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Evaluation CO_2 Emissions of Flight Delay at taxiing phase in Bandaranaike International Airport (BIA)

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Abstract

On-time performance is one of the most important Key Performance Indicators for airport operations since flight delays carry a huge economic cost in the industry. Many types of research were conducted to measure aviation delay and its economic cost as consequences[1] while environmental impact due to the flight delays was sparsely addressed. Flight delays result in excess fuel consumption and more emission. Existing literature addressed the aggregate emission of the aviation industry[2]. However, assessment of emission levels under different phases of flight separately was slightly covered. Assessing the emission from phases of flight separately allows initiating emission reduction strategies. In this research, a methodology was developed with available technologies to evaluate the flight delays, emission and its cost at taxing phase for both arrivals and departures. Bandaranaike International Airport (BIA) was taken as a case for developing the methodology.

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Keywords: Departure/Arrival taxing delay, emission, unimpeded taxing time, flight mix, monetary cost of emission

1. Introduction

The demand for air transport shows rapid growth due to globalisation and increasing affordability for air travel. It was recorded by ICAO that 4.1 billion passengers used scheduled flights in 2017. This figure indicated a 7.1%

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increase over the year 2016[3]. The annual growth rate of air passengers was forecasted at 6.2% in the Asian Pacific region for the year 2015 to 2040[4].

Currently, many Asian hub airports are operated with under capacity. Other Asian airports are starting to experience capacity strains. As a consequence of this infrastructure constraint, aircraft congestion delays, long queues for take-off and cycling of aircraft in stacks prior to landing are experiencing. In 2013, only 57% of departures from Asian airports were on time[5]. However, as the airline schedules absorb delays[6], the actual delay of flight is not accounted for by most airlines.

The aviation growth influences on global climate by emitting Greenhouse Gases (GHG) which increase the average temperature of the earth. The contribution of aviation to the total GHG emission is estimated at 2% [2]. Common air pollutants from aircraft emissions are oxides of nitrogen, oxides of carbon, sulphur oxides (SO_x), unburned hydrocarbons (HC) and smoke. The aviation industry gives the most concern on CO_2 because large quantities are released and its long residence time in Earth's atmosphere[7][8].

2. Background

Taxi-out time is defined as the time between the point at which a flight actually pushes back from its gate and the time at which it takes-off. Taxi-out times depend on number of factors such as the active runway (the wind direction or time of the day), the distance from the gate to the runway, weather (de-icing needed or low visibility), congestion levels (length of the queue to take-off), apron/taxiway layout and aircraft type (wake vortex)[9]. Taxi-in time is defined as the time between the point at which a flight actually touches down and the time at which aircraft reaches its parking position at the bay.

Unimpeded taxiing time is defined as the time spent for taxiing when there is no congestion or any interference. Taxiing delay can be defined as the additional waiting time compared to unimpeded taxing time. This situation occurs when the current arrival/departure demand exceeding the arrival/departure capacity of the airfield components. While airlines buffer delay in their schedules, the true delay compared to unimpeded operation time is considerably higher.

Whenever the flight movements are greater than airfield capacity, flight delays can be expected. Airfield capacity can vary due to various inefficiencies in capacity utilization. In a typical airport, the primary bottleneck is the capacity constrained runway system. The delay of an aircraft carries a ripple effect. When an aircraft delays it affects to the other aircraft in a queue of landing or taking off. A flight delay can carry a huge impact on the number of stakeholders.

Generally, when the same runway is used for both arrival and departure, arrival flights are received priority over departure flights since the airborne delay is more costly and riskier compared to ground delays[10]. The tower controllers of the airport issue clearance for take-offs during the gaps in the arrivals. Therefore, departure flights spend more time in the taxiing phase compared to arrival flight.

When considering flight delays at movement area; the gates, apron area, taxiways and runways are the areas where congestion could occur. A departure flight has to be in queues for the push back clearance at the gate as well as the departure clearance at runway entrance. Even though engines are not switched on when waiting for the push back clearance, Auxiliary Power Unit (APU) of aircraft is operating and it consumes additional fuel for idling. When an aircraft is waiting for departure clearance at the runway entrance with its engines on, it consumes additional fuel for idling.

The Intergovernmental Panel on Climate Change (IPCC) has developed and revised over time guidelines for calculating greenhouse gas from emission inventories on behalf of aviation industry[2]. However, these methodologies address the aggregate aviation emission without segregating it to different phases of flight. Nevertheless, aggregated emission does not support to initiate emission reduction strategies under segregated phases

of flight. Specific stages where emission occurs should be identified separately to develop emission reduction solutions. Most of the researches in aviation calculated aggregated aviation emission by following the above method.
Harshad Khadilkar tried to calculate emission from taxi-out phase only. There the data was obtained for flight data recorder which can provide accurate information about the behaviour of the flight. However, this method cannot be applied to each airport due to the restricted access to the flight data recorder.

Nikoleris Tasos (2011) tried to calculate emission at taxing phase using aircraft position data which was obtained from The Airport Surface Detection Equipment (ASDE-X) database. Processing operational data with the Surface Operations Data Analysis and Adaptation (SODAA) tool more accurate information of aircraft generated to calculate emission. However, these tools are not available at BIA and this methodology cannot be applied to the airports where it is not equipped with those sources.

Levent Kuzu, S (2017) calculated aircraft emissions from Landing and Take-Off (LTO) cycles in Atatürk International Airport (AIA). Levent addressed the emission of different phases of LTO, standard LTO cycle times given by ICAO were used for the calculation. The standard LTO cycles are 26 min for taxi/idle, 4 min for approach, 0.7 min for take-off, and 2.2 min for climb-out[11]. Nevertheless, the actual operational time-in- mode, may vary from airport to airport depending on the traffic, environmental factors, topographical conditions, engine type, weather, runway configuration and such like.

Airport Council International (ACI) issues Airport Carbon and Emissions Reporting Tool (ACERT) for calculating emissions of all the emission sources at airport. ACERT which is a simple IT solution and Excel spreadsheet contains methodologies following with the ACI Guidance Manual on Airport Greenhouse Gas Emissions Management (2009) and the GHG Protocol[12]. This generates an informative airport GHG emission inventory report. However, the drawback of this tool is the inability to disaggregate emission from various key sources of the airport.

