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Operational Feasibility Assessment of the Free Route Airspace concept in the ASEAN Region

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Free Route Airspace (FRA) allows airspace users to freely plan a route in en-route airspaces within certain restrictions, and it is anticipated that the FRA offers the benefit of fuel saving and flexibility. In this paper, the benefits and operational feasibility of the Free Route Airspace concept within the ASEAN consisting 12 Flight Information Regions (FIRs) are evaluated using fast-time simulation. We simulated approximately 10000 flights per day for 15 days (or double the volume of it) for two routing scenarios (conventional Air Traffic Services airways rules vs. FRA rules). Results showed that traffic efficiency metrics are fewer in FRA than in the conventional rules via Air Traffic Services airways, with approximately 2 % improvement in fuel burn, flight duration and flown distance. The number of potential conflicts, an operational feasibility metric, was fewer in FRA. When zooming into individual FIRs, we found that local FRA routing rules could be added to avoid cluster of conflicts. This study presents one of the first systematic benefits and operational feasibility studies of FRA in the Southeast Asia region. All results considered, this study presents an initial confirmation and prospect towards application of the FRA concept in the region.

Key Words : Free Route Airspace, Environment, Air Traffic Management, ASEAN airspace, Fast time simulation

1. Introduction

Free Route Airspace (FRA)[1,2] lets airspace users (AUs) to freely plan a route in en-route airspaces within certain restrictions such as avoiding special use airspaces including military airspaces as well as entry and exit waypoint requirements. It is a stark contrast to the more common routing rule via Air Traffic Services airways and other published routing in Aeronautical Information Publication. FRA offers the benefit of fuel saving and planning flexibility to the AUs.[3] At the same time, at least in its deployment in Europe, air traffic controller workload has not been increased due to the introduction of FRA, and safety has not been compromised. Whereas the FRA implementation is mandated in European Commission, there is no FRA application outside of Europe to date.

Against the background of the introduction of FRA a more flexible air traffic and airspace management is needed. The sector-less approach[4] is limited to a maximum number of six flights that an air traffic controller can monitor (cf.[5]) and validation scenarios show only slight improvements over current procedures.[6] Especially for more complex traffic scenarios, a higher workload is to be expected despite support by advanced controller working position.[7] Approaches for dynamic airspace configuration[8] and sectorization[9] show an appropriate solution to handle a different amount of traffic over the day of operations but still consider the concept of sectors.

As FRA provides airspace users with a new degree of freedom to choose their preferred routes, it also results in a more heterogeneous, disordered traffic pattern. Since traffic complexity increases controller workload, sector capacities could be affected by new traffic management concepts. Traffic complexity considers, for example, individual flight characteristics (e.g., changes in altitude, heading, speed) or interactions between two or more flights.[10] The latter is addressed by determining potential conflicts, which are significantly determined by the disorder among aircraft, which is driven by, for example, the variability of heading and speed.[11] Optimized, flow-based, aligned structures may reduce the complexity of traffic situations, decrease workload, and increase airspace capacity.[12] In the future, operational FRA systems must be able to bundle user-oriented trajectories and offer dynamic control structures for efficient and safe flights.

This paper provides an operational feasibility assessment of the FRA concept, applied to the ASEAN en-route airspaces. We aim to identify and advise on regional or local limitations that hinder deployment through a macroscopic Fast-Time Simulation (FTS) study. We further evaluate the efficacy of FRA in the eventual traffic demand, projected to be double in late 2030s in the Asia Pacific (APAC) regions.

2. Airspace and routes configuration

Today's Air Traffic Services route network in the ASEAN region are depicted in Figure 1. Keeping to the Transfer of Control (TOC) waypoints and the directionality between the Area Control Centres in the region, we sketch a realisation of the FRA concept in the region, where direct traffic is made between (1) the horizontal entry waypoint or the end of the departure procedures (SID, Standard Instrumental Departure Route) and (2) the horizontal exit waypoint of the beginning of the arrival procedures (STAR, Standard Arrival Route), where restrictive areas (prohibited, danger, or restricted) are avoided via the shortest circumference (Figure 2).

3. Simulator experiments

3.1. Design of experiment

A 2 $\times$ 2 factorial design on two factors (traffic volume and lateral routing) are considered in this study. Traffic volume represents the demand for the commercial use of the ASEAN airspaces, having two levels (pre-COVID19, and double of it). Lateral routing represents the lateral routing rule, also having two levels (the conventional ATS Route Network rules and the FRA rules, assumed to follow direct routing via TOC waypoints at FIR boundaries). The scenarios are coded as shown in Table 1.

Table 1 Simulation scenarios.

Code	Lateral routing	Traffic volume
Pre-COVID19 ATS	ATS	Pre-COVID19
Pre-COVID19 FRA	FRA	Pre-COVID19
Double ATS	ATS	Double
Double FRA	FRA	Double

As for simulation repetition (i.e., number of days), we run continuous 15 days of simulation in which a day starts at 00:00 UTC and ends at 23:59 UTC. There is necessary warm-up and cool-down hours, but these hours are not monitored for metrics. The period captures a typical busy season, specifically 13-27 December 2019 for the current scenario. The period 13-27 December was previously identified in a Singapore study for year 2016, based on the en-route flight count in Singapore. The synopsis of the traffic scenarios is provided below (Table 2, Table 3, Figure 3).

3.2. Monitored metrics

The following metrics are extracted from simulation runs and used for comparison between the scenarios.

