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PRIMARY RESEARCH

NO_X and CO_2 emissions from current air traffic in ASEAN region and benefits of free route airspace implementation

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Abstract— The ASEAN region is affected by many climate-change inducing factors such as Forest Fires, Transboundary Haze Pollution, and Forest Degradation. However, within the next few years there may be one more significant contributor in making the ASEAN region vulnerable to climate-change–Air Transportation. Air Traffic Demand in the ASEAN region is growing tremendously. It is expected that air traffic in the region will triple by the year 2033, thus, posing the need for reduction of Green House Gas emissions from aircraft to reduce air pollution. This paper highlights the estimated amount of key air pollutants such as NO_X and CO_2 emitted in the ASEAN region due to current air traffic demand and the potential benefits of free route airspace implementation in the region. The environmental emissions were estimated using System for Traffic Assignment and Analysis at a Macroscopic Level (SAAM) tool. A simplified version of EUROCONTROL's Advanced Emission Model was adopted for estimating the environmental emissions. This paper also discusses future ATM technologies that may be implemented in the ASEAN region, which could support the feasibility of the Free Route Airspace Concept in the region.

I. INTRODUCTION

According to the Asian Development Bank's report [1], Southeast Asia's long coast lines, tropical climate, increasing population and unique economic and social characteristics make it one of the world's most vulnerable regions to climate change impacts [1]. Transboundary haze pollution has been occurring nearly every year over the last 20 years. Though there are significant efforts by the ASEAN countries to mitigate climate change, one important aspect that must be now considered is the rising air traffic demand in the region. According to the Airbus Global Market Forecast (2013-2033) [2], Air Traffic in this region is expected to grow at a Compound Annual Growth Rate (CAGR) of 6.5%, a rate at which traffic could triple by the 2030s. This suggests the need for increased flight efficiency to reduce fuel consumptions and emissions of Green House Gases such as NO_X and CO_2.

The Free Route Airspace Concept, which is already implemented in Europe, allows pilots to fly freely between

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a defined entry and exit point without following the original fixed ATS route [3]. This results in increased flight efficiency, with reduced fuel consumption and NO_X and CO_2 emissions.

This paper estimates the total amount of NO_X and CO_2 emitted in a day by current air traffic demand in ASEAN region and the reduction in such gas emissions with the application of the free route airspace concept in the model. This paper also discusses to a certain extent, future ATM technologies that may be implemented in ASEAN and how it couldboost the implementation of Free Route Airspace Concept in the region with enhanced capacity.

II. MODEL FOR ESTIMATING AIRCRAFT NO_X AND CO_2 EMISSIONS

EUROCONTROL's SAAM tool was used for the analysis. The approach used for estimating fuel consumption and NO_X & CO_2 emissions by the model we have adopted is summarized in Table 1 below [4].

TABLE 1
APPROACH FOR ESTIMATING FUEL CONSUMPTION AND GAS EMISSIONS [4]

	Fuel Burn	NO_X	CO_2
Above 3000 ft Non-Landing Take-Off phases	BADA Data	Boeing Method 2	Proportional to Fuel Burn

Fuel consumption is estimated based on the aircraft-engine characteristics provided in the Base of Aircraft Data (BADA) for different aircraft types [4]. The formula for estimating total gas emissionsbased on EUROCONTROL's Advanced Emission Model, which is an improvisation to the original Boeing Method 2 model, is provided as [5]: Total (HC,CO,NOx)

$$= N \times \Sigma_i (EIHC, EICO, EINOX)_i \times Wf_i \times t_i \times 10^{-3} \quad (1)$$

Where,
N = Number of Engines;
EIHC= Emission Index of HC;
EICO= Emission Index of CO;
EINOX = Emission Index of NOx;
Wf = Fuel Flow;
t= Time [5]

Thus, the model for calculating total NO_X emissions could be simplified from equation (1) as [5]:

$$Total\ (NOx) = N \times \Sigma_i (EINOx) \times Wf_i \times t_i \times 10^{-3} \quad (2)$$

The emission index for CO_2 is 3,149 kg/kg fuel [6]. This emission index will be constant for all flight phases, as CO_2 is proportional to fuel burn [6].

III. ESTIMATION OF NO_X & CO_2 EMISSIONS FOR CURRENT ASEAN AIR TRAFFIC SCENARIO

A. *Modeling Current ASEAN Air Traffic Scenario*

First, the ASEAN air traffic services route network and airspace were modelled by referencing information from online mapping and aeronautical charts provider, SkyVector as can be seen in Fig. 1. The details of historical flights in ASEAN Region were derived from data obtained from Flight Global INNOVATA and the extracted traffic information were then simulated using SAAM software.