Furthermore, a disaggregate analysis enables accurate estimation of base emission levels with respect to individual sources. Key sources of emission due to airport activity can be listed: landside vehicular traffic (passenger and cargo), terminal building operation, airside vehicular movement and ground handling equipment and aircraft operations. Aircraft operations at an airport can be separated according to landing, taxiing-in, ground handling, taxiing-out and take-off and climb. Airport capacity issues directly influence delays and ensuing GHG emission in all the above phases of aircraft operation. The attention of this paper is given for evaluating the emission in the taxiing-in and taxing-out only.

2.1 Case study Airport; Bandaranaike International Airport (BIA)

Bandaranaike International Airport (IATA: CMB, ICAO: VCBI) is the main international airport serving in Sri Lanka. BIA presently handles over 9 million passengers per annum, although the designed handling capacity of the terminal building stands at 6 million[13]. The aircraft handling capacity of the runway at BIA is 25 movements per hour (13 departures and 12 arrivals per hour)[14]. The current peak number of operations is 15 movements per hour.

BIA consists with 5 taxiways (TWY) (A, B, C, D and E) TWY A and E are situated 120m from runway Centre line while taxiways B, C and D are situated 90m away from runway Centre line. BIA operates 24 hours and the runway is closed from 0845 to 1115 (GMT) on every Wednesday for maintenance. BIA consists of 4 aprons (A, B, C and D). Apron D is allocated for domestic light aircraft as well as non-scheduled aircraft. Apron A, B and C are allocated for all other aircraft by tower controllers at the airport.

The key objective of this paper is to estimate annual CO_2 emission aroused due to aircraft delays at taxiing phase and estimate the monetary cost of such delay. The above main objective is achieved by estimating an unimpeded operational value for the taxiing phase and assessing additional fuel burn due to delay.

3. Methodology

Figure1 depicts the research framework of this study.

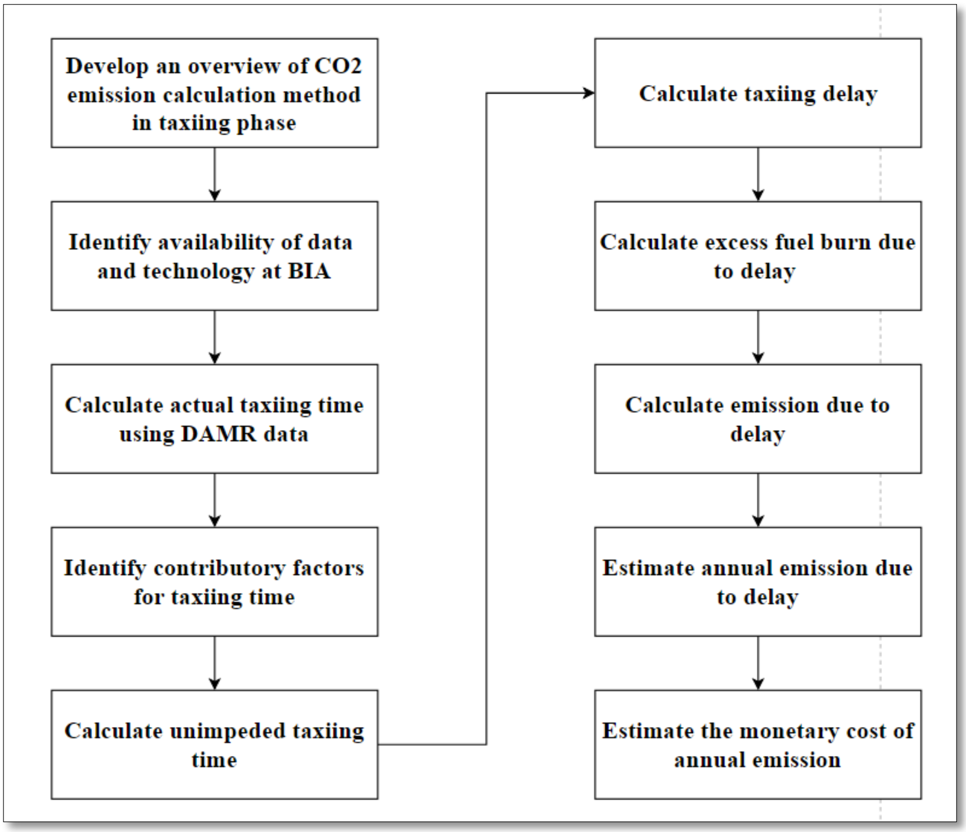

Figure 1-Research framework

3.1 A methodology for calculating delay

Current industry practice for calculating taxiing delay is based on a reference value which was statistically computed using historical data of the airport. The additional taxiing time is defined by ICAO as the difference between the actual taxiing time and a reference taxiing time(unimpeded)[15]. ICAO proposes two approaches for calculating unimpeded time. The basic method recommends using the 20th percentile of actual taxiing time. The advanced method recommends to separate value for each gate and runway combination and to use the average actual taxiing time during non-congested periods[16]. Both approaches are accepted and used in European industry[17]. Currently, the industry defines the reference value for the unimpeded taxiing time as the 20th percentile of observations[18][19]. European Union and FAA follow for the application of a consistent methodology for determining unimpeded taxiing time. The method uses the 20th percentile of the distribution of observed values[18]. The same approach followed in this research to calculate unimpeded taxiing time. Then the actual delay at the taxiing phase was calculated using the difference between actual taxiing time and the unimpeded taxiing time.

3.2 Data collection

3024 departures and 2921 arrivals operated at BIA in the month of January 2018 were observed for this study. The data was extracted from the Daily Aircraft Movement Record (DAMR) which is maintained by Air Traffic

Controllers (ATC). The database contains information such as type of the aircraft, movement type (arrival, departure, touch & go), take-off/ landing time, category of flight (scheduled, non- scheduled), gate departure/arrival time and parking bay. The ATC tracks the aircraft and records the time of the flight at specific places at the airport. These data were used to calculate aircraft actual taxiing time.

The departure process of a flight is depicted in Figure 2. It explains the steps followed by a departure flight from the terminal gate to take- off phase. This study focused on this area where the ground movement of the departure flight happens.

