

**A MODEL TO ESTIMATE CO₂ EMISSIONS FROM AIR
TRAFFIC MOVEMENT IN AIRPORTS**

D.M.M.S. Dissanayaka

(188010T)

Degree of Master of Science in Transport and Logistics Management

Department of Transport and Logistics Management

University of Moratuwa
Sri Lanka

February 2020

**A MODEL TO ESTIMATE CO₂ EMISSIONS FROM AIR
TRAFFIC MOVEMENT IN AIRPORTS**

Dissanayaka Mudiyanseilage Manori Sanjeevani Dissanayaka

(188010T)

Thesis submitted in partial fulfillment of the requirements for the degree Master of
Science in Transport and Logistics Management

Department of Transport and Logistics Management

University of Moratuwa

Sri Lanka

February 2020

Declaration, copyright statement and the statement of the supervisor

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date:

The above candidate has carried out research for the Master's thesis under our supervision.

Name of the supervisor: Dr. V.V. Adikariwattage

Signature of the supervisor:

Date:

Name of the co-supervisor: Dr. H.R. Pasindu

Signature of the supervisor:

Date:

Abstract

A model to estimate CO₂ emissions from Air Traffic Movement in airports

The importance of airport emission inventory is more specific in the local context as it directly affects the local air quality. The assessment of emission from different phases of flight separately has not received sufficient attention. The specific gap addressed by this research is evaluating the CO₂ emission from different phases of aircraft within the Landing Take-off (LTO) cycle and the CO₂ emission from flight delays since they allow initiating more precise emission reduction strategies. Using currently available methodologies for assessing the emission from the LTO cycle in the Sri Lankan context has significant limitations. Industry-wide standards have been found to overestimate actual volumes specific to local conditions.

Reviewing current CO₂ emission calculation methods related to aeronautical activities within the LTO cycle, developing a model incorporating data specific to local conditions to estimate CO₂ emission and estimating additional CO₂ emission due to delay and validating the model are the main objectives of this study. The results of the suggested methodology for calculating CO₂ emission were compared with the industry standards and actual operational values. The CO₂ emission of different phases of flight and the CO₂ emission due to delays within the LTO was assessed using the suggested methodology.

The suggested methodology shows the unnecessary fuel burn and emissions according to current practices. The outcomes encourage stakeholders to initiate emission reduction methods. This study can be used as a reference when implementing those reduction methods. The suggested methodology can be applied in any airport which has data and technological constraints. The CO₂ emission from delays at the taxiing phase has a significant influence on local air quality. The taxiing out phase which is the highest contributor to delays within the LTO should be given the most priority when initiating emission reduction methods.

Keywords- CO₂ emission, LTO cycle, taxiing delays, APU, WTC

Acknowledgement

First and foremost, I would like to express my heartfelt gratitude to my research supervisor, Dr. V. Adikariwattage and Co-supervisor, Dr. H. R. Pasindu for their unlimited support during my MSc studies. I am grateful for their encouragement, continuous attention, patience and guidance throughout the research period.

I would like to express my profound gratitude to Senior Prof. Amal S. Kumarage, Head of the Department of Transport and Logistics Management for giving approval and assistance to conduct the research work.

I am grateful to the staff of the Bandaranaike International Airport for the assistance during the field visits. I am also grateful to Mr Sumith Tennakoon, Mr Thilina Sri Warnasinghe, Air traffic controllers at Airport & Aviation Services (Sri Lanka) Limited for providing guidance during the collection of data for this research.

I would like to extend my special gratitude to Prof. J.M.A. Manathunga and Dr. Y.M.M.S Bandara members of the Progress Review Committee, who were more than generous with their expertise, precious time and provided many suggestions and corrections.

I would like to thank Senate Research Committee for financial support. The research study was funded by Senate Research Council Grant (SRC/LT/2018/03) by the University of Moratuwa.

Last but not least, I am sincerely thankful to all the staff members and the non-academic staff of the Department of Transport and Logistics Management. I am also thankful to my family members, colleagues and friends who supported me in many ways throughout the research.

