a function of the number of aircraft controlled (N_H) and average number of routine event type i (k_i). Routine event type i and corresponding average number of the event (ki) are given in Table 2.

Event Type (*i*)	Average number of event frequency per flight (k_i)
Coordination	0.4
Pilot request	0.1
Traffic structuring	6.0
Hand off	2.0
Point out	0.3

Table 2. Average event frequency coefficients

5. $W_c E_c (N_c/N_0)^2 + \bar{k} N_c = 100$, Sector capacity ($N_c$) is found when the CDI scale (given in left hand side of the equation) reaches 100. In the equation, the scale is a function of N_o (= E_c+E_o, i.e., frequency of potential conflicts at the current demand) and $\bar{k} = \sum_{i=1}^{n} w_i k_i$(i.e., weighted sum of routine events) with given in Tables 1 and 2.

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APPENDIX B

AIRSPACE CAPACITY ESTIMATION PROCESS OF TAAM MODEL

1. When an aircraft enters a sector, TAAM assumes that the sector controller accomplishes an accept-handoff task that consists of four activities including assessing separation, receiving neighbor contact, receiving pilot contact and confirming handoff letter of agreement (LOA).

2. Table 1 shows an example of four controlling activities needed for carrying out the "accept-handoff" task. The duration in the last column of the table shows the amount of time needed to accomplish controlling activities/tasks.

3. The TAAM includes total 27 controlling tasks, each of which is defined by selectively using 64 control activities.

Airspace event	**Tasks**	**Activities codes**	**Activities Descriptions**	**Duration (sec)**
Sector entry	Accept-handoff	ASEP	Assess actual separation	3
		CGOTNBR	COMMS- Receive Neighbor Contact	6
		CGOTPIL	COMMS-Receive Pilot Contact	5
		CHOLOA	COMMS-Confirm Hand off LOA	10

Table 1. Example of a Control Task and Activities in TAAM

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