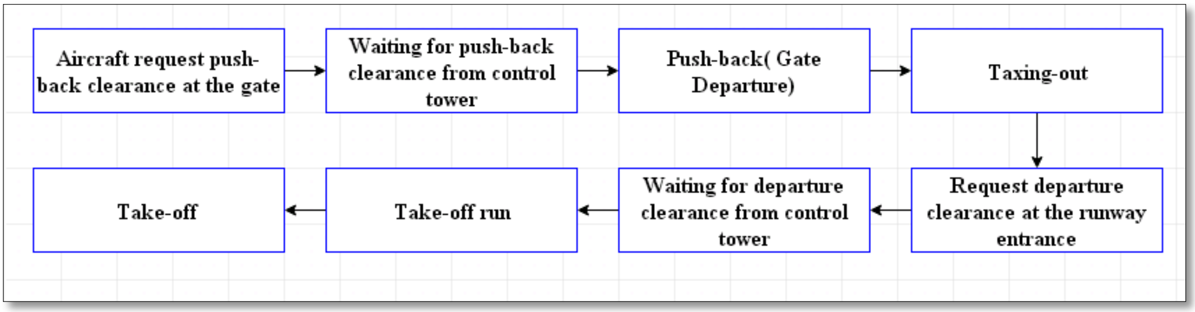

Figure 2-Departure Process of the flight at the airport

The arrival process of a flight is depicted in Figure 3. It explains the steps followed by an arrival flight from the touchdown to gate arrival. This study focused on this area where the ground movement of the arrival flight happens.

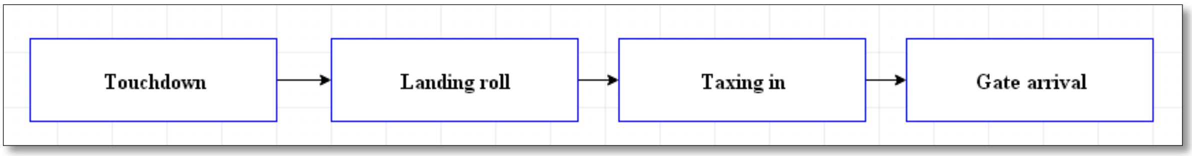

Figure 3- Arrival process of the flight at the airport

3.3 Taxi-out/Taxi-in time calculation

Actual taxiing time was calculated using the difference between take-off /touchdown time and gate departure/arrival time.

Actual Taxi-out time = Take-off time - Gate departure time (1)
Actual Taxi-in time = Gate arrival time - landing time (2)

When calculating the taxi-out time according to equation 1, the time spent for push back phase, time of take-off roll are also included even though those phases do not belong to the taxiing phase. Calculating the time spent on the push-back process and take-off roll are complicated since the required data are not recorded. Thus, in this research, it is assumed that the pushback process and take-off roll phase are also a part of the taxing-out phase. When calculating taxi-in time according to equation 2, the time spent for landing roll is also included in taxing in phase even though it does not belong to that phase. However, due to unavailability of data, it is assumed that landing roll is also part of the taxi-in phase for this research analysis.

3.4 Identify contributory factors for taxiing time

Taxiing times were categorized as taxiing in time for arrivals and taxiing out time for departures. They were analyzed separately. Taxiing time according to the parking apron (A, B, C and D), the day of the week (Monday to Sunday) and ICAO Wake Turbulence Category (WTC) (heavy, medium and light) were the subcategories used for this analysis. After the subcategorisation, ANOVA test was conducted to different distributions separately in order to identify whether this data set can be considered as a part of the population.

ANOVA test was conducted under different subcategories to identify all the sample means within the group are equal or the factor did not have any significant effect on the results. The null hypothesis for the ANOVA test was that all the sample means are equal or the factor did not have any significant effect on the results. Whereas, the alternate hypothesis is that at least one of the sample means is different from another. When results rejected the null hypothesis, the Bonferroni approach in Excel was used to check which samples had different means.

3.5 Unimpeded taxi-in/out time calculation

Once the taxiing time distribution was calculated with sorting from the shortest time to the longest time, the 20th percentile of the distribution from the observed values were selected as the unimpeded taxiing time following the industry practices.

3.6 Taxi in/out Delay calculation

The taxi-in/out delay is calculated using the difference between the actual taxi-in/out time and the unimpeded taxi-in/out time for that flight.

Taxi-out delay = Actual Taxi-out time - Unimpeded taxi-out time (3)
Taxi-in delay = Actual Taxi-in time - Unimpeded taxi in time (4)

3.7 Calculation of excess fuel consumption due to delay

The delay was converted to excess fuel consumption. ACERT tool was used to determine fuel usage at the taxiing phase. ACERT provides fuel consumption (kg) per minute at the taxiing phase according to different types of aircraft. Equation 5 used to calculate additional fuel usage per flight at BIA.

$$\text{Fuel (kg)} = \text{Time}_{\text{taxiing delay}} * \text{Fuel per minute}_{\text{taxiing phase,aircraft type}} \quad (5)$$

3.8 Calculation of emission due to delay

The delay was converted to CO_2 emission. ACERT tool was used to determine CO_2 emission aroused at taxiing according to different types of aircraft. ACERT provides CO_2 emissions (kg) per minute at the taxiing phase according to different types of flight. The equations 6 used to calculate CO_2 emission due to delay per flight at the taxiing phase.

$$CO_2 \text{ Emission (kg)} = \text{Time}_{\text{taxiing delay}} * \text{Emissions per minute}_{\text{taxiing phase,aircraft type}} \quad (6)$$

3.9 Annual Emission estimation

Average fuel consumption (kg) per aircraft (according to WTC) at taxiing phase and average CO_2 emission per aircraft (according to WTC) were calculated with available 1-month data. With the available data of 1 month, the flight mix of that month was calculated. BIA monthly flight schedules show slight differences[21]. Therefore, it was assumed that flight mix of BIA also showed slight differences. It was assumed that the calculated flight mix was consistent throughout the year. The aircraft mix percentage was used to estimate monthly aircraft mix as the aircraft movement data is available for each month of the year 2017. Once the monthly aircraft mix according to WTC was obtained, it was multiplied with average fuel consumption per aircraft in order to obtain monthly additional fuel consumption. Monthly aircraft mix was multiplied with average CO_2 emission per aircraft in order to obtain monthly emission.

3.10 Monetary cost estimation for emission

CO_2 emission aroused in taxiing delay is converted to its monetary cost and equation 7 indicates that. The social cost of CO_2 is estimated by Interagency Working Group (IWG) on Social Cost of Greenhouse Gases, United States Government. This Working Group ensures that the social cost of carbon estimates with the best available science and methodologies with the support of the National Academies of Sciences, Engineering, and Medicine[22]. IWG recommends social cost of CO2 values for use in regulatory analyses in the USA. IWG recommended social cost of CO_2 value for the year 2017 was used for this analysis.