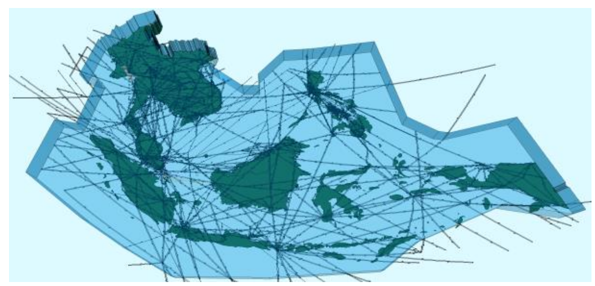

Fig 1. ASEAN airspace and air traffic services route network.

B. *4D Profile Generation and NO_X & CO_2 Emission Calculations for Current ASEAN Air Traffic Scenario*

The 4D flight trajectories for the selected one-day traffic sample were simulated using the shortest routes available based on the route network modelled. The simulated flight profiles can be seen in Fig. 2. Using these simulated 4D profiles, the NO_X and CO_2 emissions were calculated.

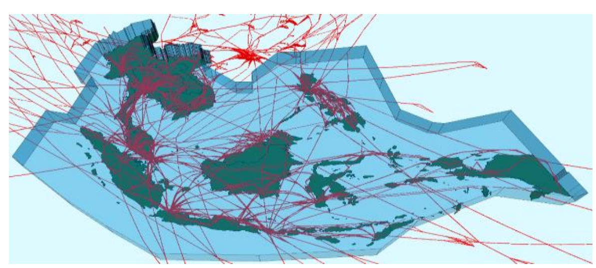

Fig. 2. Simulation of 4d flight profile for current air traffic in ASEAN region.

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The results, as summarized in Table 2, show that the current traffic demand in ASEAN region is about 8788 flights/day emitting a total of 677,411 kg of NO_X and 118,752,563kg of CO_2.

TABLE 2
DAILY NO_X AND CO_2 EMISSIONS FROM CURRENT ASEAN AIR TRAFFIC

Total Flights in a day	Tot. NO_X (kg)	Tot. CO_2 (kg)
8,788	677,411	118,752,563

IV. ESTIMATION OF REDUCTION IN NO_X & CO_2 EMISSIONS WITH THE APPLICATION OF FREE ROUTE CONCEPT

The new scenario was modelled by assigning direct routes between entry and exit points within the boundary of each FIR in ASEAN airspace. In order to do that, we first modelled the 12 FIRs in ASEAN region as can be seen in Fig. 3, using information from SkyVector.

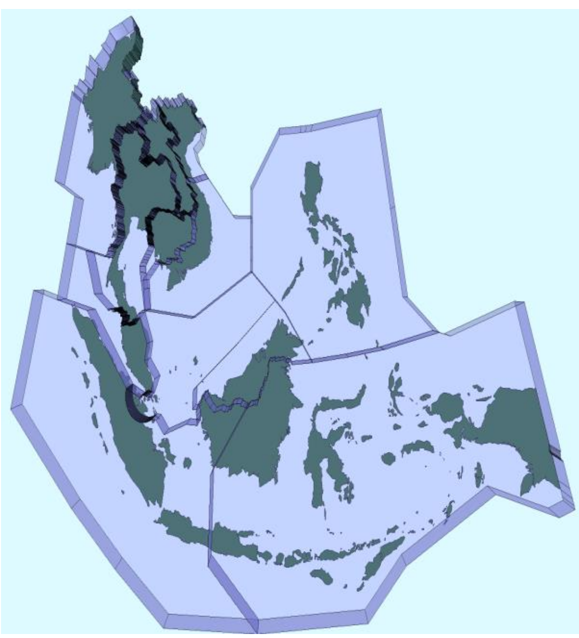

Fig. 3. 12 ASEAN FIRs

The first waypoints by which the flights enter the FIR boundary were selected as the entry points and the last waypoints which the flights pass through before leaving the FIR boundary were selected to be the Exit Points. Fig. 4. Shows the Original fixed ATS routes in Red and the generated Direct Free Routes in Green. The flights were then simulated to pass through these direct free routes between the selected entry and exit points.

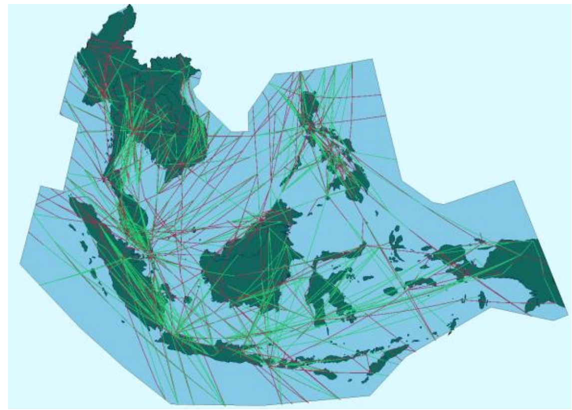

Fig. 4. ATS route vs free route.

Comparison Thresholds were set to ignore flights that show lesser NO_X and CO_2 difference between the current and new scenarios for the analysis. The comparison thresholds that were used for the experiment are provided in Table 3.

