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SURBANA JURONG

WHITE PAPER

Air Traffic Management Advanced Concepts of Operations

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Abbreviations	Term
A-CDM	Airport Collaborative Decision Making
ADS-B	Automatic Dependent Surveillance - Broadcast
AIXM	Aeronautical Information Exchange Model
ASEAN	Association of Southeast Asian Nations
ASI	Aviation Studies Institute
AMAN	Arrival Manager
ANSP	Air Navigation Service Provider
APAC	Asia Pacific
APANPIRG	Asia Pacific Air Navigation Planning and Implementation Group
APV	Approach Procedures with Vertical guidance
ASBU	Aviation System Block Upgrade
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
CDM	Collaborative Decision Making
EMS	Enterprise Messaging System
FAA	Federal Aviation Administration
FF-ICE	Flight and Flow Information for a Collaborative Environment
FIR	Flight Information Region
FIXM	Flight Information Exchange Model
FMS	Flight Management System
FRA	Free Route Airspace
FRTO	Free Route Operations
GANP	Global Air Navigation Plan
GATMOC	Global Air Traffic Management Operational Concept
ICAO	International Civil Aviation Organisation
IWXXM	ICAO Meteorological Information Exchange Model
NM	Nautical Mile
PBN	Performance Based Navigation
RECAT-EU	European Wake Turbulence Categorisation and Separation Minima
RNAV	Area Navigation
RNP	Required Navigation Performance
SEA	Southeast Asia
SESAR	Single European Sky ATM Research
SWIM	System Wide Information Management
TBM	Time-based Management
TBO	Trajectory-based Operations
USA	United States of America
WTS	Wake Turbulence Separation

Foreword

The Aviation Studies Institute (ASI), based within the Singapore University of Technology and Design, has been established to address the needs of aviation stakeholders and advance the development of aviation in the Asia-Pacific region.

A key part of the aviation industry (and a key dependency) is the role of air traffic management to provide a safe and expeditious movement of aircraft during all phases of operations.

The functions commonly associated with air traffic management (air traffic services, air traffic flow management and airspace management) require continual investment to keep pace with the evolving needs of the industry. Benefits are often interdependent upon stakeholder capabilities, including aircraft operators, airports and other air traffic management providers in other localities. To coordinate and align development progress across the stakeholder groups, most regions of the world have intra-regional development plans. Reaching agreement on the content of these plans brings its own challenges; yet further challenges await in their implementation.

During the 1980s, states across Europe experienced steady growth of air traffic. Whilst it was recognised by the industry that a finite capacity existed to service the demand, improvement works did not keep pace. Eventually delays became frequent and widespread enough that they became a political issue[1]. This brought about concentrated efforts that led to the creation of coordinated improvement programmes across the European continent and industry[2]. Around a similar time, deregulation in North America had opened markets to new airlines and lower passenger fares which also lead to growth of air traffic movements. By the 1990s the airspace in the USA was experiencing rising congestion and consequent flight delays. The dissatisfaction by the public and industry spurred the creation of similar improvement programmes within the country[3]. In Canada, attempts had been made to invest in new Air Traffic Systems but were hampered by structural issues and this led to the privatization of their then government-controlled air navigation service provider[4]. Whilst these improvement programmes did eventually get underway, the size of the challenges meant that it would take further time for the benefits to be felt.

Today, passenger and industry needs have evolved – there is no longer a singular focus on capacity and on-time performance, but a range of factors, such as the efficiency of flightpaths, environmental performance and connectivity.

The long tail before improvements are felt is a lesson for aviation stakeholders everywhere.

Within Asia-Pacific, various multi-state initiatives have been embarked upon to keep capacity of air traffic management ahead of demand. However, many of these initiatives are behind their original implementation schedules.

- Is there enough will in the region to bring these back on track, or does the region face similar experiences of Europe and North America before collaborative progress is made?

This White Paper has been produced to provide an overview of the key initiatives underway in Southeast Asia and help to shine a light on the stumbling blocks to their realisation.

It has been commissioned by ASI to Surbana Jurong, an infrastructure and urban development consultancy involved in various aviation developments in the region.

[1] **https://api.parliament.uk/historic-hansard/lords/1988/jul/15/air-traffic-congestion**
[2] **https://www.eurocontrol.int/sites/default/files/publication/files/tat2-air-traffic-delay-europe-2007.pdf**
[3] **https://www.faa.gov/nextgen/background/**
[4] **'The Test of Time, How Nav Canada Really Works', NavCanada 2013, http://web.archive.org/web/20150211041145/http://www.navcanada.ca/EN/media/Publications/Test of Time-EN.pdf**

It complements an area of research the Aviation Studies Institute is undertaking. This research considers the performance of the overall Air Traffic Network in Southeast Asia and fosters the collaboration required to provide benefits to each stakeholder in the region.

We hope that you find the analysis and recommendations provided useful.

Mr Jamie Bloomfield

At the Aviation Studies Institute we are keen to utilise research to solve real-world challenges and work with industry partners to translate our outcomes into industry-wide capabilities. If there is an improvement you would like us to investigate, a partnership opportunity you would like to explore, or a way we can help aviation in Asia-Pacific to develop further, please get in touch:

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You can also find more details on our website: https://asi.sutd.edu.sg/

On behalf of the Aviation Studies Institute, Assistant Professor Karthyek Murthy recently completed research into the benefits of enhanced collaboration in airport ground delay programmes in Southeast Asia.

If you are keen to learn more about this work, please let us know.

Assistant Professor Karthyek Murthy has an interest in Applied Probability and Operations Research, he has published several papers and received awards for his work. In addition to his research work, he also serves as Associate Editor of 'Stochastic Systems' the flagship journal of the INFORMS Applied Probability Society.

Karthyek was a post-doctoral researcher in the Department of Industrial Engineering and Operations Research, Columbia University. He received his PhD in 2015 from the Tata Institute of Fundamental Research, Mumbai.

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Introduction

This White Paper has been compiled to describe the developments in Air Traffic Management (ATM) capabilities in the Southeast Asia (SEA) region. Whilst this paper looks at long-term time horizons, and many of these developments pre-date the COVID-19 pandemic, the recent period of disruption and gradual resumption of passenger air travel as restrictions are eased, brings a timely juncture to consider these plans and the post-pandemic environment.

Air transport comprises of passenger and cargo transportation, both of which are key contributors to the economic activity of countries. Before the COVID-19 pandemic, the air transport sector thrived and demonstrated continuous growth of air traffic movements worldwide. Many countries faced a situation of their ATM systems reaching maximum capacity. Several initiatives had been started to modernise the ATM systems in an evolutionary way. These initiatives continue today with a particular focus on advanced concepts of operation supported by new technologies. Several factors have been taken into account, such as the role of humans, airspace user requirements and investment cycles.

These initiatives are internationally coordinated with the desired performance outcomes agreed as part of a global vision for ATM. Several regions of the world have adopted the modernisation initiatives and the UN specialised agency, International Civil Aviation Organisation (ICAO), provides coordination and monitoring support. Each state can create its own development schedule, although most coordinate and agree plans as regional groups. Up to the start of the pandemic, states were progressing even though some were facing challenges.

Unfortunately, the COVID-19 pandemic has dramatically halted international passenger transport with unprecedented consequences for the air transport industry. This has placed additional challenges for each state’s modernisation plans to endure. This is likely to have cascaded down into an impact upon some stakeholder’s efforts and commitments towards the ATM developments.

This paper focuses on the ATM development plans in Southeast Asia and attempts to prioritise the capabilities in light of the current environment.

Future Air Traffic Management vision

Air Traffic Management

ATM is the dynamic, integrated management of air traffic and airspace including air traffic services, airspace management and air traffic flow management – safely, economically and efficiently - through the provision of facilities and services to collaborate with all parties involving airborne and ground-based functions[5].

ATM is often perceived as an invisible infrastructure with the general public commonly associating it only with air traffic control where people are working inside the air traffic control tower at airports. The world of ATM and how flights are managed between city pairs are only known with a relatively small community working in the aviation sector. ATM is crucial for allowing flights to take place safely and efficiently and for air transport in general to flourish, both domestically as well as internationally. However, ATM systems have yet to catch up with the technological advances made and as such the current air traffic management system is still sub-optimal.

Following the given definition of ATM, the first component of air traffic control comprises of the air traffic controllers' day-to-day work to tactically separate air traffic movements and to ensure safe operations from departing airport to arriving airport. This is often visible and understood in part by many. The second component is airspace management that includes the way the airspace has been defined and allocated for the various airspace users like small, general aircraft, commercial and military air traffic. In recent years, the airspace also needs to include unmanned aerial vehicles. The last component is Air Traffic Flow Management (ATFM) which includes the planning stage several months prior up to the day of operations. The ATFM processes vary per State depending on the maturity level of their implemented ATFM system. Having a thorough understanding of ATM enables the Air Navigation Service Provider (ANSP) and aviation authority to accommodate air traffic growth while maintaining current safety level and allows the State to keep pace with the modernisation developments that are taking place in other parts of the world. ATM is not only about managing the capacities in the airspace and at airports, but also about improving the system through efficiency.

Global Air Traffic Management Operational Concept

In the 1980s, the ICAO recognised that the fragmentation of the air navigation system was limiting aviation growth and constraining improvements in air safety, efficiency and regularity and a plan of actions were needed. The Global Air Traffic Management Operational Concept (GATMOC) was introduced to present ICAO vision of an integrated, harmonised and globally interoperable ATM system. GATMOC laid the foundation by establishing the operational requirements for an integrated and global Air Traffic Management (ATM) system. GATMOC established 7 key interdependent concept components (ICAO, 2005):

1. Airspace Organisation and Management
2. Aerodrome Operations
3. Demand and Capacity Balancing
4. Traffic Synchronisation
5. Airspace User Operations
6. Conflict Management
7. ATM Service Delivery Management

Global Air Navigational Plan

To transition from the current ATM system to the future environment as envisioned in the GATMOC, it requires an orchestrated programme that is agreed and committed to by all aviation stakeholders, and it also requires a

[5] ICAO Doc 4444 Procedures for Air Navigation Services – Air Traffic Management

massive investment in equipment, effort, and time. The transition is a multiyear process that needs to be phased and scoped into manageable components. ICAO has therefore designed the Global Air Navigation Plan (GANP) to serve as a driver for the harmonised evolution of the global air navigation system. Aviation System Block Upgrade (ASBU) methodology and its modules were introduced to provide a programmatic and yet flexible global systems engineering approach allowing states to advance the air navigation capabilities based on their operational requirements (ICAO, 2016). Each component must include one or more concepts to show the benefits of implementation. The initial version of the GANP was developed in the early 2000s, and it has been continually updated since.