Cost of CO_2 emission = CO2 emission (metric tons) * Social cost of CO_2 ($ per metric ton) (7)

4 Results and Analysis

4.1Overview of the sample of data analysed

BIA runway handles average 204 flights per day. Within 1 month (within 31 days), 6246 flight data were observed for this study. Since BIA has a single runway to handle both arrivals and departures, the observed data were categorised under arrivals and departure flights. Then the flight data were further categorised under the heavy, medium and light aircraft category. The graph depicts the summary of all flights observed within 1 month and these data were analysed for calculating emission in the taxiing phase.

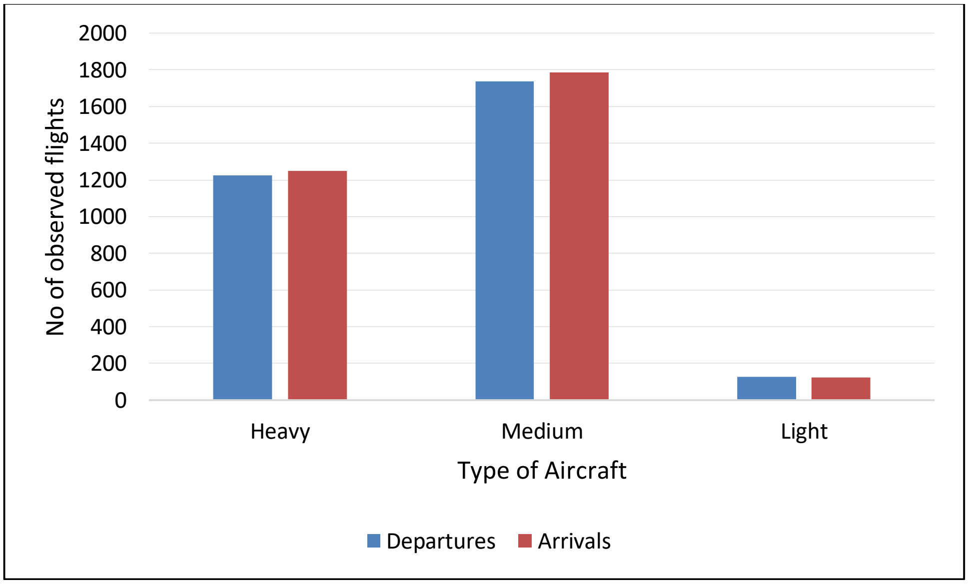

Figure 4-Categorization of flights according to the type of aircraft

4.2 Taxi-out/in time calculation

Actual taxiing time was calculated according to equation 1 and 2. After calculating actual taxiing times separately for arrivals and departures, it was subcategorized according to the parking apron (A, B, C and D), the day of the week (Monday to Sunday) and ICAO Wake Turbulence Category (WTC) (heavy, medium and light). ANOVA test was conducted to different distributions separately in order to identify whether this data set can be considered as a part of the population. ANOVA test was conducted under different categories to identify all the sample means within the group are equal or the factor did not have any significant effect on the results. The null hypothesis states that all the sample means are equal or the factor did not have any significant effect on the results. Whereas, the alternate hypothesis states that at least one of the sample means is different from another.

According to the ANOVA results, the sample means are equal and the factors (the day and the parking apron) did not have any significant effect on the results. Thus, the data set can be considered as a part of the population. P-value is greater than the alpha level (0.05) selected. Therefore, the alternative Hypothesis can be rejected. Appendix 1 depicts the ANOVA results.

According to the ANOVA results (Appendix 1), WTC was selected for further analysis as heavy and medium aircraft belong to the same population while light aircraft belong to another population. According to the ANOVA results, other subcategories showed the distributions belong to the same sample within the group.

Taxi-out time distribution according to the aircraft type is depicted in figure 5. Taxi-in time distribution according to the aircraft type is depicted in figure 6. There is a significant difference in the distribution according to flight type. The average taxi-out times are in different ranges according to the flight type. It was proven by the ANOVA test.

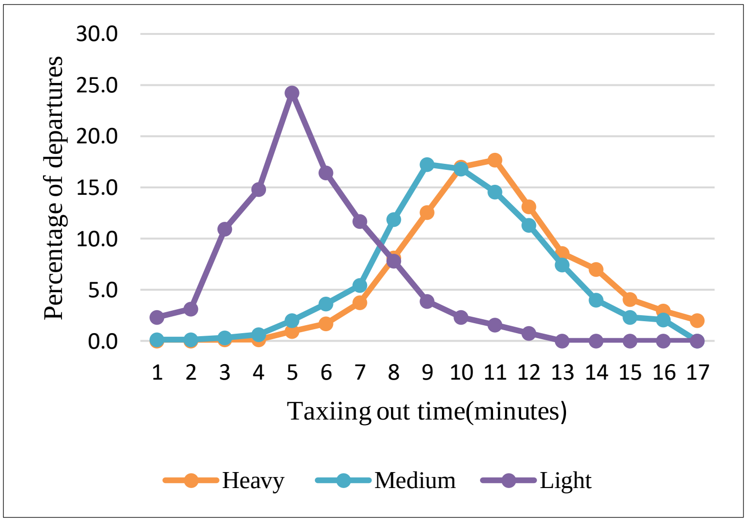

Figure 5-Taxi-out time distribution according to the aircraft type

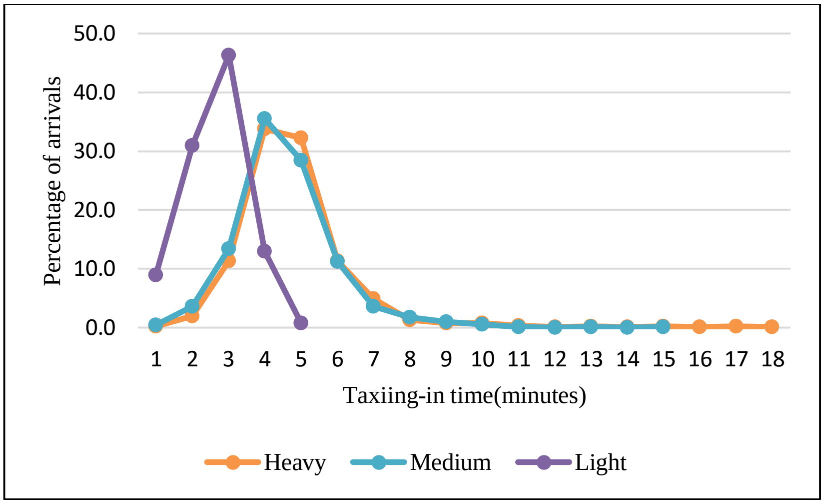

Figure 6- Taxi-in time distribution according to the aircraft type

4.2 Deciding unimpeded Taxi-out/in time

3 unimpeded taxi-out times were decided according to the flight type. The figures below show distributions of actual taxi out time according to flight type (Heavy, light and medium). It is assumed that 20th percentile taxi-out time as the unimpeded taxi-out time[23]. The 20th percentile is selected according to industry practices. The 20th percentile taxi out time is represented in red in each graph and it is 9, 4, 8 minutes unimpeded taxi-out time for respectively heavy, light and medium aircraft at BIA.