For the environment Key Performance Area:

- Fuel burn (kg).
- Flown distance (NM).
- Flight duration (hour).

For operational feasibility:

- Potential conflict: Potential conflicts are identified when any two aircraft lose both lateral and vertical separation requirements (<5 NM and <1000 feet, respectively). Potential conflicts are assumed to be resolved in real operations (not simulated in this study), either by ATFM measures, pre-tactical planning, or tactical ATC.
- Classification of potential conflicts: 3 types of vertical conflict types [Both Cruising, One In Vertical, Both In Vertical], and 3 types of lateral conflict types [Same Track, Crossing, Opposite] – i.e., total of 9 combination types – are recorded.
- Cluster of potential conflicts: A cluster represents a chain of potential conflicts that happen within an 8-minute time window.[13)] For example, if a time window contains potential conflicts between flights A and B, A and C, B and C, A and D, as well as B and D, then the cluster has 5 conflicts and is involved by 4 aircraft A, B, C and D.
- Cluster size: Cluster size refers to the number of aircraft involved in a cluster. In the above example, the size is 4. The greater the cluster size is, the more challenging the ATC provisions typically becomes.
- 'Large' clusters: We follow an understanding that conflicts of a cluster involving many aircraft are challenging to resolve. In this study, we use a convenient term 'large' to refer to clusters size 6 or greater (involving 6 aircraft or more).

3.3. Simulated airspace and simulator

We consider the following airspace configuration (Table 4) for the simulation scope. We deploy the fast-time simulator AirTOp in this study. In its simulator setting we did not simulate Air Traffic Control. In other words, we do not instruct the simulator to detect conflicts in advance or resolve them. Instead, the simulator is configured to report the duration of the conflict, i.e., time at which both separation requirements are not met, and the subsequent time at which one of the separation requirements is met.

3.4. Traffic scenarios

For the purpose of running this simulation study, the term traffic refers to the following: a set of flights with information on origin and destination aerodromes, aircraft type, entry point into the studied airspace, time at the entry point into each FIR, and cruising altitude (or RFL), as well as lateral routing (point to point routing). We refer to flight schedule data for constructing simulation traffic. See Table 5 for the overview of these data requirements.

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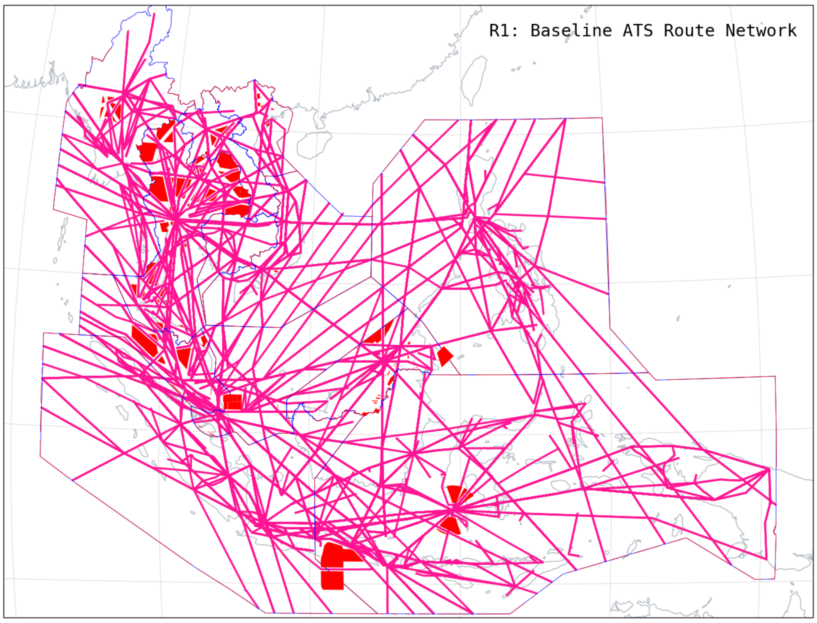

Fig. 1 Baseline ATS route network of ICAO airways in the region

Table 2 Synopsis of traffic scenarios.

Class	Coding	High-level representation	Main description
Traffic volume	Pre-COVID19	Pre-COVID19 busiest demand	Approximately 10000 flights per day (for entire ASEAN)
	Double	Possible future demand in late 2030s or early 2040s	Double of Pre-COVID19
Lateral routing	ATS	Present routing rules	ATS airways + STARs/SIDs
	FRA	Alternative (FRA) routing rules	DCT segments between the TOC waypoints (avoids D areas, FIR boundaries) + STARs/SIDs

3.4.1. Lateral routing: general

We consider 2 levels of lateral routing: ATS Route Network (to represent the baseline) and FRA. Common to both routing scenarios are about departure and arrival routing, namely:

- Use of SIDs where available, and
- Use of STARs where available.

The ATS and FRA scenarios differ in routing between the end of the SID and the beginning of the STAR. If airspace data regarding SID and STAR are not available, the routing via a nearby waypoint or navigation aid is created. For ease of reading, we refer to either the end of SID or the origin aerodrome for the case without SIDs as simply the entry waypoint (the entry to en-route routes). Likewise, we refer to either the beginning of the STAR or the destination aerodrome for the case without STARs as simply the exit waypoint (the exit from en-route routes). We consider entry and exit waypoints in a similar manner as FRA Horizontal Entry/Exit Points or FRA Arrival/Departure Connecting Points (E, X, A, D, respectively). Table 6 indicates how these points are decided.