Table of Contents

Declaration, copyright statement and the statement of the supervisor	i
Abstract	ii
Acknowledgement.....	iii
Table of Contents	iv
List of Figures.....	viii
List of Tables	ix
List of Abbreviations.....	x
List of Appendices.....	xi
1. INTRODUCTION	1
1.1 Background	1
1.2 GHG Emissions from aviation	1
1.3 Flight cycle.....	2
1.4 Emission sources of Aviation.....	2
1.4.1 Emission sources at airports	3
1.5 International approaches towards Climate Change	4
1.5.1 United Nations (UN).....	4
1.5.2 International Civil Aviation Organization	5
Standards and Recommended Practices.....	6
1.5.3 Committee on Aviation Environmental Protection (CAEP).....	7
1.5.4 Sustainable Development Goals (SDGs).....	7
1.5.5 Intergovernmental Panel on Climate Change (IPCC)	10
1.5.6 United Nations Framework Convention on Climate Change (UNFCCC).....	11
1.5.7 Kyoto Protocol.....	11
1.5.8 The Paris Agreement.....	11
1.5.9 Nationally determined contributions (NDCs).....	12
1.6 Importance of evaluating GHG emission in Sri Lankan aviation Sector	12
1.7 Methodologies available to calculate GHG emission of Aviation	13
1.7.1 IPCC recommended method.....	13
1.7.2 Airport Council International (ACI)	13
1.7.3 Airport Cooperative Research Program (ACRP) Report 11	14
1.7.4 CORSIA.....	14
1.7.5 Airport Carbon Accreditation (ACA).....	15
1.7.6 Excess emission due to aircraft delays	15
1.8 Research Gap	16
1.9 Research Scope	18
1.10 Research Objectives.....	19
1.11 Significance of the research	20
1.12 Layout of the thesis.....	20
2. LITERATURE REVIEW.....	21

2.1 Emission calculation methods	21
2.1.1 Basic method of calculating emission	21
2.1.2 Emission calculation methods of ICAO	22
2.1.3 Emission calculation methods recommended by IPCC	24
Tier 1	24
Tier 2	25
Tier 3	27
Emission of APU	27
2.1.4 Emission calculation methods followed by European Airports	28
2.1.5 Other methods of emission calculation within LTO	29
2.2 Tools used to gather information on flight operations and emission factors	31
2.2.1 Automatic dependent surveillance-broadcast (ADS-B)	31
2.2.2 Flightradar24	32
2.2.3 FlightAware.....	33
2.2.4 Airport Carbon and Emissions Reporting Tool (ACERT).....	33
2.2.5 Emission index (EI)	34
2.2.6 Carbon emission accreditation.....	34
2.3 Auxiliary power units (APUs).....	35
2.3.1 APU usage at different airports.....	35
2.4 Taxiing delays and calculation methods	36
3. METHODOLOGY	36
3.1 Research Problem.....	36
3.1.1 Evaluation of CO ₂ emission level within the LTO cycle.....	36
3.2 Research Framework	38
3.2.1 Proposed model to estimate the CO ₂ emission level within the LTO cycle.....	39
Recognizing the airport specific conditions in CO ₂ emission level estimation	40
3.2.2 Methodology for the analysis of excess CO ₂ emission due to delays.....	41
3.3 Phases of flight within the LTO cycle	42
3.3.1 Departure flight.....	42
3.3.2 Arrival flight.....	43
3.3.3 Auxiliary Power Unit (APU).....	44
3.4 Carbon Dioxide (CO ₂) Emission	44
3.5 Data Sources	45
3.5.1 Taxiing phase and Turnaround	45
3.5.2 Take-off, Climb-out and Approach.....	45
3.5.3 ICAO Aircraft Engine Emissions Databank	47
3.5.4 Emission index (EI)	47
3.6 Data Collection.....	47
3.7 Estimating emission under different phases of flight	48
3.7.1 Aircraft Categorization.....	48
3.7.2 Taxiing phase	49
Comparison of average taxiing time with ICAO recommended values.....	50
Converting taxiing time to CO ₂ emission	51