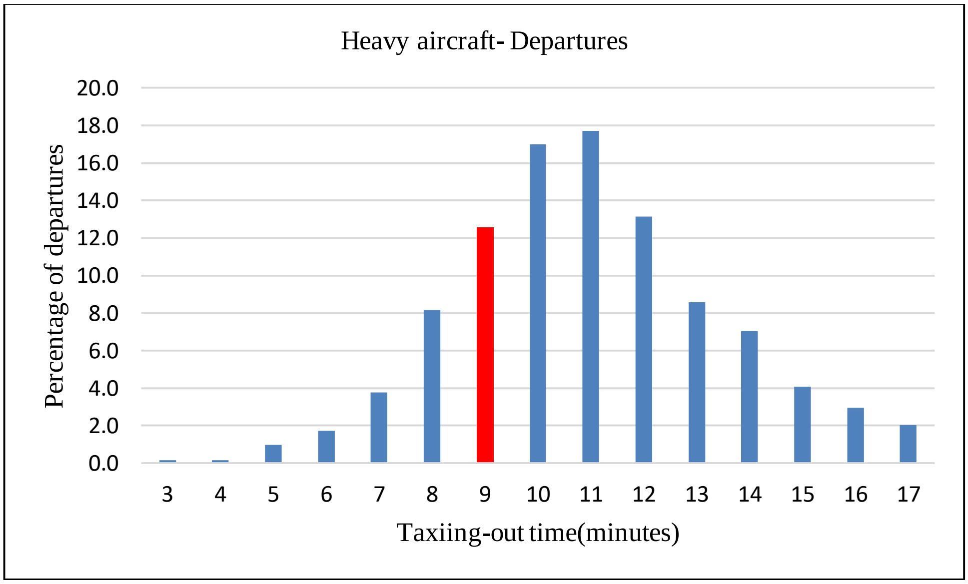

Figure 7-Taxi-out time of Heavy aircraft

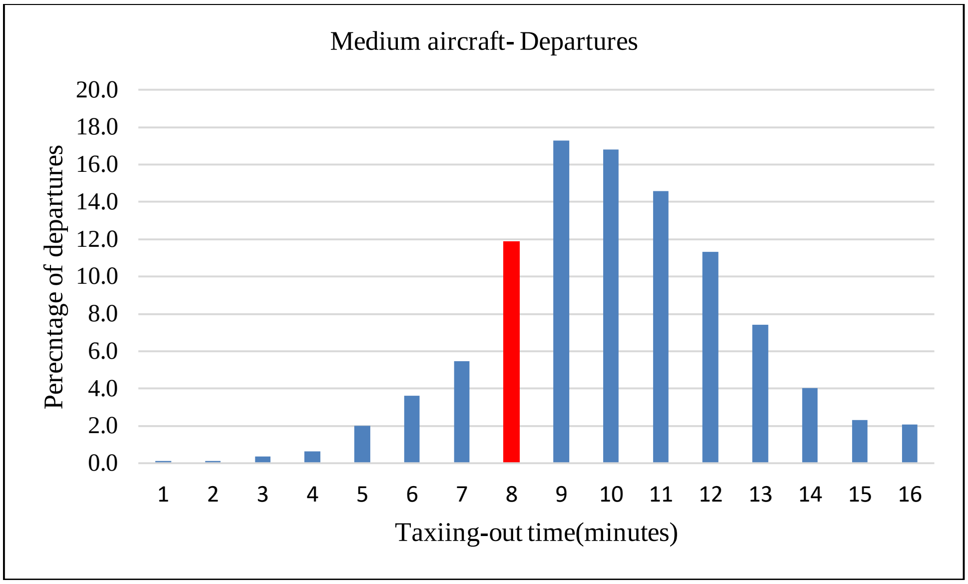

Figure 8-Taxi-out time of Medium aircraft

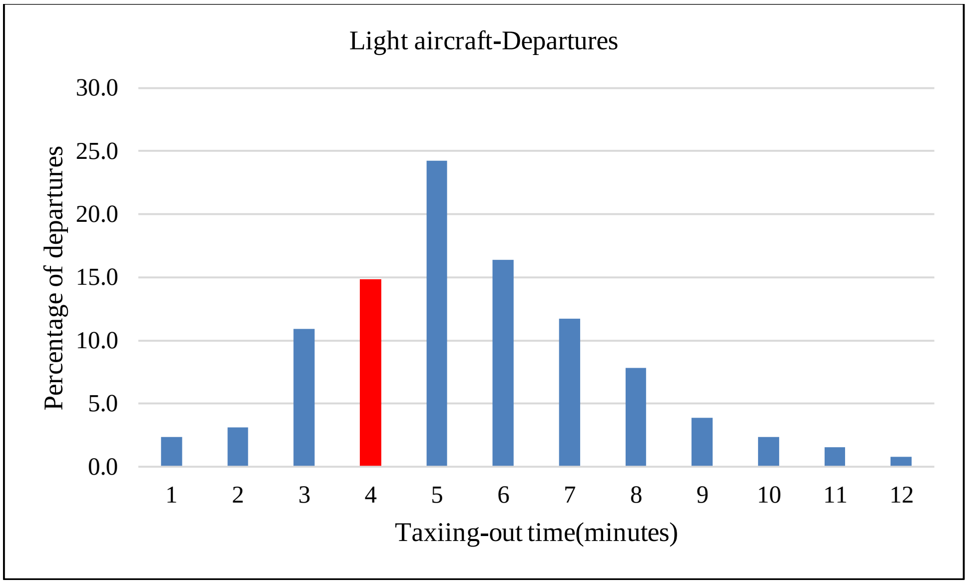

Figure 9-Taxi-out time of Light aircraft

3 unimpeded taxi-in times were decided according to the flight type. It is assumed that 20th percentile taxi-in time as the unimpeded taxi-out time[23]. The 20th percentile is selected according to industry practices. The 20th percentile taxi-in times are 4, 2 and 4 minutes unimpeded taxi-in time for respectively heavy, light and medium aircraft at BIA.