The ASBU refers to the target availability timelines for a group of operational improvements. Block 0 was utilised as a starting point (base reference) for harmonisation efforts based on existing capabilities, whilst Block 1 considered current and anticipated capabilities. These were originally targeted for implementation between 2013 and 2018 respectively, although subsequent updates to the GANP have adjusted these timescales. These also considered various ATM modernisation programmes being progressed independently in many countries. Blocks 2 and 3 had availability milestones, pre-Covid, between 2025 and 2031 respectively. The technology and procedures needed within each block were originally organised into unique modules categorised by one of four target Performance Improvement Areas:

1. Airport Operations
2. Globally interoperable systems and data
3. Optimum capacity and flexible flights
4. Efficient flight paths

Whilst these provided guidance on which parts of the Aviation System would benefit, they did not show the specific performance outcomes. The 6th Edition of the GANP (the latest version that was published in 2019) provides guidance in the form of 11 Key Performance Areas[6] and accompanied by a range of Key Performance Indicators[7].

This white paper focuses on the strategic improvements to air traffic management related to airspace operations and as such, airport operations are not covered.

States need not implement every module mentioned in the GANP and should first determine which capabilities they should have in place based on their operational requirements. However, to allow for maximum use of the enhanced capabilities provided by the technical advances, states need to follow the ASBU process for the modules applicable to them for a unified path to the future Air Navigation System. The intent of the GATMOC and GANP is to harmonise the technologies and operational procedures that enable the concepts to be realised on a world-wide scale.

The aviation sector is not able to undertake all the modernisation changes at the same time. The concepts need to be introduced step-by-step to allow for a better understanding of the impact on operations, their benefits and associated adjustments required. Through the benefits, others in the aviation sector will be convinced to join in the modernisation effort.

[6] **https://www4.icao.int/ganpportal/ASBU/PerformanceObjective**
[7] **https://www4.icao.int/ganpportal/ASBU/KPI**

Future Air Traffic Management operational environment

In this chapter, the concepts are described to show how they should operate and meet the performance objectives of the future ATM environment. By doing this, the differences between current and future operations should also become more apparent.

Globally interoperable systems and data

As ATM is a global operation, systems need to be in place to allow for communication and data transfer between operating regions for smooth and efficient planning and execution. The original GANP performance improvement area of achieving 'globally interoperable systems and data' relies on a variety of capabilities. One particular capability is the operational concept of System Wide Information Management (SWIM) to improve the level of Information Sharing. Implementation of SWIM will enable the improvement of ATFM processes and allows further operational concepts to be trialled and implemented to the benefit of both air navigation service providers and airlines.

System Wide Information Management

Current problems with information sharing

Current ATM communication systems consists of applications dedicated towards a specific purpose that were developed over time and are very often point-to-point connections between systems and stakeholders. This causes the information systems to be incompatible as each custom communication protocols are in their own self-contained systems (ICAO, 2015). As a result, the information systems like Aeronautical Information, Meteorology, Flight and Flow Information are separated and not compatible across different functions and regions. The incompatibility and separation make the current ATM system unable to facilitate timely and accurate information that is required for efficient ATM. This results in:

- Maintenance of those separate systems to become expensive and difficult.
- Limited scope for stakeholders to communicate within a comprehensive and integrated manner.
- Difficulty to upgrade and interlink different systems within a single ANSP that are not part of the established point-to-point connections, leading to information silos.

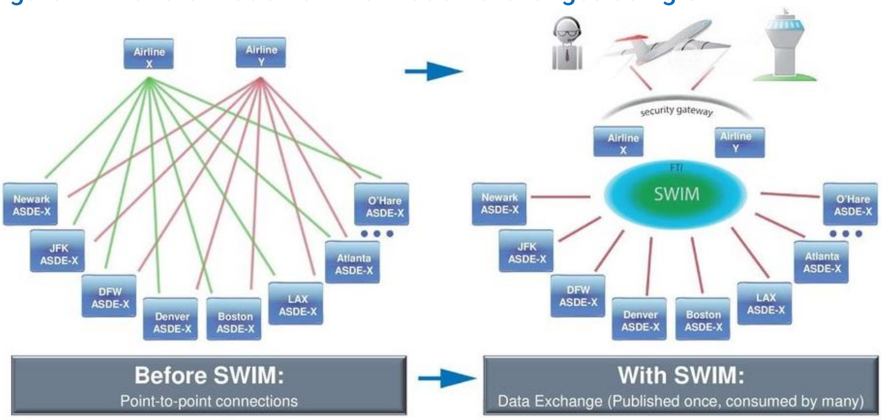
A good example here is that of airline operations centres, which need to obtain the latest information on weather and air route diversions in order to determine the right amount of fuel for a flight to carry. Especially for long-haul flights, where the payload is often high and flight preparations take a long time, information needs to arrive in a timely manner to avoid exceeding cut-off times after which decisions cannot be reversed.

Introduction to System Wide Information Management

The SWIM concept was introduced to create a globally operable information sharing concept for the aviation community. The SWIM concept covers the aviation communication infrastructure that includes standards and governance enabling the management of ATM related information and its exchange between qualified parties via interoperable services (ICAO, 2015). The objective of SWIM is to ensure that the right information is made available to the right users at the right time.

The concept of SWIM and its information technology infrastructure supporting it, is IP-based. This resembles a private version of the internet with similar infrastructure requirements. The upgrade includes a more network centric approach as shown in Figure 1. SWIM prepares the aviation sector to make better use of internet technologies that many of us are already used to.

Figure 1 - Transformation of information exchanges using SWIM



Source: FAA SWIM Program[8]

ATM SWIM-enabled applications on the SWIM platform are being developed instead of standalone applications. Similar to the public internet where a domain registry enables a website owner to determine if a user can upload information onto their website, for SWIM the registry is governed by civil aviation authorities and the service providers. For example, meteorological and ATC organisations can determine how much information is shared to which users and whether they can upload new information or not. The internet protocols with which content has been created have also been defined for aviation content in SWIM.

Benefits of System Wide Information Management

SWIM provides flexible and secure information management solutions at the overall system level. This enables the entire network to be more expandable than the current system and better able to accommodate new users. New non-SWIM communication protocols are still possible, and some stakeholder might choose to utilise these in some situations. However, these come at higher costs as they require individual design, development, approval and maintenance. These are unlikely to be compatible with the global network, further impacting the benefits offered.

Supplementing the SWIM infrastructure, standardised information exchange languages provide a further level of interoperability. These facilitate the sharing and consumption of information by publishers and users across the network in a set of common digital languages. Flight Information Exchange Model (FIXM), ICAO Weather Information Exchange Model (IWXXM) and Aeronautical Information Exchange Model (AIXM) are current examples of digital languages being developed.

Advanced ATM concepts are increasingly reliant on secure, accurate and timely information sharing to be achievable. How the advanced ATM concepts rely on information sharing system will be further discussed in following sections.

Air Traffic Flow Management

Introduction to Air Traffic Flow Management

Although not representing what we consider ATFM today, initial attempts to manage the flow of air traffic across airspace were performed as early as 1985 in the USA, under the purview of the Federal Aviation Administration[9]. In the subsequent decade traffic delays in the American national airspace system, chiefly due

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[8] **ICAO SWIM Task Force, https://www.icao.int/APAC/Meetings/2017 SWIMTF1/ WP06_FAA-Brief overview of the SWIM Program -2017-0508.pdf**

[9] **FAA Experiences with ATFM (for the ACAO/ICAO Air Traffic Flow Management Workshop), Midori Tanino, 2019: https://www.icao.int/MID/Pages/2019/ATFM Wksp.aspx**

to weather, generated a need to share meteorological information with airlines and airport stakeholders and pro-actively mitigate the impacts upon air traffic operations across the whole network in a coordinated manner. The FAA, in its role as air navigation service provider for both the airspace and major airports in the USA, made it well placed to interface with the airlines and airport personnel via it's 'Air Traffic Control System Command Center'. This concept was not just about managing flows from a network-wide perspective, but also engaging the stakeholders in the decision-making process. This brought about the related concept of Collaborative Decision Making (CDM)[10].

In Europe, a similar concept has been developed, however, in addition to airlines and airport stakeholders, Europe has a variety of different ANSPs. Coordination of information, decisions and the overall network picture was and still is performed by EUROCONTROL, an international organisation founded by multiple states in 1960. In Europe the concept is referred to as Air Traffic Flow Management (ATFM) and EUROCONTROL performs the function as part of its Network Manager Operations Centre, and previously the 'Central Flow Management Unit' (CFMU)[11].

On both sides of the Atlantic ATFM was further developed to incorporate forecasting and planning mitigation measures ahead of daily operations. As part of this development, it was found that the role of airport operators and their stakeholders (e.g., ground handlers) should be better integrated. This resulted in the concept of 'Airport-Collaborative Decision Making', known as A-CDM. This primarily involves the timely sharing of real-time information on air traffic arrival and departure times for airport stakeholders to incorporate into their service planning.

In this white paper ATFM and CDM are considered closely intertwined functions and are referred to interchangeably, however CDM should not be confused with A-CDM.

The objective of ATFM is to ensure the optimal traffic flow from a network-perspective especially when demand in one or more parts of the ATM system is expected to exceed the available capacity of those parts. ATFM improves operations by allowing the ATM stakeholders such as air traffic controllers, flight operators and airport managers to have a common view of traffic flows through a specific part of the system and thereby obtain a better awareness of the consequences of decisions made on the system and stakeholders. For example, where the traffic demand into a given airspace is forecast to exceed a given rate of flow, early communication with stakeholders can encourage flight operators to plan different routings, or to adjust their departure times. Whilst doing so, identification of the knock-on consequences of those new plans, such as creating new demand-capacity imbalances in other parts of the airspace space can be assessed.

ATFM is carried out in three phases: Strategic planning, Pre-tactical planning and Tactical flow management, as shown in Table 1.

[10] **FAA History of CDM: https://cdm.fly.faa.gov/?page_id=300**
[11] **EUROCONTROL Network Operations: https://www.eurocontrol.int/network-operations**

Table 1: ATFM phases

ATFM Phase	When it is conducted	Actions taken during the phase
Strategic	Two or more days before the day of effect. Normally carried out two to six months in advance.	Examination of traffic demand and available capacity for the forthcoming season and taking steps to resolve imbalance by: Arranging with ATC authority to provide adequate capacity at the required place and time. Re-routing traffic flows Scheduling and rescheduling flights as appropriate Identifying the need for tactical ATFM measures.
Pre-tactical	One day before the day of operation.	Fine-tuning of strategic plan Re-route traffic flows where needed Off-load routes may be coordinated Tactical measures will be decided upon Details of ATFM plan for following day to be published and made available to all concerned.
Tactical	On the day of operation.	Executing agreed tactical measures Monitor the evolution of air traffic situation and effects of ATFM measures. Initiate remedial actions to address long delays Re-routing of traffic and flight level allocation to maximise ATC capacity.