3.4.2. Lateral routing: ATS Route Network

The ATS Route Network scenario represents the routing rules presently applied and serves as the baseline. As the name suggests, the routing is via airways in the ATS Route Network. We refer to static airspace data by Lido, which are based on AIPs in the region, dated as of February 2021. However, owing to the lack of detailed local knowledge regarding routing restrictions, we have limited veracity of real operations. We compute the shortest path from the entry waypoint to the exit waypoint via the network (segments) of airways. We retain the directional nature of TOC waypoints as in the present operations. We use a simple Dijkstra's algorithm[14)] with the cost (weight of the edges of the graph) being scaled to the distance and vertices being the waypoints and the aerodromes.

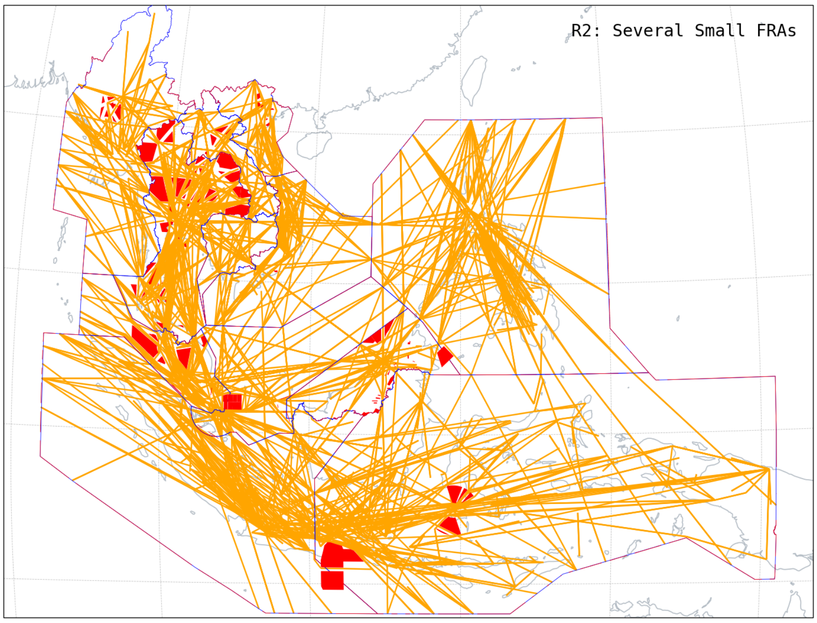

Fig. 2 Hypothetical Free Route Network routes studied in this paper

Table 3. Number of simulated flights (per day, 90th percentile) in each scenario. The numbers for the ATS and FRA scenarios slightly differ due to a shorter routing set which might traverse a different set of FIRs en route.

FIR designator	Name	Pre-COVID19 ATS	Pre-COVID19 FRA	Double ATS	Double FRA
RPHI	Manila	1444	1445	2887	2889
VDPF	Phnom Penh	459	443	1013	972
VLVT	Vientiane	1036	1068	2282	2340
VTBB	Bangkok	2475	2482	5137	5158
VVHM	Ho Chi Minh	2027	1992	4128	4062
VVHN	Hanoi	1174	1175	2460	2461
VYYF	Yangon	907	907	1841	1840
WAAF	Ujung Pandang	2092	2080	4190	4166
WBFC	Kota Kinabalu	608	592	1217	1182
WIIF	Jakarta	2387	2337	4771	4673
WMFC	Kuala Lumpur	1896	1896	3800	3804
WSJC	Singapore	1880	1855	3775	3730

3.4.3. Lateral routing: Free Route Airspace

The FRA lateral routing scenario represents a possible near-time-horizon implementation of FRA in the ASEAN region, where the existing TOC waypoints at the FIR boundaries are considered. This near-term FRA could are based on 'several small' FRAs, and can be contrasted for a more ideal longer-time-horizon implementation of 'single large' FRA, where all individual FRAs are collapsed into a big cross-border FRA (not studied in our simulation).

We consider military use of certain airspaces to be excluded from usage by commercial traffic. The routing is determined (or 'drawn') according to the following. From the entry waypoint or the beginning of the en-route phase (i.e., the end of SID), all connecting TOC waypoints interfacing to adjacent FIRs are considered, thereafter a network of TOC waypoints to TOC waypoints are considered as possible segment candidates. This is repeated in the next FIR. Ultimately, the segment connection arrives at the destination FIR, in which the route from the TOC waypoint candidates to the exit waypoint or the end of en-route phase of flight are considered (i.e., at the beginning of STAR). This exercise creates a mathematical graph of all possible routes, with which we could compute the shortest path according to the Dijkstra's algorithm. The following matters are additionally considered:

- Avoiding restrictive areas. P (prohibited), D (danger), R (restricted) areas are considered as 'airspace reservation' and routings must avoid them with minimum 2.5 NM around it. We compute the shortest path while avoiding these areas using a mathematical algorithm.
- Staying within the FIR. The FRA routing within an FIR must remain in the FIR unless some arrangements are made with the adjacent control authorities. In this study we assume that such arrangements where a short cutting of routing into adjacent ACC or FIR is not made. The flights are to stay away from the FIR boundary with minimum 2.5 NM around it.
- Direction at TOC waypoints. We retain the uni-