4.3 Excess fuel and emission calculation due to delay

Actual taxiing delay was calculated using equation 3 and 4. The unimpeded times under WTC was obtained from 4.2 analysis. Then the actual delay was converted to excess fuel using equation 5. The actual delay was converted to emission using equation 6. Once the emission was calculated under WTC, departure flights taxi out time emission were higher compared to arrivals. Among departures, heavy flights had a huge contribution to emission. The following graph depicts the hourly emission contribution of flights for a particular day of a week.

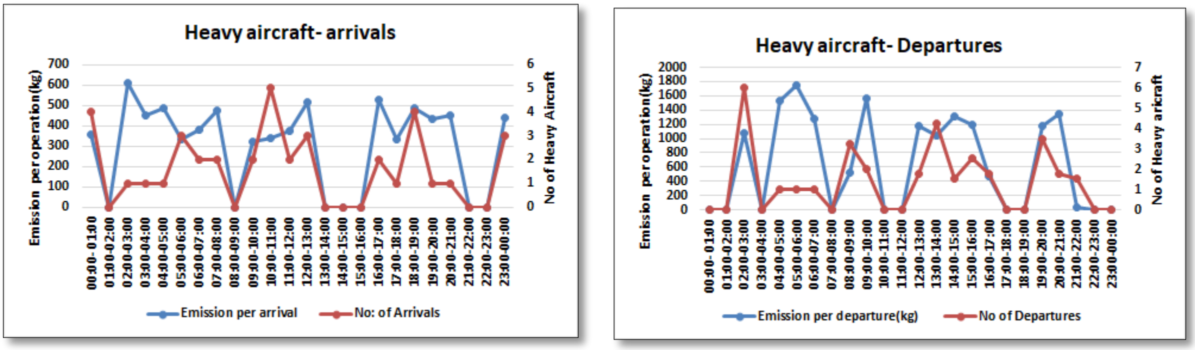

Figure 10- Emission per operation, Heavy aircraft

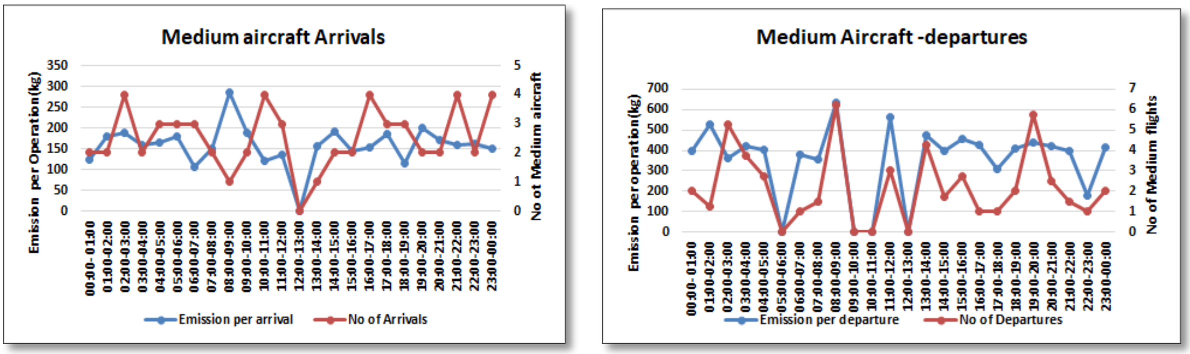

Figure 11- Emission per operation, Medium aircraft

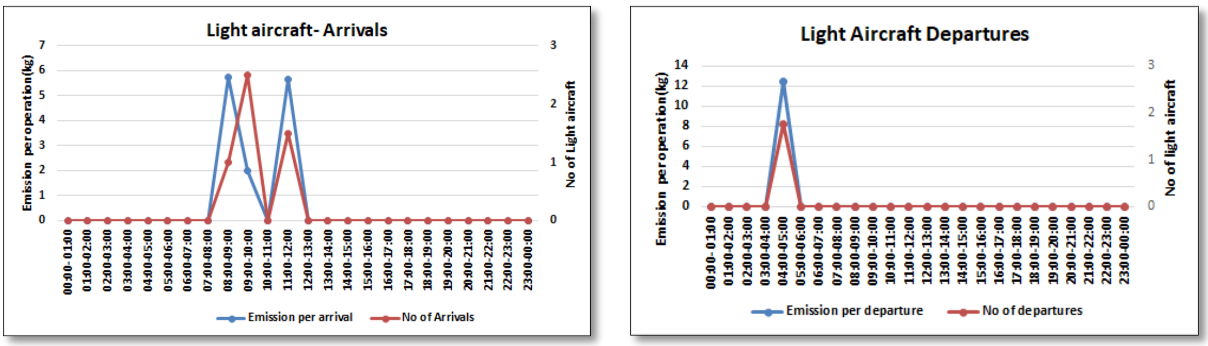

Figure 12- Emission per operation, Light aircraft

4.4 Estimating flight mix at BIA

According to calculated aircraft mix with the available data, it is assumed monthly mix is consistent throughout the year. According to that, there are 38% heavy flights, 59% medium flights and 3% light flights are using BIA.

With the available data, percentages of aircraft delays per aircraft type were calculated. According to that, there 71% heavy aircraft delays, 75% medium aircraft delays and 51% light aircraft delays were estimated. The flight mix with delayed flights according to the types of aircraft was calculated using the above percentages.

With the available data average delay per flight, average excess fuel per flight and average emission per flight according to the aircraft type were calculated. Table 4 depicts those calculated values. When calculating delay per flight, it was given a weight according to the percentages of delayed aircraft mix.

Table 1-summary of the calculated values

	Heavy	**Medium**	**Light**
Delay arrival (minutes/flight)	2.02	1.75	1.9
Delay departure (mintues/flight)	3.23	3.54	2.33
Fuel(liter/flight)	84.21	32.03	1.87
CO_2 Emission(kg/flight)	273.89	100.76	5.86

Monthly flight mix has multiplied the values contained in table 1 and obtained monthly flight delay, monthly additional fuel consumption due to delay and emission aroused due to delay. Then the emission was converted to cost. The IWG proposes that the social cost of emission is 40 US $ per metric tonne for the year 2018[22]. That value is used in this paper to calculate the emission cost. Figure 13 depicts the estimated total taxiing delay for each month of the year 2018 at BIA. Figure 14 depicts the estimated excess fuel consumption due to delay at the taxiing phase for each month of the year 2018 at BIA. Figure 15 depicts the estimated emission due to taxiing delay and its cost.