Source: ICAO Doc 4444 Procedures for Air Navigation Services – Air Traffic Management

The improved view of the traffic flows through the airspace is dependent upon ANSPs providing ATC sector and airfield capacity information; these are dependent on a range of factors such as ATC staffing levels, systems availability, runway availability, meteorological conditions and the nature of the traffic flows.

Sharing of information is a key principle for ATFM to work, hence new concepts such as SWIM that improve the ease, timeliness and scope of information sharing can lead to greater efficiency of ATM systems. Better information can lead to informed decision-making which is one of the central tenets to ATFM. By sharing information, values and preferences, stakeholders learn from each other and build a common pool of knowledge, resulting in ATM decisions and actions that are most valuable to the system[12].

Air Traffic Flow Management enablers

More accurate, timely and comprehensive information sharing provides ATC with better visibility of traffic and congestion. This enables better planning of air traffic during the tactical stage. Air Traffic Service providers are made aware of the traffic situation before the traffic enters their area of responsibility and remedial action can be taken in anticipation of congestion.

The envisaged end goal of ATFM has shifted from managing the impact of localised disruption on groups of flights to managing constraints across a network in a collaborative manner with multiple stakeholders.

A network-based information exchange platform such as SWIM is essential to make this new goal a reality.

Uncertainty comes with costs

Airlines are keen to manage operating costs; minimising the amount of fuel carried and burnt on each flight is a significant contributor to this goal. Dispatchers in airline operations centres can estimate the required amount of fuel an aircraft needs to carry based on historical data. However, if weather conditions or local airspace

[12] **FAA Collaborative Decision Making Home: https://cdm.fly.faa.gov**

restrictions cause changes to the planned flight routing, the fuel required will change. In this situation accurate and timely information is essential for the dispatcher to plan accordingly. Greater uncertainty leads to lower conviction and particularly during the flight planning stage this can lead to carrying more fuel than needed.

The geopolitical situation in Southeast Asia resembles that of Europe in many ways. The airspace across Southeast Asia is characterised by several Flight Information Regions (FIRs) and managed by ANSPs from the various States. Each State has at least one or more international airports often operated by different entities. While in Europe the planning of air traffic flows at strategic and pre-tactical levels is facilitated by EUROCONTROL, in Southeast Asia no such equivalent organisation exists. Some states have however sought to improve collaboration in ATFM through regional initiatives and frameworks, such as the Asia-Pacific Cross-Border Multi-Nodal ATFM Collaboration (AMNAC)[13].

The AMNAC is based on a network of ATFM Nodes responsible for demand-capacity balancing within their own areas of responsibility whilst being connected to an information exchange network. A range of communications channels are currently used, and the requirement for effective information sharing makes SWIM an important foundation for CDM and future ATFM procedures. The ICAO Task Force for SWIM in the APAC region, agreed at their third meeting that higher priority should be given to the SWIM implementation for cross-border ATFM and A-CDM (Airport-Collaborative Decision Making) operations[14].

Efficient and Sustainable Flight paths

Performance Based Navigation

Introduction to Performance Based Navigation

Performance Based Navigation (PBN) makes use of a more accurate path planning utilising satellite-based position information rather than conventional ground-based navigation aids. The requirements for PBN are governed under an international regulatory framework (ICAO, 2008).

With improvements in navigational performance of aircraft becoming common, concepts such as Area Navigation (RNAV) (formerly known as 'Random Navigation') and Required Navigation Performance (RNP) have been implemented by airspace managers as part of airspace design. This has enabled greater utilisation of airspace.

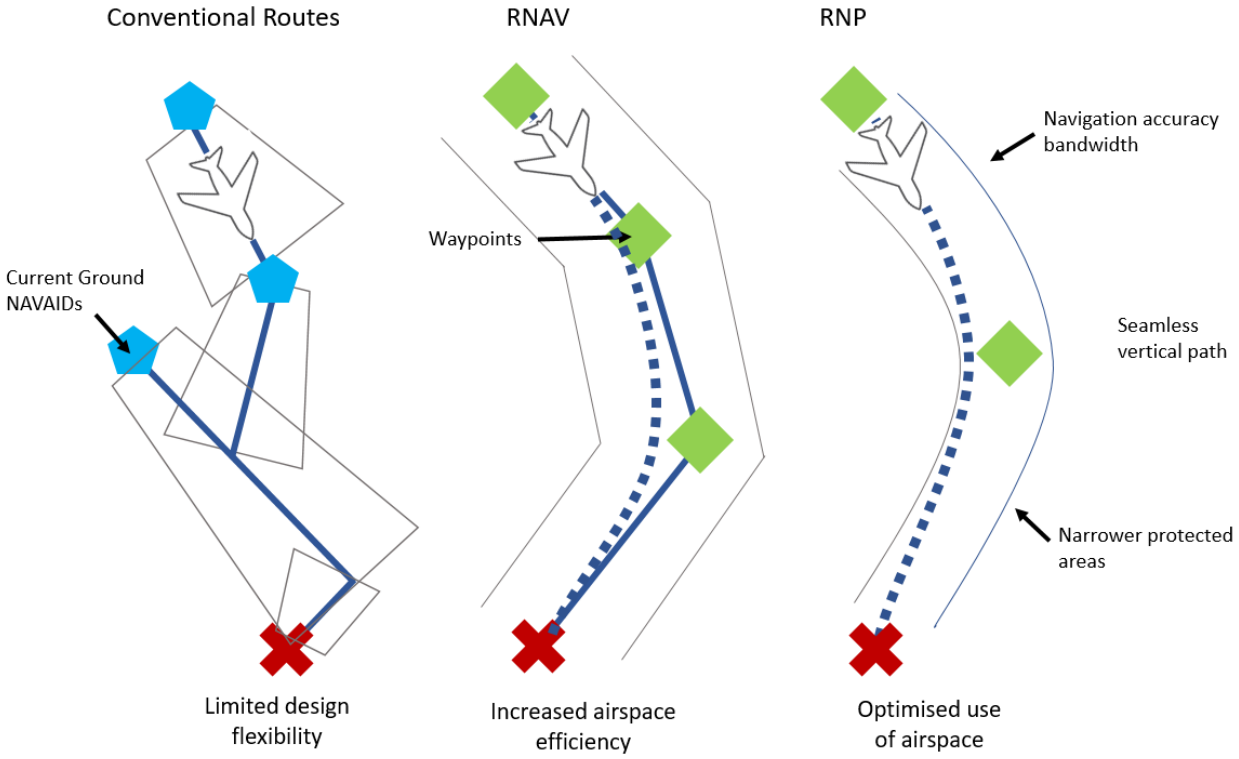
Figure 2 shows how conventional routes transition to RNP based on PBN. Having PBN routes enables greater utilisation of airspace for the following reasons:

- Greater flexibility of air traffic route design:
    - Waypoints can be readily created and changed as they are not dependent upon a limited set of fixed ground-based navigation aids.
    - More types of interaction between lateral profiles and waypoints are possible, such as fly-over and fly-by path planning.
- Lower of maintenance than ground-based navigation aids.
- Aircraft can fly the paths in a more accurate manner, leading to reduced spacing requirements between adjacent routes.

[13] **https://canso.fra1.digitaloceanspaces.com/uploads/2020/12/AMNAC-Briefing-for-CANSO-Web_final-che-DS.pdf**
[14] **https://www.icao.int/APAC/Meetings/Pages/2019-SWIM-TF3.aspx**

- In the case of RNP, there is greater assurance of conformity due to onboard (aircraft) conformance monitoring and alerting to flight crew. This provides further reductions in spacing requirements and reduces workload for air traffic controllers.

Figure 2 - Transition from conventional routes to RNP



Source: Edited from CASA[15]

For decades, commercial flights have relied on ground-based navigation aids as waypoints or beacons to fly from their origin to destination. Aircraft would fly over those waypoints before turning and navigating to their next waypoint. With the introduction of RNAV, aircraft no longer needed to fly over waypoints before turning, enabling them to turn earlier ("cutting the corner"). In addition, the use of satellite navigation enabled new waypoints to be defined as a point in space rather than as a physical ground-based location, limiting their presence to places with physical terrain.

Benefits of Introduction to Performance Based Navigation

The RNP concept introduces an integrity check of the navigated position onboard the aircraft and allows the automatic detection of non-conformance to the agreed trajectory. When using RNAV or conventional navigation, this conformance monitoring is a function of the air traffic controllers. RNP applications within an airspace contribute de facto to a re-distribution of the surveillance and conformance monitoring functions. This results in lowering the air traffic controller workload and enables them to manage more movements.

Another benefit of RNAV and RNP is a reduction in the number of ground-based navigation aids. There are some longer-term intentions in the industry to eventually make these obsolete by replacing them entirely with satellite-based navigation and surveillance systems. This is expected to reduce the current day costs (procurement, installation and maintenance) usually borne by ANSPs, compared to satellite-based navigation. This should eventually reduce ANSP overflight charges. However, some questions do remain regarding the resilience of operations.

[15] **https://www.casa.gov.au/search-centre/safety-kits/cnsatm-resource-kit/cnsatm-resource-kit-chapter-6-performance-based-navigation**

Trajectory-based Operations

Introduction to Trajectory-based Operations

Trajectory-based Operations (TBO) is an ATM method for strategically planning and managing flight trajectories throughout their operation. The basic principle for TBO is to consider and manage the trajectories of aircraft across all phases of flight to achieve optimum ATM system outcomes with minimal deviation from the user requested flight trajectory. This concept relies on an aircraft's ability to fly trajectories in time and space (in short, a 4-Dimensional trajectory), the exchange of information between air and ground systems and Time-based Management (TBM) - a process of coordinating specific times for aircraft to reach designated waypoints. The time dimension available in TBM adds more predictability to the current ATC system.

Benefits of Trajectory-based Operations

TBO helps to increase airspace and airport throughput, flight efficiency, flexibility and predictability through TBM, PBN procedures, and increased collaboration with airspace users regarding preferred trajectories and priorities. TBO include, but are not limited to, arrival metering, surface metering, terminal metering, and departure scheduling[16].

