Airline Emission Forecast Through Empirical Analysis of Its Contributing Factors

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Abstract

Climate change and environmental degradation are the greatest challenges of this century. Governments and various international organizations are aiming at the reduction and stabilization of emission level that does not endanger the environment. International Civil Aviation Organisation (ICAO) is fully engaged to achieve a global solution to address emission from the civil aviation across the globe. Since the usage of civil aviation is increasing at a rapid rate due to various economical and technological reasons, a clear understanding of the factors affecting the aircraft fuel consumption and its CO_2 emission is essential. The primary objective is to estimate the CO_2 emission from the aircrafts, which is done by estimating the fuel consumption as the amount of emission is directly proportional with fuel consumption [1,2]. The data regarding the aircraft fuel consumption and its influencing factors, sector details and trip details are collected from the various databases of an Airline. The work has been accomplished with a detailed study of the factors affecting fuel consumption through regression analysis using MINITAB and thereby forecasted the fuel consumption. The validation has been carried out using ANOVA, Durbin-Watson statistics and Mallow's Cp Statistics. The CO_2 emission has been predicted using the forecasted fuel consumption and found to be more accurate.

Keywords
Airline emission, Carbon emission calculator, Empirical analysis.

1. Introduction
Aviation has recently experienced a phenomenal growth that has created new opportunities and new challenges for airlines, airport operators, aircraft manufacturers, air traffic service providers and other related air transport organizations including Government who make policies in this respect. The development and growth of air transport depends on various factors including economic, trade, fuel price changes, airline productivity gains, airports and airspace capacity. The increase in the personal income affects the level of consumer purchasing power and the tendency to undertake luxury travel. The world economy maintained its growth momentum in 2007 despite higher prices for crude oil and refined products. The economies of China and India showed remarkable GDP growth at 11.5 percent and 8.9 percent respectively, driven by growing exports, investment and growing demand with the increase in the emission rate. Asia's newly industrialized economies posted a 4.9 percent GDP growth [3]. Worldwide, the total number of annual passengers has grown by 46 percent in the past 10 years, as the number of passengers flying climbed from 1.46 billion to 2.13 billion per year. Freight tonne-kilometre figures show an almost identical rate of increase. The International Air Transport Association (IATA) forecasted that in 2011 the air-transport industries will handle 2.75 billion passengers and 36 million tonnes of freight. International passenger demand is expected to rise from 760 million passengers in 2006 to 980 million in 2011 at an annual average growth rate of 5.1 percent [4].At the end of 2006 from 1997, the reported number of commercial air transport aircraft in service increased by about 30

percent [3]. It is clear that the world's scheduled airlines experienced material operating profits and overall net profitability despite rising fuel prices. The upcoming private airlines have been one of the greatest transformations in air transport industry along with the increase in emission level.

2. The Objective and Data Collection

There is an ongoing debate about possible taxation of air travel and the inclusion of aviation in an emissions trading scheme, with a view to ensuring that the total external costs of aviation are taken into account. Virtually all airlines with operations, to and fro and within the European Union will come under the scope of the EU's emissions trading scheme from 2012[5]. Airlines are required to submit a monitoring plan by August 2009 and to monitor data from 2010 along with the methodology in which it is done. To meet these criteria the following objectives were framed.

- To analyze the factors affecting the fuel consumption and
- To forecast the fuel consumption thereby calculating the CO_2 emission.

Data collection and integration was a crucial part of this work as three different sources such Fuel Management System (FMS) for fuel requirement and fuel efficiency, ARMS server for flight performance details, and Manufacturers Manual for flight equipment and engine data were collected and was used for analyzing and forecasting fuel consumption. The passenger details, the passenger ratio and the cargo details in a particular sector were also collected for flight performance analysis.

3. Empirical Analysis

Multiple regression is a procedure that separates the systematic effects (associated with the explanatory variables) from the random effects (associated with the error term) and also offers a method of assessing the success of the process [6]. Multiple regression is useful in determining whether a particular effect is present; [7] in measuring the magnitude of a particular effect; [8] and in forecasting what a particular effect would be, but for an intervening event [9]. In this work the multiple regression analysis is used to find the various effects of the independent variables such as the time of flight, take of weight, captain of the flight, center of gravity, temperature, etc on fuel consumption.

3.1 Methodological Approach

The purpose of multiple regression is to establish a quantitative relationship between a group of independent variables (Xs) and a dependent variable, Y [10]. This relationship is useful for understanding which independent variable have the greatest effect, knowing the direction of the effect (i.e., increasing X increases or decreases Y), and using the model to predict future values of the dependent variable, when only the independent variables are currently known. If two variables are correlated, then knowing the value of one variable will allow predicting the value on the other variable. The stronger the correlation, closer the value will fall to the regression line and therefore more accurate prediction. Multiple regression is simply an extension of this principle, where prediction of dependent variable lies with the influence of several other independent variables. Using multiple regression tests, regression models (or theories) are generated and identify precisely which set of variables is influencing the fuel consumption. Figure 3-1 displays the flowchart for emission analysis through empirical analysis.