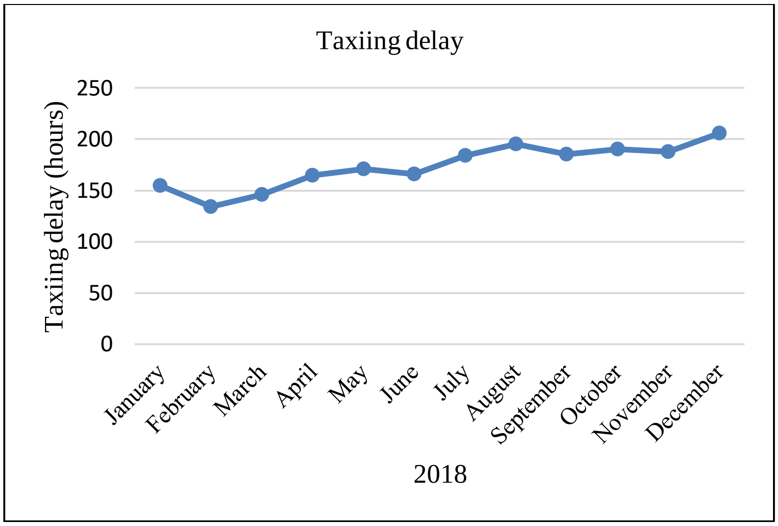

Figure 13- Estimated taxiing delay

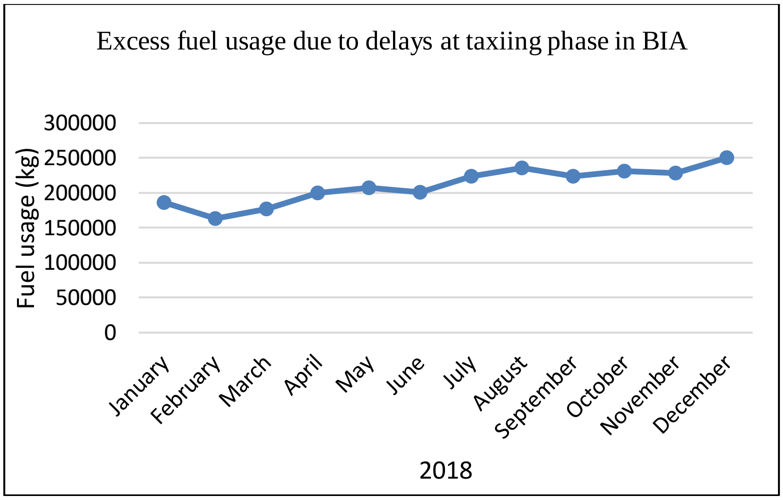

Figure 14- Estimated excess fuel consumption due to taxiing delay

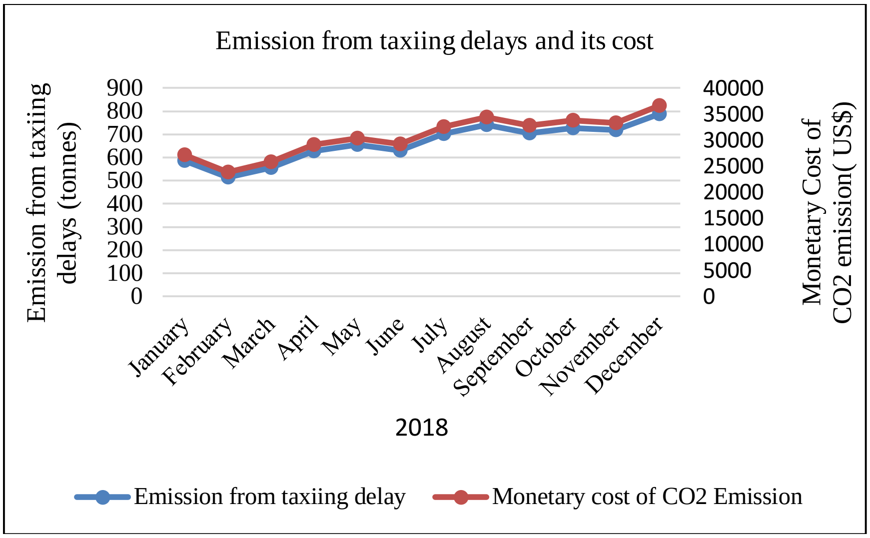

Figure 15- Estimated emission due to taxiing delay and cost

Conclusion

According to the study, CO_2 emission from delays of aircraft at the taxiing phase has a significant influence in local air quality. Taxiing delay causes significant fuel waste and emission with a huge economic and environmental cost. With the rapid growth in aviation, more delays, fuel waste and emission can be expected as infrastructures become more constrained. If the capacity of the airport is not increased proportionate to future demand, more delays at the airport can be expected. In 2018, the emission cost is estimated at 307825 US$ at BIA. The emission cost can be reduced once the infrastructures have been improved.

The study outcomes can be used to make the relevant parties aware of the emission that they are responsible for. Impact of emission due to delay can also be identified. Thus, the outcomes encourage stakeholders to initiate emission reduction methods. Specific stages where emission occurs should be identified separately in order to improve emission reduction strategies. Even though this methodology support for taxiing phase, it can be developed to other phases of flights. This methodology shows the unnecessary fuel burn, its emissions and cost according to current practices. Moreover, this study can be used as a reference when calculating emission after implementing those reduction methods at BIA.

Even though this research is conducted for small capacity constrained airport, this methodology can be applied to calculate emission in any other airport which has similar capacity like BIA and when there are fewer technologies to measure accurate taxiing times and emission.

As the airports get busier due to high demand, the delay tends to increase exponentially. Thus, the environmental impact of delay is several times greater than the case studied in future. However, Green practices improve the international image of the airport. Thus, by maintaining an emission inventory, an airport can obtain more economic and environmental benefits.