TBO will bring about significant enhancements to predictability, flexibility, safety, and efficiency in ATM. When flight intent and data concerning constraints in the ATM operational environment are automatically shared through a common information exchange platform (e.g., SWIM), it makes it possible for trajectory negotiations to be carried out between airspace users and ANSPs. This can result in a set of agreed trajectories that has considered the known airspace constraints. At ATC sector level, these agreed trajectories lead to improved air traffic flows that benefits all users and decreases the air traffic controller workload. This is a clear example of TBO promoting collaborative decision making and at the same time eliminating ambiguity in a flight's trajectory and intent in pre-tactical and tactical stages of the flight.

Trajectory-based Operations enablers

The current format of flight plans, the processes for sharing these and flight data processing systems are not yet able to support TBO in the manner described above. TBO depends on timely access to flight and air traffic flow information, by multiple stakeholders and the ability for them to collaboratively agree trajectories and subsequent revisions. This capability is being developed through the concept of 'Flight and Flow Information for a Collaborative Environment' (FF-ICE) and supported by the SWIM infrastructure mentioned above. One of the digital languages in SWIM, in this case FIXM, ensures the interoperability and integrity of flight information shared amongst the aviation stakeholders in the network.

It allows more information exchange, especially sharing of flight intent and trajectories throughout all phases of flight in greater detail. This enhanced sharing of updated and more accurate flight trajectories among the stakeholders facilitates a collaborative decision-making environment where flight trajectories could be optimised considering not only airspace users' business objectives and preferences but also restrictions and constraints of the ANSPs.

FF-ICE services and information exchanges through SWIM will create an information-rich ATM environment, where stakeholders will be able to access and promptly act on the timely, accurate and updated comprehensive flight information, thus enhancing decision making.

[16] **FAA Trajectory-Based Operations: https://www.faa.gov/air_traffic/publications/atpubs/foa_html/chap18_section_6.html**

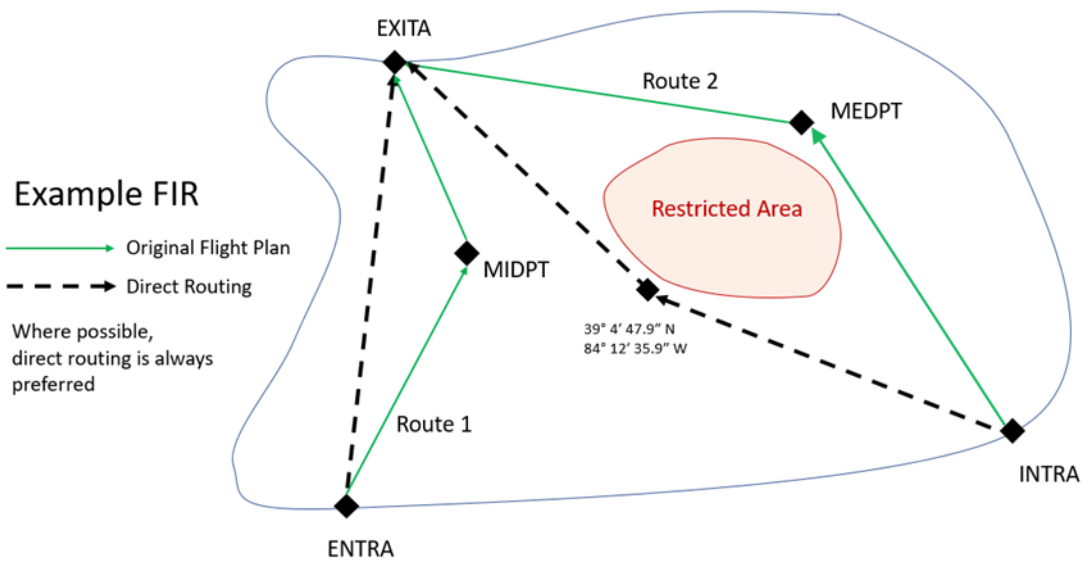
Free Route Airspace

Introduction to Free Route Airspace

Free route airspace (FRA) is a specified volume of airspace in which users can freely plan a route between defined entry and exit points, without reference to the ATS route network subject to airspace availability and ATC approval. Typically, during the actual flight operation, pilots must follow the routes stated in the flight plans that they submitted prior to the flight. FRA enables airspace users to plan and fly a route that is as close to their optimal flight trajectory as possible, subject to airspace availability, without the constraints of a fixed route network structure. Within the airspace, flights remain subject to air traffic control. This is sometimes referred to as “user preferred routes”.

In the example Flight Information Region (FIR) depicted in Figure 3, ENTRA and INTRA are entry points, EXITA is an exit point, while MIDPT and MEDPT are intermediate RNAV points. Two current day flight plans are shown within this FRA, (i) using Route 1 via intermediate waypoints that reference the ATS route network, (ii) using Route 2 via an intermediate waypoint that references the ATS route network. The FRA concept removes the need to follow the ATS route network and instead permits these flight plans to take routings that are more direct (dashed lines) and optionally via user-determined coordinate locations. Such routes inside this airspace remain subject to ATC approval. Requests to fly though the restricted area or outside of the controlled airspace would be denied by ATC.

Figure 3 - Free Route Airspace example



Source: Edited from Skybrary[17] for illustration purposes

This illustration limits FRA to a specific piece of airspace where the entry and exit locations remain fixed. The next level of FRA is to apply this concept across adjacent areas of airspace (that may be managed by other ANSPs) to create larger regions of FRA and shorten flight distances over the region. This generates a need for the exit and entry locations to be flexible. Technical limitations exist in ATC Systems that do not readily predict where and when such flights will reach the airspace boundaries and communicate this digitally between different systems. Interoperability between different ATC Systems is a key dependency of this concept.

The real benefit of FRA is the flexibility it provides when changes to traffic flows occurs. Within Southeast Asia, the ATS route structure has been developed with direct routes in mind. However, this is based on known traffic

[17] **https://skybrary.aero/articles/free-route-airspace-fra**

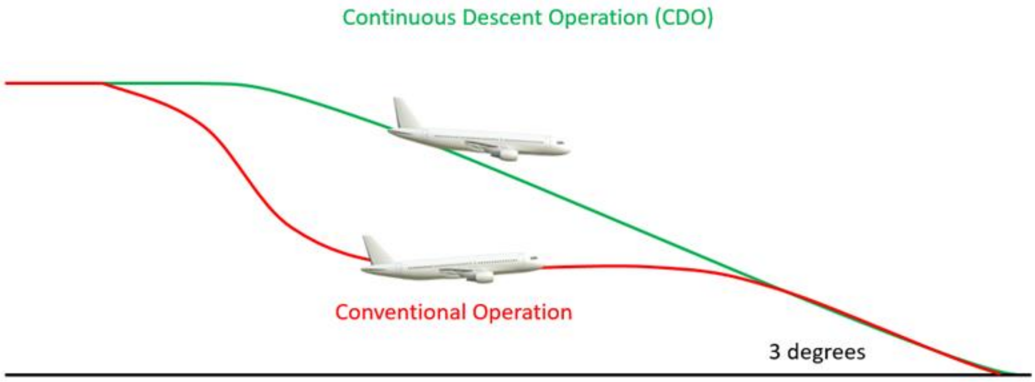
flows, often on main trunk routes. If the predominant traffic flows change over time, the ATS network may not be as direct as it is today. FRA provides a step towards flexibility and adaptability in such scenarios.

Continuous Descent Operations and Continuous Climb Operation

Introduction to Continuous Descent Operations and Continuous Climb Operation

Continuous Descent Operations (CDO) and Continuous Climb Operations (CCO) are aircraft operating techniques to execute a flight profile optimised to the operating capability of the aircraft. CDO facilitates an optimum descent profile for arrivals with low thrust settings and drag configuration. Figure 4 shows the flight profile for CDO as compared to a conventional approach. Similarly, CCO enables departures to climb continuously to their initial cruise level at optimum airspeed and engine thrust settings. These operating techniques are supported by airspace and procedure design, facilitated by air traffic control clearances.

Figure 4 - Continuous Descent Final Approach



CDO and CCO provides an efficient flight path for departures and arrivals and is supported by Performance Based Navigation (PBN). PBN provides the proper routing and navigation accuracy which CDO and CCO needs to be implemented safely.

Separation Management

In this white paper, Separation Management refers to the provision of tactical processes that keep aircraft away from hazards by at least the appropriate separation minima and any relevant changes to associated rules, procedures, and conditions of application of separation minima. For example, today much of the separation management performed by ATM is a function of the human ATC Operator, monitoring flight progress, devising traffic plans for their sector and issuing tactical action instructions.

In Europe and in the US, studies have been done on Airborne Separation Assurance Systems, sometimes referred to as “free flight”, where the separation responsibilities are fully delegated to the flight crew rather than air traffic controllers on the ground. It is obvious that in such operational environments the flight crew needs to have an accurate situational awareness fed with information on the surrounding and oncoming air traffic. Automated decision support tools to assist in the resolution of mid-air conflict situations would also be necessary to arrive at a coordinated response whilst also managing pilot workload. Much of the study results so far have been considered too academic to be applied. The furthest achievement has been fast-time and real-time simulations of the concept in high traffic density airspace with the purpose of demonstrating their proof of concept.

With the focus on Southeast Asia and assessing where the ‘low-hanging fruits’ are, the authors of this paper considered it best to focus on the reduction of wake turbulence separation minima (covered in the next section). After many decades of research and data collection, these have been reduced significantly, enabling an increase in runway capacity at major airports. Whilst many countries in Europe and North America have adopted these, many airports in the Southeast Asia are yet to follow.

Wake Turbulence Separation

Introduction to Wake Turbulence Separation

Wake turbulence (or wake vortices) are generated by every aircraft and may affect the stability of the trailing aircraft. Therefore, sufficient separation must be in place between two aircraft such that the trailing aircraft will not be affected by the preceding aircraft wake vortices. Existing ICAO wake vortex separation rules for Wake Turbulence Categories (HEAVY, MEDIUM and LIGHT) were implemented decades ago and have since become outdated since research and improved measuring methods have provided a better understanding. Over the years, air traffic controllers have applied a tabulated separation minima while monitoring their monochrome radar screens. Despite growth of air traffic movements and an increased variety of aircraft sizes over the years, the operational complexity has eased with the introduction of new technology in radar screens and the provision of a suite of decision support tools for air traffic controllers. The GANP ASBU thread, "WAKE", outlines the associated building blocks for these.

Introduction to Enhanced Wake Turbulence Separation

Knowledge about wake vortex behaviour in the operational environment has increased from measured data and improved understanding of the physical processes. This knowledge has made it possible to revise wake turbulence categorisation and the corresponding separation minima. 'Enhanced Wake Turbulence Separation' (Enhanced WTS) was introduced to reduce the separation between specific aircraft types, increasing the throughput of runways. The Enhanced WTS works by comparing the wake generation and resistance between aircraft types and splitting the current ICAO categories into smaller groups. The re-categorisation optimises the separation minima for some traffic pairs of aircraft whilst maintaining acceptable level of safety.