3.2 Factors Screening Process

Through an extensive literature review various factors affecting the fuel consumption were identified. About 28 factors of interest as shown in Table-1 were considered as the factors affecting the fuel consumption for the flight VT-KFI - understudy. MINITAB was used to find the correlation between the factors of interest and describe the direction, size, and statistical significance of the relationship between the independent variables and the dependent variable and to predict new observations.

Table - 1 Factors of Interest

➢ Date	➢ Temperature	➢ Sector
➢ Time of Flight	➢ Captain	➢ Mach
➢ Air Time of Flight	➢ Gravitational force	➢ Center of gravity
➢ Taxi Time of Flight	➢ Fuel flow rate	➢ Altitude
➢ Empty weight	➢ Take of weight	➢ Air Pressure
➢ Weight of Passengers	➢ Departure Fuel	➢ Type of flight
➢ Engine Temperature	➢ Portable water	➢ Time of Delay
➢ Night Flight	➢ Arrival Station	➢ Departure Station

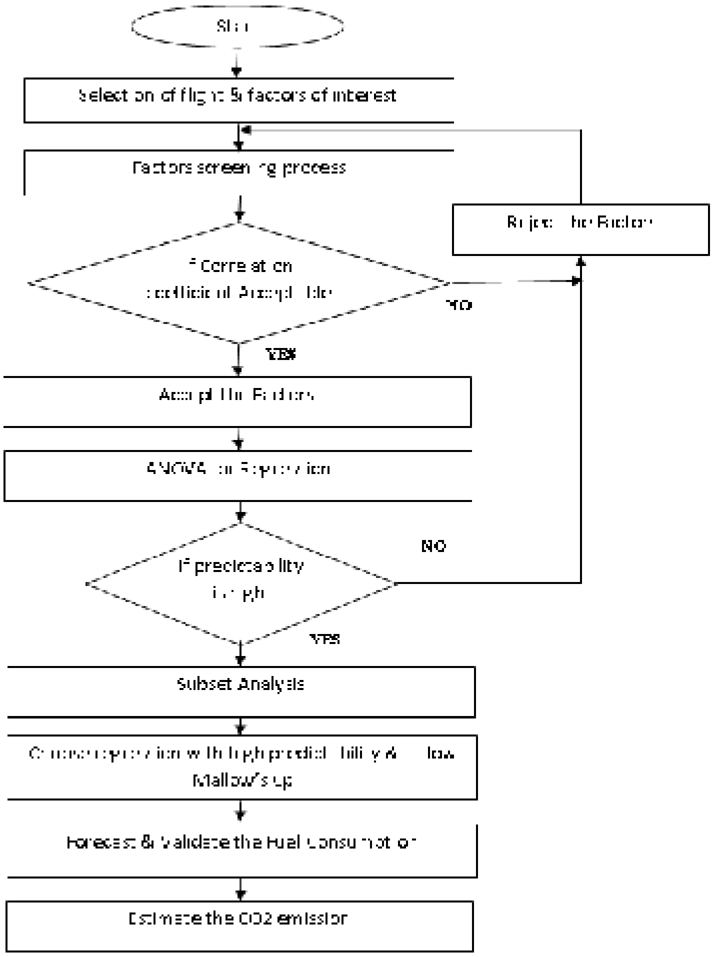

Figure: 3- 1 Flowchart for Emission Forecast- Empirical Analysis

The factors collected were segregated as qualitative and quantitative among them 17 quantitative factors were given as input along with the fuel consumption data in MINITAB. The regression equations were generated and the p-value test for each independent variable was done to screen the uncorrelated variables. Based on the p-values, 7 factors were screened and their p-values were analyzed along with the Variance Inflation Factor (VIF). The VIF measures the impact of collinearity among the variables in a regression model. There is no formal VIF value for determining the presence of multicollinearity [11]. The Regression Analysis Table (Table-2) shows the screened independent variables that are free from the multicollinearity. The regression equation arrived from the screened independent variables is shown in the Equation 1.

$$\text{Fuel consumption} = 306 + 36.7\,X1 + 0.0388X2 + 0.00235X3 - 1344X4 - 0.53\,X5 + 7.39\,X6 - 195\,X7 \quad (1)$$