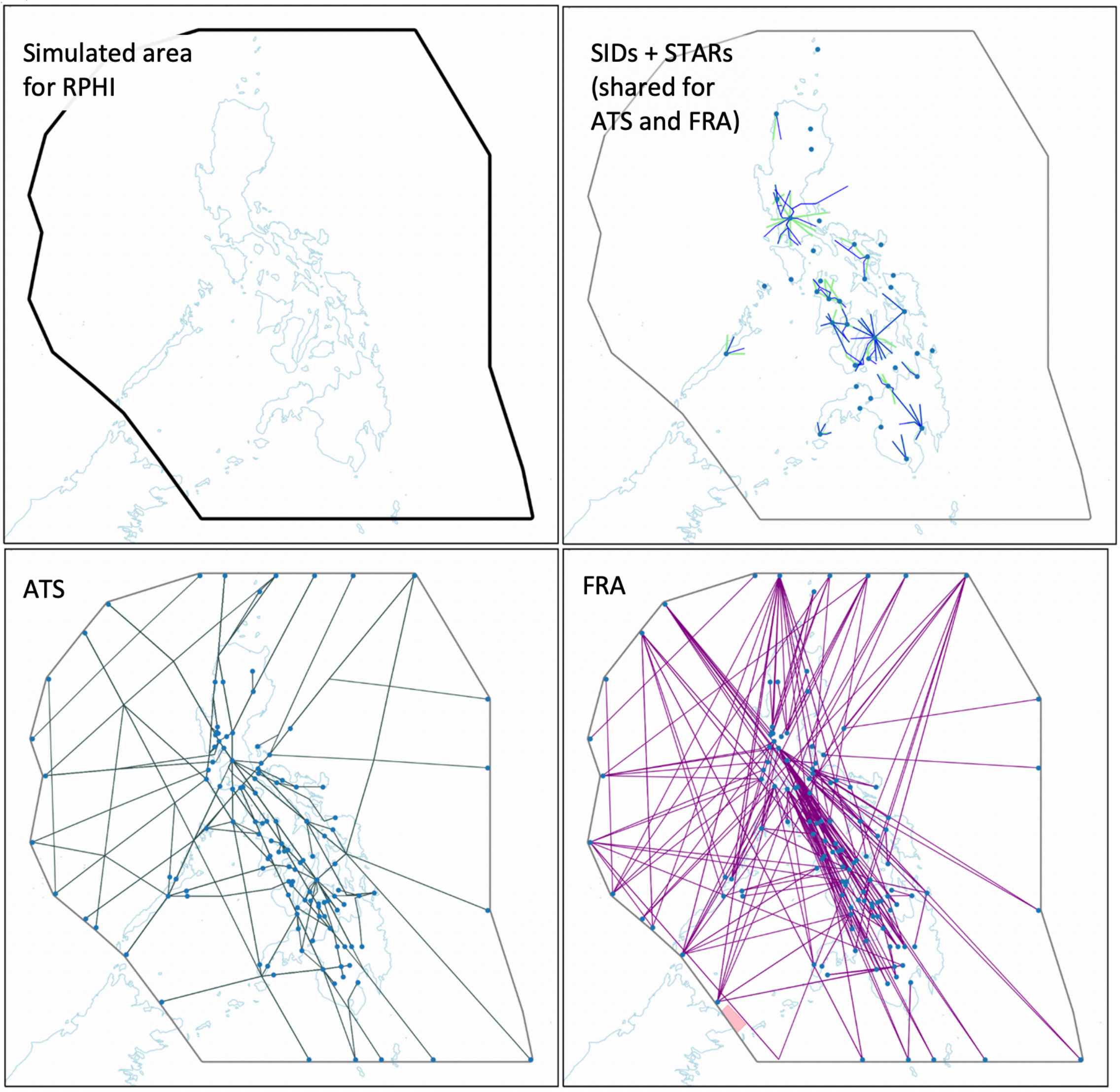

Fig. 3. Example of simulated routing: (upper left) simulated area, (upper right) routing for departures and arrivals, (lower left) en-route routing in the ATS scenario, (lower right) en-route routing for FRA scenario, for the Manila FIR (RPHI) in this simulation study.

directional nature of the TOC waypoints as in the present operations.

3.4.4. Traffic volume: general

We consider two levels of volume of traffic in this study: Pre-COVID19 and Double. Traffic volume scenario affects entry waypoint time-over and RFL.

3.4.5. Traffic volume: Pre-COVID19 scenario

First, we describe the Pre-COVID19 traffic volume scenario. The Pre-COVID19 traffic volume scenario represents the latest typically high season traffic of the pre-COVID19 era (13-27 December 2019).

The flight schedule data offers departure time as ticketed for passenger purchase. As such, it is not a precise or accurate representation of take-off time and subsequent trajectory (trackpoint times, passing times for waypoints), for which potential conflicts are relevant. Recognising this challenge, we back-compute departure time in the simulation by time-shifting the entire 4D trajectory of the flight, while we create 4-minute intervals at entry waypoints. The 4-minute intervals are computed separately for layers of RFL. By introducing the 4-minute time interval we roughly represent the impacts of

- the ATFM measures and
- ATC provisions (e.g., effecting necessary manoeuvres for maintaining separation) in the upstream airspaces, such as the departure TMAs or preceding FIRs on the traffic flow.

The 12 FIRs of ASEAN (Table 3) are simulated separately for areas in which ATC services are provided by their respec-

Table 4 Elements of airspaces considered in this study.