The FAA and EUROCONTROL are leading initiatives to implement the enhanced wake turbulence procedures and separation standards, which resulted in an update of ICAO Doc 4444 (amendment 9, Nov 2020). EUROCONTROL launched the European Wake Turbulence Categorisation and Separation Minima (RECAT-EU) and the FAA launched RECAT 1.5 which implements Enhanced WTS. RECAT-EU recategorized ICAO HEAVY and MEDIUM categories into "Upper" and "Lower" while the FAA recategorized from weight-based classes to a categorical system using aircraft matrices of weight, wingspan, and approach speed. Table 2 shows the wake turbulence separation implemented in RECAT-EU.

Table 2 - RECAT-EU wake turbulence separation

RECAT-EU scheme		"Super Heavy"	"Upper Heavy"	"Lower Heavy"	"Upper Medium"	"Lower Medium"	"Light"
Leader / Follower		"A"	"B"	"C"	"D"	"E"	"F"
"Super Heavy"	"A"	**3 NM**	**4 NM**	**5 NM**	**5 NM**	**6 NM**	**8 NM**
"Upper Heavy"	"B"		**3 NM**	**4 NM**	**4 NM**	**5 NM**	**7 NM**
"Lower Heavy"	"C"		**(*)**	**3 NM**	**3 NM**	**4 NM**	**6 NM**
"Upper Medium"	"D"						**5 NM**
"Lower Medium"	"E"						**4 NM**
"Light"	"F"						**3 NM**

Source: EUROCONTROL RECAT-EU

When a wake turbulence restriction is not required, the separation reverts back to the Minimum Radar Separation (MRS). Depending on the position and quality of the radar system that distance is prescribed by ICAO or by the ANSP as 3NM in TMA environments. States with radar systems that are less accurate may require larger MRS to maintain the same level of safety.

Current progress of modernisation effort

As the previous chapter explained how the ICAO Member States should modernise, this chapter describes how Southeast Asia is progressing with that modernisation process, for each of the ATM concepts explored in those earlier chapters. Much of the information is based on what and how detailed the individual ICAO Member States report at progress meetings, and whether or not the information was subsequently published by ICAO.

SEA and APAC organisation in ICAO

Planning and Implementation Regional Groups were formed to manage and integrate aviation planning at a regional level. Southeast Asia (SEA) is part of the Asia Pacific Air Navigation Planning and Implementation Group (APANPIRG). The objectives of APANPIRG includes ensuring continuous and coherent development of the Asia Pacific (APAC) Regional Plan, identifying specific problems in the field of air navigation and proposing appropriate actions to resolve concerns[18].

APANPIRG published the APAC Seamless ANS Plan which aims to provide a framework for a transition to a Seamless ANS environment by developing and deploying ATM solutions capable of ensuring safety and efficiency of air transport throughout the APAC region. The objective of Seamless ATM is defined as "*the safe and interoperable provision of harmonized and consistent air traffic management service provided to a flight, appropriate to the airspace category and free of transitions due to a change in the air navigation service provider or Flight Information Region*" by Asia/Pacific Seamless ATM Planning Group (ICAO, 2019).

The Southeast Asian states who are members of ASEAN also committed towards a Seamless ASEAN Sky to help airlines operate within ASEAN as a seamless block of airspaces with harmonised and interoperable procedures and operations, harmonising safety standards and increasing air traffic management capacity[19]. The ASEAN ATM Master Plan was established to provide a regional guideline and framework for the provision of Seamless ATM services and infrastructure in accordance with ICAO APAC Seamless ANS Plan.

Target Implementation Timeline

The priority of the various concepts was determined in the ASEAN ATM Master Plan and APAC Seamless ANS Plan for States in the region to follow. The ASEAN ATM Master Plan provides target dates for the development phases while APAC Seamless ANS Plan provides priority levels without target dates. Concepts not mentioned in either document are not prioritised in the region. The target dates for the remaining concepts are taken from the GANP. The target dates stated are for the concepts' "first steps" developments to kickstart the implementation of the advance concepts. Table 3 shows the priority level and target dates for the concepts in the various documents.

[18] **APANPIRG Procedural Handbook, https://www.icao.int/APAC/Documents/edocs/apanpirg/procedural_handbook.pdf**

[19] **Dr Sanchita Basu Das, https://www.iseas.edu.sg/media/commentaries/seamless-asean-sky-policymakers-need-to-look-beyond-obstacles-by-sanchita-basu-das-2/**

Table 3: Concept priority and target dates

ASEAN ATM Master Plan ASEAN Wide Harmonisation Implementation Phase 1 Target Date: End 2020 (ICAO, 2018)	APAC Seamless ANS Plan Priority 1 (Critical upgrade) and 2 (recommended upgrade) Target Date: Not stated (ICAO, 2019)	GANP Block 0 Target Date: 2013 (ICAO, 2016)
SWIM • ATM systems to be supported by digital AIM systems	FRTO (Priority 1) • Direct routing • Airspace planning and flexible use of airspace • Flexible routings • Basic conflict detection • Conformance monitoring	CDO/CCO • Improved flexibility and efficient in CDO and CCO profiles
PBN • All ATS route serving major aerodromes should be designated as RNAV2 or RNP2	TBO (Priority 2) • Introduction of time-based management within a centric approach	WAKE • Increased runway throughput through optimised wake turbulence separation
ATFM • All states should achieve at least a Level 2 capability to support cross-border ATFM operations • Established local procedures in accordance with APAC Framework for collaborative ATFM to comply with ATFM measures implemented by other states		

System Wide Information Management Implementation status

SWIM in United States and Europe

Through the well-funded ATM research and development programmes in the United States (US) called NextGen and Single European Sky ATM Research (SESAR) in Europe, SWIM has been developed and trialled on both continents. The FAA currently runs the SWIM-Industry FAA Team (SWIFT) programme, which basically runs SWIM services application nationwide. Although still in its infancy, it does provide a solid foundation to build and expand upon. In Europe, EUROCONTROL has developed various SWIM technical specifications and through the SESAR deployment programme are running trials with stakeholders[20]. The two organisations are the frontrunners on SWIM development and the rest of the world will benefit from their findings, lessons learnt and developed products/services.

SWIM progress reporting in SEA

The ASEAN member states conducted a “SWIM in ASEAN” Demonstration and released a report in November 2019 as part of SWIM Task Force[21]. The demonstration is a result of a proposal by the USA to provide assistance to ASEAN in conducting a demonstration involving ASEAN member states. The aim was to demonstrate the principles of SWIM, potential operational benefits and a model of SWIM implementation for

[20] https://www.sesarju.eu/sites/default/files/SESAR-Factsheet-2015-SWIM-Profiles.pdf
[21] https://www.icao.int/APAC/Meetings/2020 SWIM TF4/WP06_SIN and THA AI.5f - ASEAN SWIM - Revised.pdf

ASEAN. The demonstration participation level of each state as indicated in SWIM in ASEAN Demonstration Report served as a good indicator of the level of SWIM implementation in each member state. Table 4 shows the participation level of each ASEAN state in the demonstration.

Table 4: SEA states' participation levels in the demonstration

Level	Definition of participation	ASEAN states
Level 1	Observer only	Myanmar, The Philippines
Level 2	Legacy format data producer and consumer	Cambodia, Indonesia, Lao PDR, Vietnam
Level 3	Native-SWIM-format data producer and consumer	No ASEAN state in the level
Level 4	Customised Enterprise Messaging Service (EMS) Developer and native-SWIM-format data producer and consumer	Thailand, Singapore, Malaysia

Source: SWIM in ASEAN Demonstration Report (ICAO, 2019)

States should have a level of participation and capability developed to fulfil the requirements of each participation level. Their participation in the project also comes with the benefits as shown in Table 5.

Table 5: Requirements and benefits of participation levels in the SWIM Demonstration

Level	Description of activities	Benefits
Level 1	• Participate in demonstration planning, system interfacing, and system test • Provide lessons learnt from the demonstration • Active participation throughout the project	• Awareness of their own SWIM readiness • Knowledge to identify the feasible implementation approach for ASBU modules • Knowledge on possible support tool to assist decision making regarding fleet and flight management • Understanding on loose system coupling, separation of data production and consumption, open standards, and interoperable services • First level of understanding on global interoperability
Level 2	Level 1 activities and • Produce legacy-format data and provide it in native-SWIM format using the data conversion service provided • Able to consume native SWIM-format data using the viewer provided	• Knowledge and understanding on the implementation approach of ASBU modules • Knowledge on possible support tool to assist decision making regarding fleet and flight management • Working knowledge of loose system coupling, separation of data production and consumption, open standards, and interoperable services • First level of understanding on global interoperability • Knowledge and understanding on data mediation for backward compatibility in SWIM implementation
Level 3	Level 1 activities and • Produce and provide native SWIM-format data using own system • Able to ingest native-SWIM format data into own system	Level 2 benefits and • Access to complete SWIM dataset • Better information sharing for gate-to-gate operation, airport management, and increased safety
Level 4	Level 3 activities and • Early commitment to the project • Participate in all Global EMS discussions and system test • Provide services using own system	Level 3 benefits and • Working EMS prototype

Source: SWIM in ASEAN Demonstration Report (ICAO, 2019)

During the SWIM Demonstration in 2019, of the participating countries, Singapore, Malaysia and Thailand were the only ASEAN states participating at Level 4, indicating that they possess working EMS prototypes. This leads to the suggestion that they have met the target date of the ASEAN ATM Masterplan (Table 3). Based on the participation of other ASEAN member states, they should have a better understanding of SWIM. Singapore, Malaysia and Thailand have gained experience in implementing the EMS prototype and will be able to guide and assist other member states to work towards implementing an interconnected EMS network. It can be concluded that SWIM has shown its potential in terms of both concept of operations and infrastructure to serve as an information exchange platform for aviation stakeholders in SEA.

Air Traffic Flow Management Implementation Status

The implementation status of ATFM by APAC states is reported against the performance objectives stated in the Asia Pacific Framework for Collaborative ATFM. The Asia Pacific ATFM Steering Group monitors the implementation status of the APAC states yearly through the ATFM Implementation Status Report submitted by the participating states.