Table - 2 Regression Analysis Table

Variables	**Coef**	**SE Coef**	**P**	**VIF**
Constant	306	3923	0.038	
Time of flight(X1)	36.6864	0.3568	0.000	1.673
Take of Weight(X2)	0.038839	0.003308	0.000	1.127
Altitude(X3)	0.002351	0.002630	0.371	1.524
Mach(X4)	-1343.6	385.4	0.001	1.182
Temperature(X5)	-0.533	1.582	0.236	1.206
Centre of Gravity(X6)	7.393	4.725	0.118	1.025
Gravitational force (X7)	-194.7	396.6	0.124	1.047

The ANOVA for Regression equation was found to test the level of variability within the independent is shown in Table – 3. The R^2 value indicates that the independent variables explain 91.3% of the variance in fuel consumption. The adjusted R^2 is 91.3%, which accounts for the number of independent variables in the model. Both values indicate that the model fits the data well. The predicted R^2 value is 91.01% which is close to the R^2 and adjusted R^2 values, the model do not appear to be over-fit and has adequate predictive ability. The Durbin–Watson statistic (d) is a test statistic used to detect the presence of autocorrelation in the residuals from the regression analysis that always lies between 0 and 4 [12-14]. If the Durbin–Watson statistic is substantially less than 2, there is an evidence of positive serial correlation. If the Durbin–Watson statistic is greater than 2 then the factors are negatively correlated [15-17]. The d value for the regression equation is close to 2 so there is no autocorrelation effect between the variables.

Table - 3 ANOVA for Regression

Source	DF	SS	MS	F	P
Regression	7	269×10^7	3844×10^5	2733	0
Residual Error	1813	2550×10^5	140702		
Total	1820	2946×10^6			
S = 375.103 R^2 = 91.3% R^2 (adj) = 91.3% , R^2 (pred) = 91.01%,Durbin-Watson statistic = 1.92491					

3.3 Subset Analysis

Best subset regression identifies the best–fitting regression models that can be constructed with the independent variables screened. Best subset regression is an efficient way to identify models that achieve in predicting the fuel consumption with as few independent variables as possible. Subset models estimate the actual regression coefficients and predict the future responses with smaller variance when compared the full model using all independent variables [18]. MINITAB examines all possible subsets of the independent variables, beginning with all models containing one independent variable, and then all models containing two independent variables, and so on. By default, MINITAB displays the two best models for each number of independent variables as shown in the Table - 4. The table explains that each line of the output represents different regression model. Independent variables that are present in the model are indicated by X. From the table, it is not clear that which model fits the data. There are 6 models which has the highest adjusted R^2 (91.0%).

Table - 4 Subset Analysis Table

Variables	R^2	R^2 adj	Mallows Cp	S	X1	X2	X3	X4	X5	X6	X7
1	89.9	89.9	41.7	300	X						
1	41.8	41.7	1716.2	720			X				
2	90.6	90.5	20.4	290	X	X					
2	90.2	90.1	34.7	296	X						X
3	90.9	90.8	12.6	286	X	X	X				
3	90.8	90.7	14.7	287	X	X					X
4	91.1	91.0	7.2	283	X	X	X				X
4	91.0	90.9	10.4	285	X	X	X		X		
5	91.2	91.0	5.4	282	X	X	X		X		X
5	91.1	91.0	7.8	283	X	X	X			X	X
6	91.2	91.0	6.0	282	X	X	X		X	X	X
6	91.2	91.0	7.3	283	X	X	X	X	X		X
7	91.2	91.0	8.0	283	X	X	X	X	X	X	X

Mallows proposed the statistic as a criterion for selecting among many alternative subset regressions [19]. Mallows' Cp compares the precision and bias of the full model to models with the best subsets of independent variables. It helps to strike an important balance with the number of independent variables in the model. A model with too many independent variables can be relatively imprecise while one with too few can produce biased estimates [20]. A Mallows' Cp value that is close to the number of independent variables plus the constant indicates that the model is relatively precise and unbiased in estimating the true regression coefficients and predicting future responses. The simplified results from Best Subset Regression analysis shows that the highest adjusted R^2 (91.0%) and lowest Mallows' Cp value (5.4), and the lowest S value (282) has five-independent variable model with all variables except Mach(X4) and Center of Gravity(X6) .The multiple regression indicates that adding the variable Mach (X4) and Centre of Gravity (X6) does not improve the fit of the model.

3.4 Regression Result

The historical data of independent variables from the selected best subset model along with its fuel consumption produces the following (Equation 2).

$$Fuel\ consumption = -2490 + 35.7\ X1 + 0.0411\ X2 + 0.00734\ X3 + 1.78\ X5 - 8\ X7 \quad (2)$$

The Durbin-Watson statistic (1.95126) for this regression has increased from the previous regression which was 1.92491. From the equation it is clear that the time of flight has the highest influence since the coefficient is 35.7. The Table - 5 depicts the actual and predicted values of both fuel consumption and CO_2 emission for the available independent variables of VT-KFI during July 2009 to January 2010.