TABLE 3
COMPARISON THRESHOLDS FOR COMPARING CURRENT AND NEW SCENARIO

Comparison Thresholds	
NO_X	0.0022 kg
CO_2	0.8635 kg

The total number of flights impacted by these new free routes were 5,482, 62% of the current daily traffic, thus resulting in a reduction of 3,738 kg of NO_X and 815,573 kg of CO_2 as provided in Table 4 below.

TABLE 4
REDUCTION IN DAILY NO_X AND CO_2 EMISSIONS IN NEW SCENARIO

Total Flights Impacted	Tot. NO_X (kg)	Tot. CO_2 (kg)
5,482	3,738	815,573

This suggests that there could be a maximum potential reduction of nearly 300,000,000 kg of CO_2 and 1,400,000 kg of NO_X per annum in the ASEAN region.

TABLE 5
POTENTIAL ANNUAL REDUCTION IN NO_X AND CO_2 EMISSIONS IN ASEAN

Tot. NO_X /Annum (kg)	Tot. CO_2 /Annum (kg)
1,364,346	297,684,145

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V. DISCUSSIONS ON THE RELEVANCE OF FUTURE ATM TECHNOLOGIES IN ASEAN TO FREE ROUTE AIRSPACE CONCEPT AND ENVIRONMENTAL EMISSIONS

Though the forecasted 6.5% CAGR for ASEAN traffic [2] suggests that traffic will triple in this region by the year 2033, an important factor to be considered is whether or not there may be sufficient capacity to handle this demand. It should be also noted that application of Free Route Airspace Concept is structurally limited as its application in very complex airspace could reduce capacity [3]. Currently, the secondary surveillance radar coverage over ASEAN airspace is quite limited, particularly in oceanic areas [7]. Such limitation in radar coverage could subsequently limit the number of aircraft packed on the ATS routes, due to requirement to maintain larger separation standards. However, recent reports from ICAO [8] show that steps are already being undertaken by ASEAN countries to implement land-based ADS-B technology in the region. The benefits of ADS-B implementation have been proven to increase capacity and efficiency as better surveillance could mean lesser separation standards and more aircraft. This would enhance the capacity of ASEAN airspace in meeting the forecasted traffic demand, which can subsequently result in large amounts of environmental emissions. However, it should be noted that implementation of ADS-B technology could also support reduction in environmental emissions due to aviation, if optimum flight levels are allocated to the aircraft [8] [9]. With Singapore being the first country in the Asia-Pacific region to sign for the provision of space-based ADS-B for its airspace [10], more ASEAN countries could also be expected to plan implementation of space-based ADS-B in the future. This could provide increased surveillance, safety and efficiency benefits in comparison with land-based ADS-Band other terrestrial surveillance systems [11]. Such technologies can provide better aircraft tracking and monitoring at a global level and as a result boostthe implementation of the Free Route Airspace concept in ASEAN region with increased safety. This can thus, eventually result in significant environmental benefits.

VI. CONCLUSION

This paper estimated the current daily NO_X and CO_2 emissions due to air traffic in the ASEAN region. The results suggest that the daily emissions are high. Previous research studies on the lifetime of CO_2 molecule indicate that its residence time (lifetime) ranges from 5 to 95 years [12], [13]. Though an individual CO_2 molecule may have a short residence time, the warming potential of CO_2 will still be very high as many of the processes to dissolve or absorb this redundant CO_2 vary from fast to slow. About 70% of the ASEAN airspace is oceanic region. The ASEAN region has been impacted by rising sea levels in the past 2 decades with severe sea-level trends expected in the future [14]. This contributes to slower transfer of carbon from the ocean surface to the deep oceans, thus increasing the warming potential of CO_2. The man-made CO_2 is also exhausted at a faster rate compared to the velocity of absorption by the oceans [15].

The amount of NO_X emitted per day due to current air traffic is also considerably high. NO_X is a long-lived and surface-flux species [16] and contributes to production of Ozone in the Troposphere. The results produced in this paper show that with the implementation of Free Route Airspace in ASEAN region, there may be a maximum potential reduction of nearly 300,000,000 kg of CO_2 and 1,400,000 kg of NOx per annum in the ASEAN region. It should be noted that the results are indicative of a macroscopic application. However, the application of Free Route Airspace Concept in complex airspace could reduce capacity [3]. To address this issue, this paper also discussed on the implementations of land-based ADS-B Coverage over the ASEAN airspace and potential upgrade to space-based ADS-B in the future. Such new ATM technologies can promote enhanced safety and efficiency, thus allowing more aircraft to fly freely using direct routes. With air traffic in the ASEAN region expected to triple by the 2030s, the implementation of the Free Route Airspace Concept boosted by ATM technologies such as land-based and space-based ADS-B may contribute to significant environmental benefits. The flight routings simulated for this experiment were not based on actual routings and were simulated based on the shortest available ATS routes between each city-pairs in ASEAN. This paper also considered only the structural limitations of Free Route Airspace Operations. Future work could be based on actual routings and could also provide estimations of environmental emissions due to the forecasted traffic. More limitations of Free Route Airspace Operations and its feasibility to ASEAN region could also be discussed.

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