Even though the exact impact of the COVID-19 pandemic on the implementation of ATFM measures is unknown, it was recognised that the pandemic may have caused a lack of reporting in late 2020, with only 4 states submitting their reports as compared to 23 in the 2018 to 2019 period (ICAO, 2021). This indicates that the COVID-19 pandemic disrupted the activities of ANSPs in multiple states, pushing back the priority of implementing ATFM measures.

The number of ATFM implementation reports received improved in 2021 with 14 states reporting as the region began to normalise operations. Table 6 shows the Southeast Asia implementation status of ATFM measures. The ATFM measures can be found in the Regional ATFM Implementation Status Report by the Asia Pacific ATFM Steering Group. Enabling CDM capability is one of the ATFM measures states are expected to fulfil.

Table 6: Implementation status of ATFM measures in Southeast Asia

States	% of ATFM measures implemented		Implementation Status
	2020	2021	
Brunei Darussalam*	Never reported	No report	Did not report
Cambodia	63	No report	Incomplete
Indonesia	68	71	Incomplete
Lao PDR	Never reported	No report	Did not report
Malaysia	16	No report	Incomplete
Myanmar*	30	No report	Incomplete
Philippines	74	61	Incomplete
Singapore	96	97	Robust
Thailand	83	90	Robust
Vietnam	26	34	Incomplete

Source: Regional ATFM Implementation Status (ICAO, 2021)

* Brunei only controls airspace below Flight Level 145; traffic above this flight level is controlled by Malaysia[22]. Brunei airspace is too small to have a significant impact on the ATFM initiatives. Brunei and Myanmar are not expected to implement and distribute cross border ATFM measures but are expected to implement a number of other elements in the Regional Framework for Collaborative ATFM to support regional cross-border ATFM.

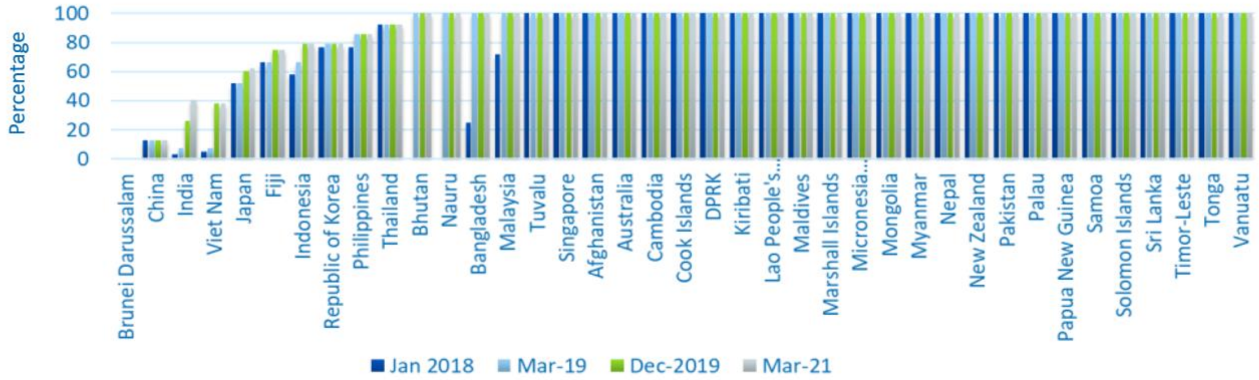
As of 2021, only Singapore and Thailand have robustly implemented ATFM. The measures needed for implementation of ATFM are already detailed in the Regional Framework for Collaborative ATFM (ICAO, 2017). States should continue to work towards implementing the measures to achieve robust implementation which will provide local benefits and improve the performance of the wider region.

Performance Based Navigation Implementation Status

The global and regional PBN implementation was updated during the 8th meeting of the PBN Implementation Coordination Group (PBNICG/8) in 2021. Figure 5 shows the PBN Implementation status at international aerodromes in the APAC region as per the integrated *Safety Trend Analysis and Reporting System 3.0* as of March 2021. Further details on the implementation progress for individual states was reported in PBNICG/8 information papers[23].

[22] https://permit2fly.com/region/asia/brunei-overflight-permits.html
[23] https://www.icao.int/APAC/Meetings/2021 PBNICG 8/Report_PBNICG 8-final.pdf

Figure 5 - PBN (Approach) implementation in APAC



Source: Report of the 8th Meeting of the PBNICG/8 (ICAO, 2021)

ICAO also tracked the implementation of Approach Procedures with Vertical guidance (APV) and PBN Standard Instrument Departure Routes (SID) and Standard Arrival Routes (STAR) which can be found in Table 7.

Table 7: Implementation Status of ICAO Assembly Resolution A37-11 (PBNICG/8)

March 2021	APV (including LNAV only)	APV		PBN SID	PBN STAR
		LNAV/VNAV	LPV		
Global (%)	71.4	59.4	34.4	49.4	44.8
Asia/Pacific (%)	57.5	47.1	0	71.6	68.8

Myanmar, Laos, Cambodia, Singapore and Malaysia have already implemented PBN (Approach) for their international aerodromes. Thailand, Philippines and Indonesia have implemented it in more than 80% of their international aerodromes and Vietnam has implemented in about 40%. Brunei has not implemented PBN. The number of aerodromes with PBN (approach) has not increased since Dec 2019 for states that have yet to reach 100% implementation, which may be the result of COVID-19.

Trajectory-based Operations Implementation Status

TBO in the United States of America and European Union

The NextGen programme in the USA and the SESAR programme in Europe are also developing TBO in their respective continents. The FAA is delivering decision support for TBO through evolving enhancements and the integration of Traffic Flow Management Systems, Time-based Flow Management, and Terminal Flow Data Management. These systems help to strengthen strategic planning and resolution of capacity demand imbalances during operations[24]. In Europe, the SESAR programme has multiple projects to implement and improve TBO in Europe like OptiFrame, an optimisation framework for TBO[25], Capacity optimisation in TBO[26], and 4D Trajectory Management[27]. The development projects not only benefit from their own region but also provide other regions the results from the studies and trials.

[24] **Trajectory-based Operations, https://www.faa.gov/air_traffic/technology/tbo/**
[25] **SESAR Optiframe, https://www.sesarju.eu/projects/optiframe**
[26] **SESAR COTTON, https://www.sesarju.eu/projects/cotton**
[27] **4D Trajectory Management, https://www.sesarju.eu/projects/4dtm**

TBO in ASEAN

TBO has yet to be implemented in Southeast Asia. A multi-regional TBO demonstration was presented in APANPIRG/32 (December 2021) which was a collaborative effort between Japan, Singapore, Thailand, the USA, and Canada. The aim of the demonstration was to identify, mature, and demonstrate key TBO capabilities and to identify the capabilities required to support TBO. The partners collaborated to design and simulate operational scenarios to better understand the workings of TBO within and across regions.

The capabilities demonstrated in multi-regional TBO included:

- Pre-departure trajectory negotiation.
- Post-departure trajectory negotiation.
- Collaborative decision-making.
- Efficient exchange of updated trajectories across all stakeholders.
- Mixed-mode operations where ANSPs and airspace users will be TBO-enabled at different time frames.
- Enhanced demand-capacity balancing.
- Enhanced predictability which will increase flight and fuel efficiencies.

Free Route Airspace Implementation Status

Free Route Operations (FRTO) is mentioned in the ICAO GANP as one of the Performance Improvement Areas under the Complexity Management Operational Concept. It is described as the use of airspace - free route airspace (FRA), with enhanced flexible en-route trajectories adjusted to specific traffic patterns to allow for shorter flight tracks and fuel savings. This operation has been trialled and implemented in many parts of the world and is considered as a low-hanging fruit to improve flight efficiency.

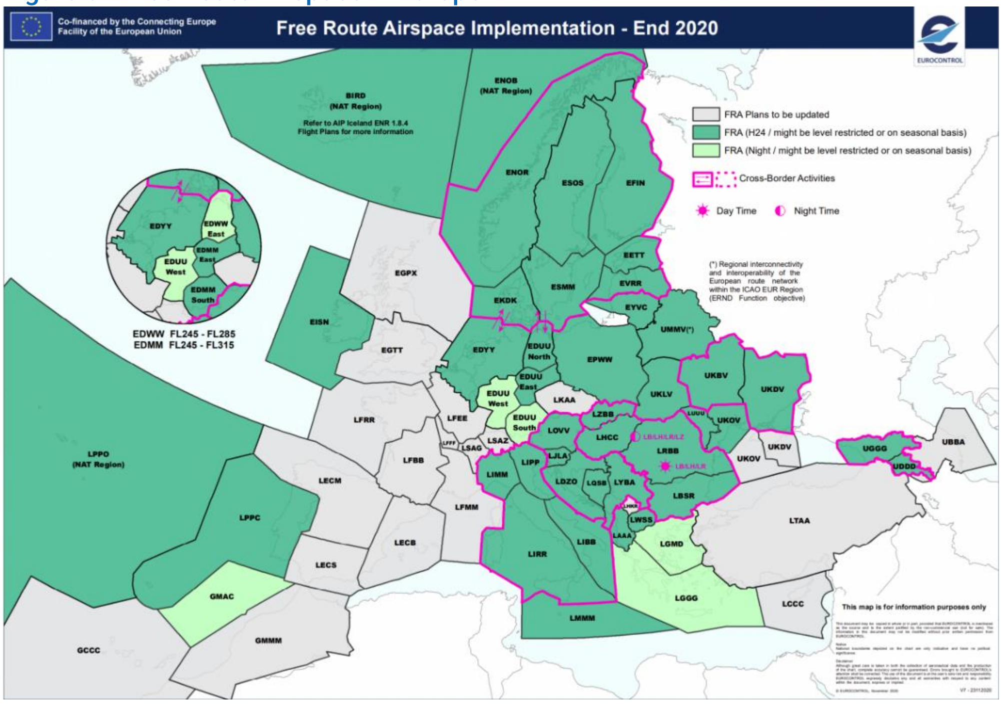
FRA in the United States of America and Europe

In the USA, part of their National Airspace System Modernization Program includes the implementation of PBN which allows direct routes using satellite navigation capability. In the USA, many airlines have lagged in fleet renewals, resulting in air carriers in the USA having ageing fleets. With the pandemic accelerating the aircraft renewal process, the introduction of user preferred routes has started to become a possibility and is welcomed for delivering fuel savings and time benefits. These have typically benefited operations in oceanic airspaces and above the Continental US airspace, outside of the busy terminal areas around large hub airports.

FRA in Europe is being introduced using a step-by-step process rather than as a single act. Most states decided to start with a limited implementation (e.g., during night hours) and then gradually expanded it to a 24-hour basis[28]. By the end of 2020, 46 Area Control Centres had implemented FRA at least partially. The implementation of FRA in Europe has progressed quite far and the situation as of 2020 is shown in Figure 6.