Similar regression equations where generated for all the tail registration which depicted the same result i.e. time of flight, take of weight, altitude, temperature and gravitational force were the primary factors of influence for fuel consumption. The regression equation 2, 3 and 4 of VT-KFI, VT-KFH and VT-KFJ illustrates that the identified independent variables are influencing fuel consumption irrespective of the flight. The comparison of the actual data and predicted data for fuel consumption proves that there is a very small residual error in the proposed method of forecasting the fuel consumption for the particular tail registration (VT-KFI). The CO_2 emission for the particular tail registration VT-KFI can be found by multiplying the 3.15 (CO_2Index number [1]) with the value generated from the regression equation with the given parameters. The CO_2 emission per kilometer per hour has been estimated and shown in Table – 5.

$$Fuel\ consumption = -1260 + 33.8\ X1 + 0.0296\ X2 + 0.0161\ X3 + 5.14\ X5 - 12\ X7 \quad (3)$$

$$Fuel\ consumption = -4220 + 37.9\ X1 + 0.0411\ X2 + 0.00585\ X3 + 2.67\ X5 - 9\ X7 \quad (4)$$

Table - 5 Result of the Regression

Obs	Fuel Consumption (Actual)	Fuel Consumption (Predicted)	SE Fit	Residual	St Resid	CO2(Actual)	CO2(Predicted)
1	2903	2780	21.8	123	0.34	9104.771	8776.46
2	5303	5041.1	30.8	148.1	0.41	18604.201	19071.7527
3	4761	5026.6	30.2	-265.6	-0.74	15030.477	15866.2752
4	5167	5832.7	25.8	665.7	1.85	16812.215	18412.8359
5	3040	3305.6	25.6	-257.6	-0.72	9625.600	10436.2152
6	7142	6839.9	68.5	302.1	0.86 X	22547.294	21593.5048
7	4527	4706.8	30.9	-179.8	-0.5	14290.050	14865.6816
8	4323	5191	23.9	803	2.41R	13603.496	16387.937
9	2932	3001.5	31.2	-69.9	-0.2	9255.324	9476.9963
10	6154	6312.7	37.1	158.7	0.44	19423.178	19929.1939
11	2495	2145.7	32.8	349.1	0.98	7870.672	6777.1319
12	2903	2752	33.5	151	0.42	9104.771	8688.054
13	4499	4435.6	40.4	63.4	0.18	14190.343	14003.7692
14	3135	3404.3	28.6	269.3	0.75	9897.195	10747.3751
15	4732	4941.4	21.4	-211.4	-0.59	14926.924	15606.3188
16	5632	5222.8	21.1	409.2	1.14	17780.224	16488.3796
17	4644	4904.4	20.9	-260.4	-0.71	14661.108	15483.7308
18	4470	4398.6	25.7	71.4	0.2	14111.79	13886.3802
19	4412	4742.7	32	-330.7	-0.93	13928.684	14972.7039
20	2555	2519.8	28.8	35.2	0.1	8066.135	7955.0036
21	4703	5126.2	26.1	423.2	1.18	14847.371	16183.4134
22	4177	5228.2	24	-651.2	-2.33R	13186.139	16505.4274
23	7460	7230.2	69.1	229.8	0.64	23551.22	22825.7414
24	3107	3187.4	17.1	-80.4	-0.22	9808.779	10062.6218
25	4259	4892.2	41.1	633.2	1.83	13382.583	15444.6754
26	4557	4777.5	32.3	-220.5	-0.62	14386.449	15082.8612
27	3019	3708.6	24.4	689.6	1.93	9530.983	11708.0502
28	5456	5279.6	33.9	176.4	0.5	17223.006	16667.6572
29	5051	4865.8	28.7	185.2	0.52	15945.007	15361.3306
30	4470	4490	25.4	-20	-0.06	14111.79	14174.93
31	4500	4637	22.1	137	0.38	14206.5	14639.009

4. Conclusion

In this work the emission inventory of airline industry has been studied with the impact of aircraft emissions on global warming. The fuel consumption factors were statistically analyzed and the best regression model was generated. The validation has been carried out using ANOVA, Durbin-Watson statistics and Mallow's Cp statistics to optimize and find the predictability of the model. The regression model was used to find the CO_2 emission for the particular tail registration with various sets of independent variables. The work can be extended to

- Finding the various set of controllable parameters for the various set of uncontrollable parameters such as temperature and gravitational force.
- User-friendly Software could be developed for the performance engineers to find the various combinations of parameters where they could reduce the fuel consumption using various operational procedures which would be both economical and eco-friendly.
- Research is going on to reduce emissions of greenhouse gases from agricultural sources [21]. A bio-fuel analysis could also be done for both ground vehicles and aircrafts to reduce the CO_2 emission from the airline industry.

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