Comparison of the taxiing emission obtained from the operational data, suggested methodology, and ICAO option B method	52
3.7.3 Take-off, Climb-out and Approach phases.....	52
Comparison of the mean durations of climb-out and approach phases with ICAO recommended values	53
Converting durations in take-off, approach and climb-out to CO ₂ emission.....	54
Comparison of the take-off, climb-out and approach emission calculated from the operational data, the suggested methodology and ICAO option B method.....	55
3.7.4 APU operation	55
3.8 Estimating emission due to delay within the LTO cycle	56
4. DATA ANALYSIS AND RESULTS	59
4.1 Case study airport- Bandaranaike International Airport (BIA)	59
4.2 Summary of methodology.....	60
4.3 CO ₂ emission under different phases of flight at BIA	60
4.4 Taxiing phase	61
4.4.1 Overview of the sample of data analyzed in the taxiing phase	61
4.4.2 ANOVA test results under the category of WTC for Arrivals.....	62
4.4.3 ANOVA test results under the category of WTC-Departures.....	64
4.4.4 ANOVA test results under the category; the days of the week for arrivals	66
4.4.5 ANOVA test results under the category; the days of the week for departures.....	67
4.4.6 ANOVA test results under the category; parking apron location for arrivals	68
4.4.7 ANOVA test results under the category; parking apron location for departures.....	69
4.4.8 Comparison between ICAO recommended values for TIM and estimated average TIM values using operational data	70
4.4.9 Estimation of CO ₂ emission level in the taxiing phase.....	74
4.4.10 Hourly CO ₂ emission distribution at the taxiing phase.....	76
4.5 Take-off, Climb-out and approach	78
4.5.1 Overview of the sample of data analyzed in the Take-off, Climb-out, approach phases....	78
4.5.2 Fuel consumption and CO ₂ emission calculation of Take-off, Climb-out, Approach phases	80
4.5.3 Climb-out	81
ANOVA test results for the data obtained phase climb-out.....	81
Comparison between ICAO recommended values for climb-out and estimated average climb-out using operational data.....	82
Estimation of CO ₂ emission level from the take-off phase	83
Hourly CO ₂ emission distribution at the take-off phase	84
Estimation of CO ₂ emission level from Climb-out phase	85
Hourly CO ₂ emission distribution at the climb-out phase.....	86
4.5.4 Approach.....	87
ANOVA test results for the approach phase	87
Comparison between the ICAO recommended TIM for the approach phase and the estimated average approach time using operational values at BIA	88
Estimation of CO ₂ emission level from the Approach phase	90
Hourly CO ₂ emission distribution at the approach phase.....	91
4.6 Estimating CO ₂ emission due to APU usage.....	92

4.7 CO ₂ emission per operation within LTO cycle	93
4.8 Estimation of annual CO ₂ Emission from the LTO cycle	95
4.8 Estimating CO ₂ emission due to taxiing delay	96
4.8.1 Unimpeded Taxiing in and out time.....	96
4.8.4 Taxiing delay	99
5. CONCLUSIONS AND RECOMMENDATIONS.....	100
5.1 Key findings	100
5.2 Limitations	105
5.3 Recommendation.....	106
6. REFERENCES	108

List of Figures

Figure 1.1 : LTO and CCD cycle	2
Figure 1.2: International organizations that commit to climate actions	5
Figure 1.3: SARPs of ANNEX 16	7
Figure 1.4: SDGs that is supported by the ICAO environment	8
Figure 1.5: Phases of departure flight within the LTO cycle.....	19
Figure 1.6: Phases of arrival flight within the LTO cycle	19
Figure 3.1: Research Framework	38
Figure 3.2: A template for other airports for estimating its emission with minimal resources	41
Figure 4.1: Phases of flight within the LTO cycle	61
Figure 4.2: Sample size for the analysis of taxiing phase.....	62
Figure 4.3: Taxiing-in time distribution of arrivals according to aircraft type	62
Figure 4.4: Taxiing-out time distribution of departures according to aircraft type.....	64
Figure 4.5: Taxiing-in time distribution of arrivals according to the day of the week.....	66
Figure 4.6: taxiing-in time distribution of arrivals according to the day of the week	67
Figure 4.7: Taxiing-in time distribution of arrivals according to the Apron	68
Figure 4.8: Taxiing-out time distribution of departures according to the location of apron...	69
Figure 4.9: Mean taxiing-in time for heavy and medium arrivals at BIA	71
Figure 4.10: Mean taxiing-out time for heavy and medium departures at BIA	73
Figure 4.11: Daily taxiing-in emission of arrivals	75
Figure 4.12: Daily taxiing-out emission of departures	75
Figure 4.13: CO ₂ emission per arrival, heavy aircraft.....	76
Figure 4.14: CO ₂ emission per departure, heavy aircraft	76
Figure 4.15: CO ₂ emission per arrival, medium aircraft	77
Figure 4.16: CO ₂ emission per departure, medium aircraft	77
Figure 4.17: The relationship between arrival rate and departure rate on CO ₂ emission per operation.....	78
Figure 4.18: Sample size for the analysis of Take-off, climb-out and approach phases	80
Figure 4.19: Climb-out time distribution of Heavy and medium aircraft at BIA	83
Figure 4.20: Daily CO ₂ emission from the take-off phase at BIA	84
Figure 4.21: Hourly CO ₂ emission per operation in the take-off phase of heavy departures .	84
Figure 4.22: Hourly CO ₂ emission per operation in the take-off phase of medium departures	85
Figure 4.23: Daily CO ₂ emission at the Climb-out phase at BIA	86
Figure 4.24: Hourly CO ₂ emission per operation in the climb-out phase for heavy departures	86
Figure 4.25: Hourly CO ₂ emission per operation in the climb-out phase for medium departures	87
Figure 4.26: Approach time distribution of Heavy and medium aircraft at BIA	89
Figure 4.27: Daily CO ₂ emission at the approach phase at BIA	91
Figure 4.28: Hourly CO ₂ emission per operation in the approach phase for heavy arrivals...	91
Figure 4.29: Hourly CO ₂ emission per operation in the approach phase for medium arrivals	92
Figure 4.30: Hourly CO ₂ emission from APU operation at BIA	93