[28] **Free Route Airspace, https://skybrary.aero/articles/free-route-airspace-fra**

Figure 6 - Free Route Airspace in Europe



Source: EUROCONTROL,
https://www.eurocontrol.int/sites/default/files/2020-11/eurocontrol-fra-implementation-end-2020-v7-23112020%29.pdf

FRA in ASEAN

FRA is not a priority concept in the ASEAN ATM Master Plan and publicly available documents show no evidence that Southeast Asia is moving towards FRA. States in Southeast Asia could follow the stepwise deployment strategy taken by EUROCONTROL in Europe if they wanted to progress this capability. States in Southeast Asia could investigate the enablers identified by EUROCONTROL which are:

- Appropriate System Support – enhancement for the purposes of Flight Planning and ATFCM, downlink of flight plan.
- Procedures – enhanced procedures where necessary for operations within FRA and at its interfaces (neighbouring sectors).
- Adaptations to airspace structures to allow for smoother direct flight routes.
- Adaptations to airspace management procedures (such as restricted areas).

No additional requirements concerning aircraft equipage or changes to flight planning procedures are foreseen for aircraft operators.

Nevertheless, modifications to flight planning systems may be required to ensure that the full benefits of the FRA can be realised[29]. The overall benefits of Free Route Operations are distance and flight time savings, resulting in reduced fuel consumption and engine emissions. The benefits will certainly lead to savings across Southeast Asia. In Europe these benefits were a cost reduction up to 3.8% when applied to the whole of Europe, saving between 2% and 3.5% of flight distance[30].

[29] **Free Route Airspace Developments, https://www.eurocontrol.int/sites/default/files/2019-06/free-route-airspace-brochure-20161216.pdf**
[30] **https://www.sciencedirect.com/science/article/pii/S0969699717302466**

Enhanced Wake Turbulence Separation Implementation Status

The Civil Aviation Authority of each state will publish the separation standards in their respective Aeronautical Information Publication. Based on that publication, it can be determined whether the state had already implemented the Enhanced Wake Turbulence Separation[31] minima or whether they are still applying the existing wake turbulence categories that ICAO published decades ago. Table 8 shows the status of Enhanced WTS for each ASEAN state based on the publications provided by the Civil Aviation Authorities.

Table 8: Enhanced WTS implementation status in *Southeast Asia*

Implemented Enhanced WTS	Did not implement Enhanced WTS	No information available
Singapore (CAAS, 2021) Philippines (CAAP, 2020)	Brunei (BDCA, 2020) Cambodia (SSCA, 2021) Thailand (CAAT, 2019) Myanmar (DCA Myanmar, 2009) Malaysia (CAAM, 2021)	Vietnam Laos Indonesia

Singapore implemented distance-based Enhanced WTS in March 2022. The Philippines have Enhanced WTS standards in place but can only be applied when approved by the aviation authority. The status of the Enhanced WTS can also be inferred from the minimum separation distances in use. With advanced radar technology, the minimum separation distance can be reduced to 3 NM. Some states, such as Thailand still require a 5 NM minimum separation distance in their terminal airspace. This indicates that their Enhanced WTS implementation status has scope to be improved by upgrading of their radar technology and subsequent implement of the Enhanced WTS standards.

[31] This term was introduced in ICAO Doc 4444, amendment 9, Nov 2020

Challenges and Recommendations for Southeast Asia

General Challenges

Despite the commitment many States in Southeast Asia made to upgrade their ATM systems, the implementation progress of the advanced concepts has faced challenges even before COVID-19 hit the region. The causes for these challenges vary from technical, operational to institutional and social economic factors. The general challenges faced by the SEA region are:

- An important foundation of change is the so-called paradigm shift where the traditionally tactical ATC is being transformed into a more strategic role. This will make the role of the human operator to regulate traffic flows, thus managing more movements with the assistance of automation. The automation refers to sharing of airspace data on one hand and operational (flight plan) data on the other hand in order to better plan and route the flights. These efficiency improvements lead to more predictable traffic flows which can subsequently be better managed by air traffic controllers tactically.

- Lack of knowledge of ATM modernisation developments in general and more specifically, the future operational concepts accompanied by the technical knowledge of communication, navigation and surveillance systems that enable those concepts.

- The advanced equipment required often means a big leap is necessary compared to existing equipment. This requires training for the ANSP operational staff but also their maintenance staff. Not to mention that the change in the concept of operations may be found to be too big of a leap, causing internal resistance to such changes.

- The required changes impact multiple aviation stakeholders. Compared to changes within a single organisation, the change process is more difficult to initiate and manage. Even in Europe and in the USA these changes were not easily implemented.

- When the Southeast Asia region is compared to the USA and Europe, especially in the context of the social-economic profile of the region, certain institutional challenges come to light. For example, the inability to mandate - all States must come to a consensus and a lack of a supranational organisation that can orchestrate technical change processes. Yet at the same time, the geography of Southeast Asia shows a strong dependency on a good and efficient air transport network in addition to maritime vessels for mainly cargo shipments.

- There is an additional complexity when the changes involve aviation regulatory changes. For one, this means that the civil aviation authority must have a very good sense of policy direction moving into the future whilst shaping the aviation safety framework for the new operational environment.

- ATM is an invisible infrastructure as compared to airport infrastructure. The general public does not see the physical changes as a result of the money spent. Sometimes the benefits are for stakeholders or users and not the cost bearer.

- In addition to a lack of knowledge, it seems that the history of air transport and huge delays due to system inefficiencies in the USA and Europe in the 1980s and 1990s has not been experienced within this region. At that time, IATA calculated the cost of delays to have mounted up to a few billion US dollars per year. The painful lessons might need to repeat in Southeast Asia for an inflection point to be reached.

- Last but certainly not least, some States in the Southeast Asia may struggle to find funding for ATM modernisation because there is a lack of priority at government level.

Impact of COVID-19 on ATM modernisation in Southeast Asia

- The drastic reduction of air traffic movements has led to a huge loss of income for the ANSPs. For example, Singapore Changi Airport reported a traffic reduction from 382,000 aircraft movement in 2019 to 125,000 and 109,000 movements in 2020 and 2021 respectively[32]. News articles on this matter suggested that other countries have been hit hard as well though their exact numbers have not always been published.

- Governments have postponed many infrastructural projects as the resources have been channelled to address immediate needs and priorities due to COVID-19[33]. For example, Singapore Terminal 5 projects were paused for at least 2 years due to the uncertainty of the pandemic[34].

- Air transport is a crucial part of the economy as it connects people, stimulates tourism, contributes to valuable or perishable cargo transport and creates jobs both directly in the aviation sector as well as indirectly in the airport vicinity. While the COVID-19 pandemic had a decimating impact on the aviation sector, the rebound of air travel in Asia has been significantly delayed due to individual government COVID-19 measures, including quarantine rules and test regimes leading to uncertainty for travellers. One clear example of very strict COVID-19 rules is how Hong Kong has been losing its attractiveness as regional office location for many multinational companies[35]. The delayed rebound of Asian air travel also means that many governments do not feel the sense of urgency to invest in ATM modernisation.

- The pandemic paused air traffic for passengers and remains a dampener on demand until all States in Southeast Asia can treat COVID-19 as endemic, by creating societies who can live with COVID-19. More states in the Southeast Asia are gradually embracing that principle as their economies will otherwise suffer a severe slowdown.

- Now that many Southeast Asian States are reopening their borders and the aviation sector beings to restart, it can be observed that a significant percentage of the labour force has left the aviation industry during the pandemic. Many are not returning to their previous jobs. This has resulted in a staff shortage in many countries where airports are overcrowded resulting in flight cancellations. In the USA, many flights were cancelled for this reason in November and December 2021 holiday seasons, albeit weather and ATC were often blamed[36]. In the spring of 2022, many European airports such as Amsterdam, Dublin, Frankfurt London Gatwick and London Heathrow, were also affected by airport staff shortages[37].

Impacts if Southeast Asia ignores ATM modernisation

Regardless of the challenges faced by Southeast Asia, it is important that the region continues to work towards upgrading their ATM systems and equipment to facilitate air traffic growth. There would otherwise be several consequences for not taking any action and allowing air traffic to grow according to the principle of "more of the same". These consequences are explained below:

- As air traffic grows, there comes a time that either the airspace or airport infrastructure reaches its saturation. The period just before this happens will be characterised by a structural lack of capacity, huge delays and increased workload for different stakeholders. This situation often results in a loss of safety while the huge delays contribute to higher operating costs.

- The inefficiencies of the air transport system will require more manpower and other resources which may not always be available at short notice. All this results in increased manpower costs and eventually a

[32] https://www.changiairport.com/corporate/our-expertise/air-hub/traffic-statistics.html
[33] https://asean.org/asean-discusses-impacts-of-covid-19-future-priorities-on-sustainable-infrastructure/
[34] https://www.straitstimes.com/singapore/transport/coronavirus-changi-airport-t5-construction-to-be-paused-for-at-least-2-years
[35] https://www.ft.com/content/f369920b-1873-437a-a412-994bec50b8fb
https://www.channelnewsasia.com/commentary/hong-kong-emigration-exodus-singapore-asian-financial-hub-zero-covid-finance-business-jobs-economy-2780811
https://www.koreatimes.co.kr/www/biz/2020/06/175_291110.html
[36] https://www.bloomberg.com/news/articles/2021-12-24/airlines-scrap-1-000-u-s-holiday-weekend-flights-as-covid-bites
[37] https://www.reuters.com/business/aerospace-defense/british-airport-disruption-ominous-global-travel-recovery-2022-05-31/

negative impact on aviation sector growth, further impacting the broader economic growth of each state and thus the region.

- These additional costs can be considered as "lost opportunity costs". A simple example is the cost of delays due to bad weather. Airlines suffer from additional costs when flights are delayed and passengers miss their connections or have to be compensated for meals, etc. Instead of continuing operations in the same manner, the stakeholders could invest in a new operational concept to anticipate bad weather and take timely measures to avoid or mitigate the impacts of the delay.

- Organic growth according to the principle of "more of the same" will eventually show the hard limits of the air transport system. As mentioned above, these inefficiencies will eventually lead to higher costs. In addition, when the specific knowledge about future developments in ATM concepts and enabling technologies is only limited in availability and scattered in Southeast Asia, the situation will be exacerbated. This contrasts with for example Western countries who manage to reap the benefits of their technical and operational improvements through international collaboration at a regional level. At the same time, their stakeholders get to save some operational costs along the way.