Airspace Element	Details
Vertical Limits	'Floor' at FL130; to account SID legs and STAR legs that stick out above FL130 to be counted for additional filtering of conflicts, and merging point time, vertical and profile
Horizontal Extents	All 12 FIRs in ASEAN
Flight Level Assignment	Combination of semicircular FLOS, South China Sea FLAS and Vietnam FLAS
Military Airspaces	Consider all P, D, R areas that are above FL130 and restricted most of the days, except airways that cut across them.
Internal Transfer of Control (TOC) Points, or TOC waypoints between 2 ASEAN FIRs	Geographical locations and unidirectional nature (if applicable) considered in ATS Route Network and FRA scenarios. The full details of LOAs regarding TOC procedures are not simulated. Parameters such as time intervals, any vertical movements, cruising levels, headings and turn angles at TOCs in simulation have been computed for readers to separately identify possible discrepancies if they are able to do so.
Externally Facing TOC waypoints, or TOC waypoints between an ASEAN FIR and a non-ASEAN FIR	Geographical locations and unidirectional nature (if applicable) considered in all scenarios. Parameters such as time intervals, any vertical movements, cruising levels, heading, and turn angles at TOCs in simulation have been documented for readers to separately identify possible discrepancies if they are able to do so.
Air Traffic Control	No ATC provided.

Table 5. Overview of data for constructing traffic in this simulation.

Traffic elements	Data availability	Needed for simulation
Nature of data	Schedule, only plans (not accurate timing)	n/a
Coverage of population of flights	Scheduled commercial passenger flights, representing the demand	Ideally all civil flights
Origin aerodrome	Yes	Yes
Destination aerodrome	Yes	Yes
Aircraft type	Yes	Yes
Entry point and time	No	Only either is needed
Departure time	Yes but not accurate	
Cruising altitude	No	Yes
Lateral routing	No	Considered separately in 2 scenarios

Table 6 Entry and Exit waypoints considered in simulation.

Origin or destination aerodromes		Entry	Exit
ASEAN airports	STAR/SID exists	End of SID	End of STAR
	STAR/SID does not exist	Runway	Runway
non-ASEAN airports		First TOC waypoint into ASEAN FIRs	Last TOC waypoint out of ASEAN FIRs

tive ACC(s), resulting in 12 separate simulation runs for a scenario. Longitutional separation at 4-minute intervals for each RFL are imposed, if necessary, only at the entry into respective airspace. As a result, for a flight flying from FIR A to FIR B (thus traversing between 2 simulation runs), the exit time and flight level from FIR A at a TOC waypoint, may not always coinside with the entry time and flight level into FIR B at the same TOC waypoint.

3.4.6. Traffic volume: Double scenario

In Double scenario, the cloned flights are set in addition to the original Pre-COVID19 scenario along the time axis, somewhere near the original time. We consider the two approaches depending on the frequency of a city pair (origin-destination, or OD pair).

- For a frequented OD pair, we assume that the double demand shall manifest in the same hourly time slot. Thus, cloned flights are inserted while maintaining 4-minute time intervals. If the slot is full and flights overflow, we lower the cruising level of spill-over flights to the next available level. We also consider time changes within an hour slot for lowered flights, to minimise the lowering.
- For a less-frequented OD pair, we assume that double demand manifests 3 hours after the original time. We consider the same spill-over-flights-to-next-level mechanism as frequented OD pairs.
- We define that an OD pair is considered frequented that have more than 3 flights a day on average (45 or more flights in the 15-day simulation period of 13-27 December 2019).

4. Results

An example traffic situation for FRA Double scenario at FL400 is shown in Figure 4. The presented figure consists of 12 separate smaller simulations.

4.1. Cross-FIR vs FIR-specific

Because we have 12 FIR-specific simulations representing a traffic across FIRs, we have two types of aggregations presented here: (i) cross-FIR metrics and (ii) FIR-specific metrics.

Cross-FIR metrics are summation of metrics from the 12 FIR-specific simulations, following each flight, from the entry waypoint into an en-route airspace in ASEAN to the exit waypoint out of an en-route airspace in ASEAN. Unlike the FIR-specific metrics, these cross-FIR metrics may high-