Figure 4.31: CO ₂ Emission per operation for heavy flights at BIA	93
Figure 4.32: CO ₂ Emission per operation for medium flights at BIA	94
Figure 4.33: Estimated monthly CO ₂ emission within the LTO cycle at BIA.....	96
Figure 4.34: Taxiing-out time distribution of heavy aircraft	97
Figure 4.35: Taxiing-out time distribution of medium aircraft.....	97
Figure 4.36: Daily total CO ₂ emission and emission due to delay at taxiing phase	99

List of Tables

Table 1.1: Emission sources at an airport.....	4
Table 2.1: ICAO standards for TIM.....	23
Table 2.2: IPCC 3 Tier method.....	24
Table 2.3: Default EFs and Fuel consumption for aircraft	27
Table 4.1: ANOVA single factor analysis of arrivals under WTC	63
Table 4.2: t-Test results of two samples assuming equal variances	63
Table 4.3: ANOVA single factor analysis of departures under WTC.....	65
Table 4.4: t-Test results of two samples assuming equal variances	65
Table 4.5: ANOVA single factor analysis of arrivals under the category of day	66
Table 4.6: ANOVA single factor analysis of departures under the category of day	67
Table 4.7: ANOVA single factor analysis of arrivals under the category of apron	68
Table 4.8: ANOVA single factor analysis of departures under the category of apron.....	69
Table 4.9: Estimated TIM parameters for taxiing phases.....	70
Table 4.10: One-Sample t-Test for mean comparison of taxiing-in phase	72
Table 4.11: One-Sample t-Test for mean comparison of taxiing-out phase	74
Table 4.12: Fuel flow rates at different flight phases according to aircraft type	81
Table 4.13: ANOVA single factor analysis under climb-out phase.....	81
Table 4.14: Estimated TIM parameters for climb-out phase	82
Table 4.15: ANOVA single factor analysis for the approach phase	87
Table 4.16: Estimated TIM parameters for climb-out and approach phases	88
Table 4.17: One-Sample t Test for mean comparison between estimated approach time and ICAO recommended mean value	89
Table 4.18: Percentages of emission levels under different phases according to aircraft type	95
Table 4.19: CO ₂ Emission per operation at BIA.....	95
Table 4.20: Unimpeded taxiing time Vs. Off peak taxiing time	98
Table 4.21: One-Sample t Test for mean comparison of off peak taxiing time and unimpeded taxiing time	98

List of Abbreviations

AASL	Airports and aviation services Ltd
ACI	Airport Council International
ACA	Airport Carbon Accreditation
ACERT	Airport Carbon and Emissions Reporting Tool
ACRP	Airport Cooperative Research Program
ADS-B	Automatic dependent surveillance-broadcast
AEDT	Aviation Environmental Design Tool
AEM	Advance Emission Model
APU	Auxiliary Power Unit
ATC	Air Traffic Control
BIA	Bandaranaike International Airport
CAEP	Committee on Aviation Environmental Protection
CCD	Climb, Cruise, and Descent
CORSIA	Carbon offsetting and reduction scheme for international aviation
DAMR	Daily Aircraft Movement Record
EASA	European Aviation Safety Agency
EDMS	Emissions and Dispersion Modeling System
EEA	European Environment Agency
EF	Emission Factor
EFPS	Electronic Flight Processing Strips
EIA	Environmental Impact Assessment
FDRs	Flight Data Recorders
GHGs	Greenhouse Gases
GPU	Ground Power Unit
GSE	Ground Support Equipment
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
LTO	Landing Take-off
NDCs	Nationally determined contributions
SAGE	System for assessing aviation's global emissions
SARPs	Standards and Recommended Practices
SDGs	Sustainable Development Goals
TIM	Time-In-Mode
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme

UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
WMO	World Meteorological Organization
WTC	Wake Turbulence Category

List of Appendices

Appendix –A	Layout of BIA.....	113
-------------	--------------------	-----