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Appendix 1

ANOVA test results under the category of the parking day of the week-Arrivals
Anova: Single Factor

Table 2- ANOVA results, taxiing-in distribution according to the day

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	18.95064	6	3.15844	1.687434	0.119916	2.101573
Within Groups	5675.119	3032	1.871741			
Total	5694.07	3038				

According to table 8, the F-value is smaller than the F-critical value for the alpha level selected (0.05). Therefore, the null hypothesis can be accepted and sample means are equal and the factor(the day) did not have any significant effect on the results. Thus, the data set can be considered as a part of the population. P-value is greater than the alpha level (0.05) selected. Therefore, the alternative Hypothesis can be rejected.

ANOVA test results under the category of the parking day of the week-Departures

Anova: Single Factor

Table 3- ANOVA test results, taxiing-out distribution according to the day

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	85.93036	6	14.32173	2.065094	0.054139	2.101592
Within Groups	20895.59	3013	6.935145			
Total	20981.52	3019				

According to the table 9, the F-value is smaller than the F-critical value for the alpha level selected (0.05). Therefore, the null hypothesis can be accepted and sample means are equal and the factor (the day) did not have any significant effect on the results. Thus, the data set can be considered as a part of the population. P-value is greater than the alpha level (0.05) selected. Therefore, the alternative Hypothesis can be rejected.

ANOVA test results under the category of parking apron-Arrivals

Even though BIA has 4 parking aprons, apron D is a remote apron used mostly for domestic light aircraft of 4.1%. Thus, it is removed from this analysis.

Anova: Single Factor

Table 4- ANOVA test results, Taxiing-in distribution according to the apron

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	7.255066	2	3.627533	2.12937	0.1191	2.99887
Within Groups	4875.619	2862	1.703571			
Total	4882.874	2864				

According to table 10, the F-value is smaller than the F-critical value for the alpha level selected (0.05). Therefore, the null hypothesis can be accepted and sample means are equal and the factor (parking apron) did not have any significant effect on the results. Thus, the data set can be considered as a part of the population. P-value is greater than the alpha level (0.05) selected. Therefore, the alternative Hypothesis can be rejected.

ANOVA test results under the category of parking apron-Departures

Table 5-ANOVA test results, Taxiing-out distribution according to the apron

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	28.38315	2	14.19158	2.396466	0.091228	2.998971
Within Groups	16421.36	2873	5.921876			
Total	16449.74	2875				

According to table 11, the F-value is smaller than the F-critical value for the alpha level selected (0.05). Therefore, the null hypothesis can be accepted and sample means are equal and the factor (parking apron) did not have any significant effect on the results. Thus, the data set can be considered as a part of the population. P-value is greater than the alpha level (0.05) selected. Therefore, the alternative Hypothesis can be rejected.

ANOVA test results under the category of WTC-Arrivals

ANOVA- single factor

Table 6-ANOVA test results, Taxiing-in distribution according to the WTC

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	292.4557	2	146.2278	99.03118	0	2.99881
Within Groups	4308.672	2918	1.476584			
Total	4601.128	2920				

According to the table 12, F-value is greater than the F-critical value for the alpha level selected (0.05). Therefore, the null hypothesis can be rejected and at least one of the three samples have significantly different means and thus belong to an entirely different population. Moreover, P-value is less than the alpha level (0.05) selected. Therefore, the Null Hypothesis can be rejected. The Bonferroni approach in Excel was used to check which samples had different means.

t-Test: Two-Sample Assuming Equal Variances

	Heavy	Medium	Medium	Light	Heavy	Light
Mean	4.175319	4.119385	4.119385	2.559322	4.175319	2.559322
Variance	1.31336	1.653226	1.653226	0.55628	1.31336	0.55628
Observations	1175	1625	1625	118	1175	118
Pooled Variance	1.510623		1.579508		1.244747	
Hypothesized Mean Difference	0		0		0	
df	2798		1741		1291	
t Stat	1.188416		13.01967		14.99894	
P(T<=t) one-tail	0.117385		2.39E-37		2.66E-47	
t Critical one-tail	1.645398		1.645729		1.646035	
P(T<=t) two-tail	0.23477		4.78E-37		5.32E-47	
t Critical two-tail	1.960812		1.961328		1.961803	

According to the above table, the p-value of (Heavy vs. Light) and (Medium vs. Light) is less than the alpha level selected (alpha = 0.05). Therefore, the groups Heavy vs. Light and groups Medium vs. Light have less than 5% chance of belonging to the same population. Nevertheless, for the group, Medium vs. Heavy, the p-value is much greater than the significance level and it says heavy and medium belong to the same population. According to the results, it is clear that the arrivals of light aircraft belonged to an entirely different population and had a significant effect on the taxi-in time. (It is assumed that data set is normally distributed)

ANOVA test results under the category of WTC-Departures

Table 7-ANOVA test results, Taxiing-out distribution according to the WTC

Anova: Single Factor

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3150.57	2	1575.285	209.8319	4.67E-86	2.998705
Within Groups	22679.76	3021	7.507368			
Total	25830.33	3023				

According to table 13, the F-value is greater than the F-critical value for the alpha level selected (0.05). Therefore, the null hypothesis can be rejected and at least one of the three samples have significantly different means and thus belong to an entirely different population. Moreover, P-value is less than the alpha level(0.05) selected. Therefore, the Null Hypothesis can be rejected. The Bonferroni approach in Excel was used to check which samples had different means.

t-Test: Two-Sample Assuming Equal Variances

	Medium	Heavy	Heavy	Light	Medium	Light
Mean	10.69167	10.87819	10.87819	5.706349	10.69167	5.706349
Variance	7.573724	7.523865	7.523865	6.609079	7.573724	6.609079
Observations	1680	1215	1215	126	1680	126
Pooled Variance	7.552802		7.438467		7.506884	
Hypothesized Mean Difference	0		0		0	
df	2893		1339		1804	
t Stat	-1.80217		20.26107		19.69899	
P(T<=t) one-tail	0.035811		3.96E-80		1.06E-78	
t Critical one-tail	1.645381		1.645992		1.645699	
P(T<=t) two-tail	0.071623		7.93E-80		2.12E-78	
t Critical two-tail	1.960784		1.961737		1.96128	

According to the above table, the p-value of (Heavy vs. Light) and (Medium vs. Light) is less than the alpha level selected (alpha = 0.05). Therefore, the groups Heavy vs. Light and groups Medium vs. Light have less than 5% chance of belonging to the same population. Nevertheless, for the group, Medium vs. Heavy, the p-value is much greater than the significance level and it says heavy and medium belong to the same population. According to the results, it is clear that the departures of light aircraft belonged to an entirely different population and had a significant effect on the taxi-in time.