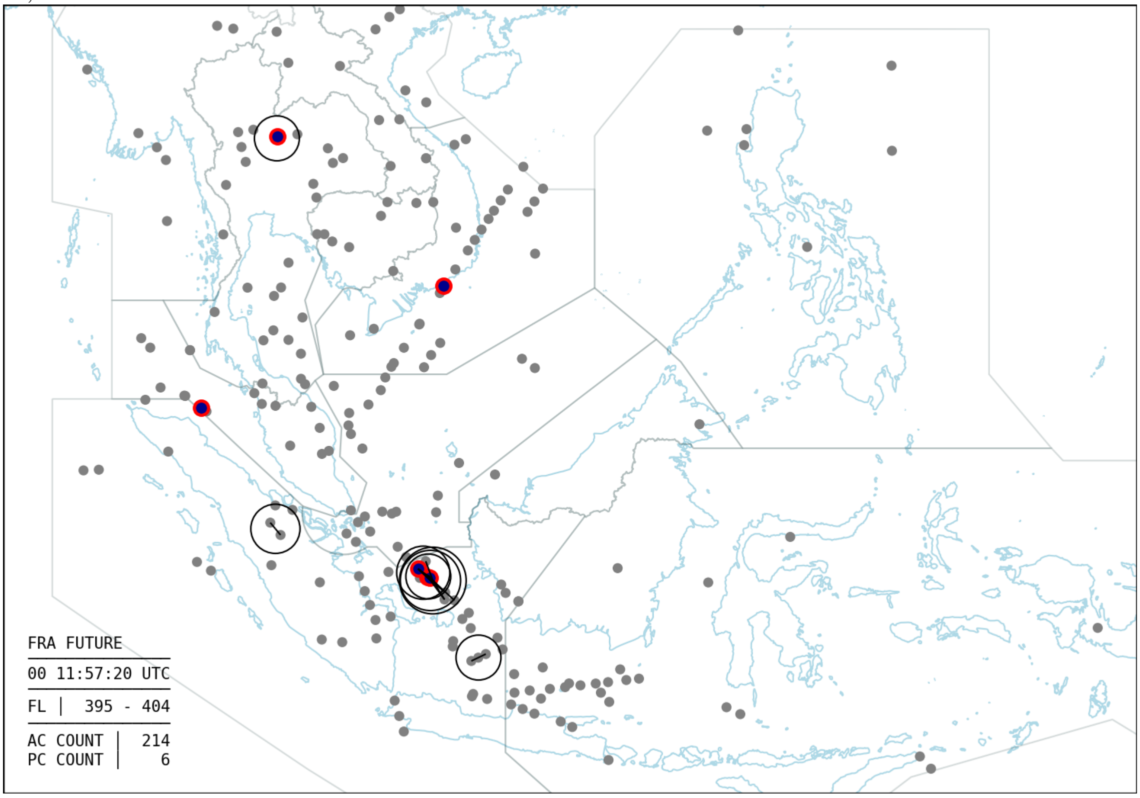

Fig. 4. An example traffic situation for FL400 under the future FRA scenario. The potential conflicts are not resolved in this simulation study and indicated in red. The cluster of potential conflicts, which are a chain of potential conflicts within an 8-minute window, are shown in black circle, with the size of circle corresponding to the size of cluster, or the number of aircraft participating in the cluster.

light more efficient full-course routings brought about by an ASEAN FRA. Airspace users may choose to alter:

- The sequence of FIRs that a flight transits through; and
- The routing of a flight within an FIR, which might be shorter/longer and might enter/exit via a different TOC waypoint.

It is therefore possible that some FIRs may face more flights transiting and/or with longer routing, whereas other FIRs may encounter fewer flights. This may bring about some changes in ATS workload in respective FIRs (Table 7).

4.2. Cross-FIR metrics

In this section we present the cross-FIR, flight-specific metrics for operational feasibility (Table 8). These are useful when one evaluates the overall, macroscopic benefits of the FRA concept.

4.2.1. Lateral routing comparison

Compared with ATS, FRA yielded more favourable values in all en-route cross-FIR metrics relating to Environment KPA and Potential Conflicts. These include (in Pre-COVID19 scenarios): 8.6 % fewer en-route potential conflicts, 51.5 % fewer large clusters of potential conflicts , 2.3 % shorter flight time, 1.2 % less fuel burn, and 2.0 % shorter distance, as well as (in Double scenarios): 10.0 % fewer en-route potential conflicts, 49.8 % fewer large clusters of potential conflicts , 2.2 % shorter flight time, 1.3 % less fuel burn, and 1.9 % shorter distance.

Our results confirm the utility of FRA (i.e., favourable metrics achieved simply by allowing lateral routing changes within FRA rules), irrespective of the traffic volume.

4.2.2. Traffic volume comparison

Although there are improvements with FRA, all the Double scenarios serving double traffic volume may pose operational feasibility challenges compared with the Pre-COVID19 traffic volume scenarios (pre-COVID19). For example, there are approximately 4 times more potential conflicts in Double scenarios than those in Pre-COVID19 scenarios. Similarly, there are approximately 20 times more large clusters in Double scenarios than those in Pre-COVID19 scenarios. These challenges are largely due to the sheer increase in traffic volume and additional ATM concepts would be needed to mitigate them.

Table 7 Benefits and possible concerns of FRA seen from various perspectives.

Perspective	Benefits of FRA compared with ATS	Concerns of FRA compared with ATS
(FIR-specific) 'FIRs with greater demand (in FRA than in ATS), where the ANSPs serve more flights for a longer time flown.	In some traffic patterns the ANSP might still enjoy fewer potential conflicts despite more flights, more flight distance, more flight time.	Concerns on having more potential conflicts, more flights to provide ATS, longer flight distance and time to provide ATS. Changes in hotspots.
(FIR-specific) 'FIRs with less demand (in FRA than in ATS)	Fewer potential conflicts, fewer flights to provide ATS, shorter flight distance and time to provide ATS.	Changes in hotspots.
(Cross-FIR) Environment KPA	Less fuel burn	Nil

Table 8 Cross-FIR daily metrics based on 15-day-long simulation.