General recommendations

It would be beneficial for an ANSP to perform a gap analysis, comparing their current air traffic management system capable of handling a certain amount of traffic movements per year, and a future air traffic management system that has already been described and agreed by international aviation organisations based on the premise of standardisation, accommodating future traffic demand, meeting environmental sustainability requirements and maintaining current safety levels. This gap analysis identifies the required operational concepts and enabling technologies to support them.

When an organisation embarks on changes to operational concepts and/or supporting technologies, there are important factors to consider prior to the change process. Each organisation needs to make its own cost benefits analysis, whereby cost is not only defined as a monetary value but also includes effort involved in training, implementation and maintenance. Important aspects to consider during such cost benefit analysis exercise, are:

- How will the new operational concept and its enabling technologies fit with the other systems, and what are the changes to the human roles interfacing between machine and operational procedures? This will impact training and system support.

- The lifespan of ATM equipment. Investments for new equipment needs to be planned near the end of system lifespan to justify replacements or upgrades.

- There is a need to thoroughly understand their ATM system. Especially by the time the system will have reached its limit because it is crucial to start working on and preparing for system modernisation well in advance. This ensures sufficient preparation time for modernisation and change management, such that the new system is operationally ready, and personnel are trained before the demand is present.

Another strong recommendation is to focus on Southeast Asian regional collaboration as this will deliver more benefits for the air transport system in the region. This can be illustrated based on the following concrete suggestions:

- Collaboration can be best setup to follow certain commonalities or topics. Large demonstrations like those used for SWIM have gathered the experts to validate the concept, systems and discuss future developments to progress its implementation. Other successful examples from Europe are:

    - COOPANS, a partnership between air navigation service providers who strive for harmonisation of functionalities and joint investments to enable the implementation of an advanced and unified air traffic control system (https://www.coopans.com/About-Coopans).

- iTEC, another partnership between air navigation service providers focusing on common operational concepts based on SESAR 4D trajectory management, improving interoperability in the system architecture and applying interchangeable system components through open standards (https://www.itec.aero).

- Without collaboration, the investment of one State may not be aligned with the region and therefore the benefits will be sub-optimal from a network standpoint. By definition air transport is international. Many of the abovementioned concepts have an underlying assumption that a large majority of the ANSPs will implement those concepts within similar timeframes. This will improve the network of ANSPs and aviation systems that work collaboratively in an efficient and interoperable manner. Deviating from the agreed and standardised concepts will be counter-productive and will lead to fragmentation that causes operational inefficiencies and higher costs for all stakeholders. Through collaboration, resources (manpower), funding and development of interoperable systems, can be put to better use to create synergy.

Varying factors and recommendation for priorities

These aspects above will continue to be underlying thoughts during the decision-making process. Assuming that funds can and will be set aside for the replacement and upgrade of ATM systems, there is a question of how to prioritise the modernisation efforts. All these concepts are very much interlinked with each other. A change in one concept may impact the progress of other concepts. For example, SWIM will enable ATFM, PBN will enable TBO and CDO/CCO.

In an effort to prioritise effort and resources to modernise the aviation system, the following rationale would be recommended for the assessment:

- What are the benefits when this operational concept is fully implemented?

- Which enabling technologies are required: do they already exist or by when would they become available?

- Does the concept rely on infrastructure development, and will this infrastructure enable many other concepts? This question is relevant to SWIM which is an important infrastructure replacing an existing system and at the same time enables other concepts. This makes SWIM an obvious choice for development.

- Looking at the current state of technology and operations, how much investment in terms of resources (not just solely monetary but in terms of development, training, transition, etc.), does it require to develop and implement the operational concept including its enabling technologies (if any)?

Enhanced Wake Turbulence Separation

This concept is considered as a low-hanging fruit as it involves the implementation of reduced wake turbulence separation minima for arrivals and departures at airports. There may be several reasons why it has not yet been done until now.

- The ANSP in the country requires modern surveillance equipment to accurately detect where exactly each aircraft is for at least every second in order to maintain the reduced separation minima. There may be a lack of sophisticated equipment which is also often coupled with a lack of knowledge / experience regarding that surveillance capability.

- As airports are still able to accommodate air traffic demand by increasing airport throughput, there might not be a sense of urgency to implement those reduced minima. Once the airport throughput is almost reaching it maximum physical capacity, the airport and ANSP may then react by searching for solutions for marginally capacity increases.

- Building staff competences takes time. The ability to effectively use new capabilities relies on the knowledge and aptitude of air traffic controllers and maintenance engineers. It is recommended building the requisite competencies starts sooner rather than waiting until capacity issue arises.

Free Route Airspace

Free Route operations require good communication and surveillance coverage in the managed airspace; however, this is not the case with many ANSPs in Southeast Asia, especially over oceanic airspace. Ironically, the oceanic airspace is often offering the vast area where free routing can be best applied.

- Improvement of the surveillance function can be done in a few ways. In airspace above a land mass, radar equipment can be installed, apply Automatic Dependent Surveillance – Broadcast (ADS-B) with a network of receiver stations on the ground or satellite surveillance services. In oceanic airspaces, the option of satellite surveillance services would be best using ADS-B. Satellite Based Augmentation System are being deployed in various region to provide accurate navigation guidance.[38]

- Free Route operations also require good communications coverage to manage. The current communication system relies on ground-based VHF communications which are not available over oceanic airspace. Singapore is currently conducting a research collaboration to study the possibility of deploying a space-based VHF communication system to provide communication capabilities over oceanic airspace[39].

- The states in Southeast Asia are recommended to collaborate with their neighbouring states to analyse the route structure in the airspace and simplify where possible. This will result in direct routing options, lower fuel burn and reduce air traffic controller workload. Initiatives in Europe can be good examples for Southeast Asian states where the focus of collaboration is on removing restrictions to allow for continuous descent/climb profiles and common procedures at the borders to optimise flight profiles and traffic handling. For example, EUROCONTROL's Maastricht Upper Area Control Centre (MUAC) and DFS Deutsche Flugsicherung GmbH collaborated to improve airspace optimisation, technical cooperation and harmonisation of procedure[40].

System Wide Information Management

Many ANSPs have seen the benefits of SWIM during the ASEAN SWIM demo in 2019 however implementing SWIM in the respective States is difficult for many reasons.

- SWIM requires a telecommunications infrastructure which is often not a policy responsibility of the Ministry of Transport. As such, there needs to be an orchestrator at government level who can be the focal point and take responsibility to champion the need for SWIM in aviation and drive the implementation process.

- The same orchestrator also needs to bring together the relevant stakeholders in aviation to collaborate, define their future needs and jointly develop the operational applications in SWIM. This process requires commitment from all to invest in effort, time and equipment where needed.

- The pandemic has shifted the focus of many aviation companies to a survival mode and faded the sense of urgency for SWIM. Now that borders are slowly opening-up with air traffic demand expected to climb, many organisations and companies are expected to return to their pre-Covid mode of operations.

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[38] **https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/Gnss/library/factSheets/media/SBAS_Worldwide_QFact.pdf**

[39] **https://www.caas.gov.sg/who-we-are/newsroom/Detail/singapore-takes-next-step-towards-implementing-world's-first-space-based-vhf-communications**

[40] **https://www.eurocontrol.int/news/eurocontrol-muac-and-dfs-sign-agreement-enhance-efficiency-core-european-airspace**

Air Traffic Flow Management

Only a handful Southeast Asian States have an advanced ATM computer system in their ATC centres to manage air traffic. The level of sophistication also determines how much each ANSP could participate in earlier organised demonstration projects and subsequently with SWIM. The principle of ATFM is to provide the operational information in a timely manner, preferably hours before the flight starts so the flight operations department can take measures accordingly and flight crew can anticipate the disruptions or changes to their flight plans.

The ideal situation is when all these functions are integrated into one computer system located at the work console of the ATFM position. The challenge with lesser sophistication is that the information and the information exchange platforms are not integrated in one system causing delays in messaging the relevant airspace users.

Trajectory-based Operations

This concept is perhaps a bridge too far in the immediate period as it has several implementation dependencies (PBN, SWIM and excellent communication and surveillance systems) to make it work.

Continuous Descent Operations and Continuous Climb Operations

- These operations require a large airspace where one ANSP can control the flight from the airport all the way to its cruising level and vice versa. Given that there are no airspace requirements, many ANSPs are able to offer these operations during periods of low traffic density.

- For CCOs the ANSP has to organise its SIDs and STARs in such a way that the relevant SID has a free corridor with both lateral and vertical separation safety margins to perform a CCO up to cruising flight level and connect with one or more published ATS routes. In low traffic situations, an ANSP can allow flights to perform CDOs in its airspace. The challenge lies in consistently performing CDOs in airspace with medium to high traffic flows. This is because each aircraft has its own weight and aerodynamic performance which determines its descent profile, speed and time to reach the runway. The trailing aircraft that does the same CDO has an additional requirement that it has to maintain the wake vortex minimum separation at final approach caused by the previous aircraft. Keeping that final approach separation to as low as possible ensures a high landing rate. While modern flight management systems (FMS) can already optimise such CDO paths, the air traffic controller managing the arrivals need an automated tool to manage a flow of CDO flights. The tool often used by the air traffic controller to manage the arrival sequence is an Arrival Manager (AMAN). For CDOs the AMAN would be integrated with other tools that provide the capability of incorporating additional data sent between the aircraft and a ground-based systems. These enable the receiving of downlink data of the CDO trajectory calculated by the aircraft's FMS and 'up linking' information to tweak the trajectory to align and comply with the minimum separation minima at the runway.

- The investments for the ANSPs to develop and implement such AMAN capabilities is quite high while the direct benefits of fuel burn reduction are reaped by the airlines. The same applies for redesigning the terminal airspace to allow for CCOs. As such, implementing these CCO/CDO operations in high traffic densities requires proper incentives for all stakeholders involved.

Concluding remarks

At a government level, ATM modernisation does not get the sense of urgency it deserves. It is often the stakeholders in the air transport sector that have to show the initiative and create a momentum to set the development in motion and keep the pace. Very often, a good orchestrating entity or government body helps to overcome various institutional barriers. In the context of Southeast Asia, getting the Civil Aviation Authority (CAA) involved is key to encapsulating the required regulatory framework and to ensuring the safety of operations. In addition, the CAA can help interface with neighbouring States to initiate and deepen collaboration and therefore achieve the benefits from a network perspective.

With an initiative that is supported by aviation stakeholders, necessary government funding can be arranged to secure the project through development and implementation. The recommendations in this paper could guide the selection of the operational concept(s) to be further progressed in collaboration with international aviation stakeholders from other States. Experience from earlier large-scale demonstrations could be tapped upon to organise the next for demonstrating their benefits and/or to further progress the implementation that has been delayed by the pandemic.

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