	Pre-COVID19 Scenarios			Double Scenarios		
	ATS	FRA	Difference (%)	ATS	FRA	Difference (%)
Potential Conflicts (total)	2765	2320	-16.1	10842	8818	-18.7
Potential Conflicts (+FL285)	1983	1603	-19.2	7752	6025	-22.3
Potential Conflicts (FL130-FL285)	812	736	-9.4	3156	2839	-10.0
Large Clusters	33	16	-51.5	630	316	-49.8
Flight Time (hour)	9447	9234	-2.3	19187	18774	-2.2
Fuel (tonne)	30172	29803	-1.2	61519	60721	-1.3
Flight Distance (NM)	4130964	4050209	-2.0	8421259	8258392	-1.9
Number of Flights	9915	9915	0	20158	20158	0

4.3. FIR-specific metrics

Table 9 presents the total count of potential conflicts as well as count layers by upper en-route (above FL285) and lower en-route (FL130-FL285) airspace, with the boundaries at FL130 and FL285 chosen at convenience for presentation purpose. In most scenarios, the potential conflict counts are lower in FRA than in ATS, as expected. For the Pre-COVID19 traffic scenarios, there were instances when conflict counts were lower in ATS than in FRA (highlighted in green).

The following are the possible explanations for FRA yielding more potential conflicts.

- More flights in FRA than in ATS (VLVT Vientiane FIR and VTBB Bangkok FIR). These two FIRs are located centrally and along the direct great world circle between origin and destination (if both ASEAN) or between entry to ASEAN and the destination (if non-ASEAN origin), or the origin and the exit from ASEAN (if non-ASEAN destination).
- Routing overlapping due to the new routing in FRA environment (VYYF and WSJC).

Table 10 presents the metrics related to the clusters of potential conflicts, which are additional metrics that aim to represent traffic complexity that add on to the ATC workload. Observing the Double scenarios, we note that both the number of large clusters and the maximum size of potential conflict clusters are fewer and smaller in FRA than in ATS (9 FIRs out of 12 FIRs). An ad hoc investigation revealed that these cases in which FRA is worse than ATS are due to one FRA routing in each FIR involving descending and climbing AC, which became evident only after the simulation runs following a broad-stroke routing rules for the entire region. An FTS study such as the present study offers utility in detecting such clusters. Towards implementation, these hotspots can be mitigated either at the planning and airspace design stage, by introducing local routing rules, or at the tactical stage by level-off manoeuvring.

We dig further into the classificaiton of these potential conflicts by horizontal and vertical movements of the pair of involved aircraft. The results show that the various composition changes in the potential conflict classification between ATS and FRA scenarios (Table 11).

5. Analyzing hot-spots

We embarked on an ad hoc analysis of conflict hotspots observed in the Fast-Time Simulation for the en-route airspace in which Singapore provides ATS. Here, the hotspots are computed by spatially connecting the potential conflicts recorded in the simulation. Geometric buffer of 5 NM is applied to each potential conflicts. The resultant polygons are dissolved, and the convex hull operations are applied. We retain those hotspots which has more than 4.0 occurences per day.

Figure 5 shows the hotspot locations. In FRA, some hotspots originally present in the ATS scenario will be shifted, disappear or appear. However, based on the present simulation study, there will be predictable (or recurring over days) hotspot locations. Thus, en route ATCOs will require

Table 9 Number of potential conflicts per days.

Metric	Number of flights				Conflicts total				Conflicts +FL285				Conflicts FL130-FL285			
Traffic volume	Pre-COVID19		Double		Pre-COVID19		Double		Pre-COVID19		Double		Pre-COVID19		Double	
Lateral routing	ATS	FRA	ATS	FRA	ATS	FRA	ATS	FRA	ATS	FRA	ATS	FRA	ATS	FRA	ATS	FRA
RPHI	1443	1444	2887	2889	240	138	954	503	174	87	712	298	66	54	243	202
VDPF	458	443	1012	971	35	25	135	109	30	20	109	84	7	5	31	29
VLVT	1035	1068	2282	2340	116	119	475	447	112	118	464	433	3	2	12	15
VTBB	2475	2482	5137	5158	459	421	1849	1656	298	264	1208	1066	166	158	655	595
VVHM	2027	1992	4127	4061	369	303	1316	1000	308	243	1074	789	68	61	249	224
VVHN	1174	1174	2460	2461	97	85	376	315	61	48	242	181	36	38	137	137
VYYF	906	906	1840	1840	70	74	253	252	48	58	183	198	23	18	76	57
WAAF	2092	2080	4190	4165	378	251	1507	1028	285	166	1129	699	100	91	372	331
WBFC	608	591	1217	1182	56	45	214	172	35	27	145	107	22	19	73	68
WIIF	2386	2336	4770	4672	529	451	2140	1718	354	301	1426	1150	178	148	721	576
WMFC	1895	1895	3800	3804	241	235	962	923	148	141	575	525	95	96	394	401
WSJC	1880	1854	3774	3730	175	173	661	695	130	130	485	495	48	46	193	204

Table 10 Metrics for clusters of potential conflicts.

Metric	Number of flights				Large clusters				Maximum cluster size			
Traffic volume	Pre-COVID19		Double		Pre-COVID19		Double		Pre-COVID19		Double	
Lateral Routing	ATS	FRA	ATS	FRA	ATS	FRA	ATS	FRA	ATS	FRA	ATS	FRA
RPHI	1443	1444	2887	2889	1	0	45	8	6	5	10	7
VDPF	458	443	1012	971	0	0	15	1	4	3	9	6
VLVT	1035	1068	2282	2340	0	4	41	29	5	6	9	9
VTBB	2475	2482	5137	5158	8	2	103	48	9	6	14	9
VVHM	2027	1992	4127	4061	7	0	92	21	7	5	16	8
VVHN	1174	1174	2460	2461	2	0	9	7	6	5	9	7
VYYF	906	906	1840	1840	2	2	5	11	6	6	6	7
WAAF	2092	2080	4190	4165	5	2	85	28	6	6	16	9
WBFC	608	591	1217	1182	0	0	3	0	5	4	7	5
WIIF	2386	2336	4770	4672	6	1	157	82	8	6	16	12
WMFC	1895	1895	3800	3804	1	5	60	63	6	7	10	11
WSJC	1880	1854	3774	3730	0	0	10	14	5	5	7	8

time to adjust/update their mental and memory familiarity of hotspot locations, but the recurring nature enables their learning of the new airspace organisation.

6. Discussion

Towards realizing FRA operation, a key challenge is reducing potential hot-spots and composing "ideal" patterns of air traffic. Our past works clarified that ATCOs would accept handling larger amount of air traffic volume if there were less interference among the traffic. For example, it was acceptable to control clusters of flights cruising at the same direction. However, if even one aircraft crossed the cluster, it would significantly increase ATCOs' workload.

For realizing the ideal traffic pattern, our future works will tackle on the following challenges. Firstly, we analyze the features of the traffic patterns at the potential hot-spots. Secondly, we propose a systematic approach to update time-schedules of air traffic, which groups oncoming flights while avoiding traffic interference. Applying time-varying queuing theory enables us to understand the features of air traffic patterns and to control time-varying air traffic inflow and outflow in the target areas. In the past researches, the time-varying queuing model was applied to reducing departure queue at a single runway.[15] Authors' work[16] developed time-varying queuing network models to provide a framework for integrated departure and surface air traffic management at airports. These works discussed that the proposing model-based framework was applicable to design general ATM systems, not only for airport operation, but also for air traffic flow control in airspace.

7. Conclusions

This work presents a macroscopic simulation, which supports the benefits and operational feasibility of the Free Route Airspace concept in the ASEAN region. The benefits include about 2 % improvement in traffic efficiency metrics (fuel burn, flight duration, and flown distance), as well as a general reduction in potential conflicts. Utility of fast-time simulation for identifying a possible hotspot, which can be circumvented by introducing local traffic rules are also presented. When zoomed into a specific FIR, there will be shifting in the nature of the conflicts, as evidenced by the composition of potential conflicts by horizontal and vertical movements, as well as by the change in hotspot positions.

Towards implementation, beyond this initial fast-time simulation study, evaluating the local and regional capabilities in

Table 11. FIRs in which potential conflicts were more in Double FRA scenario than in Double ATS scenario, layered by classification of potential conflicts based on horitonal and vertical movements of the pair of aircraft creating the potential conflict.

	RPHI	VDPF	VLVT	VTBB	VVHM	VVHN	VYYF	WAAF	WBFC	WIIF	WMFC	WSJC
Both cruising - crossing	x					x	x		x	x	x	
Both cruising - opposite			x			x				x		x
Both cruising - same track			x		x	x		x		x		x
One in vertical - crossing		x	x			x	x		x	x	x	
One in vertical - opposite								x			x	
One in vertical - same track			x									
Both in vertical - crossing	x		x		x	x	x				x	x
Both in vertical - opposite		x	x	x			x					x
Both in vertical - same track		x	x	x				x				

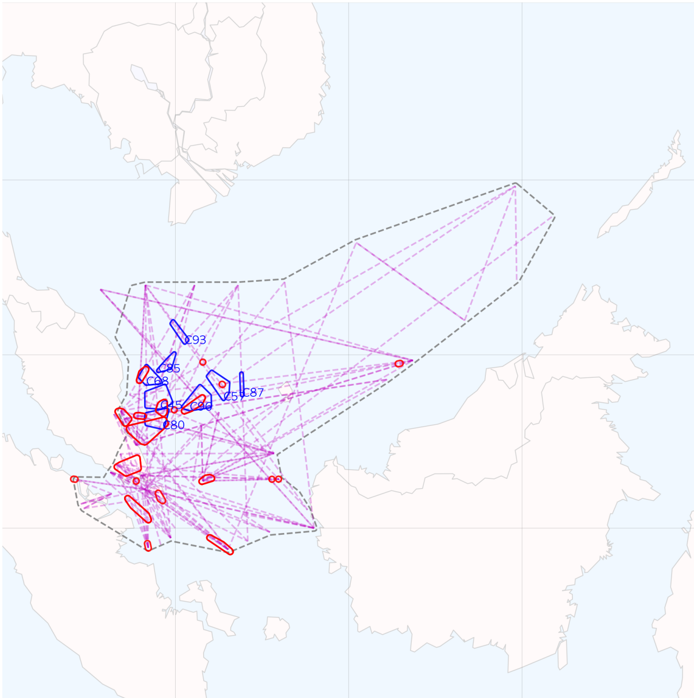

Fig. 5 Hotspot locations in Double scenarios.

communications, navigation and surveillance (CNS) will be crucial for layouting timelines. Furthermore, we discussed our future challenges to control time-varying air traffic inflow and outflow of the FRA for avoiding conflicts at the potential hot-spots. These future works will contribute to understand features of air traffic patterns and to composing the ideal traffic patterns. The expected outcomes will contribute to improve efficiency and safety of the FRA operation under acceptable ATCOs' workload.

Separately, moving ahead towards greater effectiveness of the FRA concept, the following studies are suggested. 1) Fast-time simulation assuming cross-border FRAs (where individual FRAs are collapsed into one free routing, where the transfer of control may take place along area of responsibility boundary lines, which allows even more direct and shorter routing), and 2) regional CNS capability outlook.

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