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AIRLINE PILOT PERCEPTIONS AND IMPLEMENTATION OF FUEL SAVING ACTIONS

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Abstract

With the introduction of the carbon emission cost system initiated by the Carbon Offsetting and Reduction Scheme for International Aviation(CORSIA), the improvement of fuel efficiency in flight operations will have higher impact on airline profitability than before. In-flight fuel consumption is somewhat influenced by pilots' technical actions when maneuvering aircraft during flight. This study investigated pilots' recognition and implementation of fuel efficient aircraft controls. The required data were collected using a survey on a sample of pilots from multiple airlines. This survey examined their awareness of fuel saving measures and the implementation of those measures during flight operations. The data were analyzed via Analytical Hierarchy Process(AHP) and Importance-Performance Analysis(IPA). It was determined that pilots recognized the cruise phase to have the highest potential fuel savings with shortcut route selections. Power idle descents were considered second in terms of fuel saving potential. On the other hand, the pilots did not significantly recognize or implement factors related to operations on the ground.

Keywords: flight operation, fuel efficiency, pilot behavior, AHP, IPA

1. **Introduction**

Airlines' efforts to reduce fuel consumption has always been a major issue in aviation industry economics (IATA, 2011). The improvement of fuel efficiency during flight operations is poised to have additional impact on profitability due to the introduction of the carbon emission cost initiated by the International Civil Aviation Organization

(ICAO)[1]. However, certain aspects need to be considered in the trade-off between fuel efficiency and flight safety in aircraft operations (ICAO, 2003). The primary concern of the majority of pilots has been the assurance of safety, while airline management teams have been looking to save on fuel and avoid aircraft accidents during flight operations (IATA, 2011). It is worth investigating pilot recognition as well as the actions that pilots take related to fuel efficient flight operations, as this would enable airlines to determine more feasible fuel consumption reduction measures with more accurate fuel cost savings estimations.

This study, carried out at a time when fuel savings has become even more important, investigated pilot opinions and their relevant actions related to fuel efficient flight operations. Because there are strict safety regulations with respect to an airline's aircraft operations, pilots are not always able to control the aircraft in fuel efficient ways. Accordingly, this study applied careful consideration to the constraints against fuel efficient operations caused by safety regulations and the concerns of the pilots themselves.

Besides safety concerns, there are other factors constraining pilot's discretion on fuel efficient flight operation. For example, the airport operator may not allow fuel efficient operation on the ground by setting down rigid regulations. Air Traffic Control (ATC) may also ask for inefficient operations for various reasons, which the pilot has to follow. In addition, some airlines may already have very sophisticated fuel saving systems in place, with which captains do not have room for extra discretion for fuel efficiency. Such constraints create gaps between theoretical fuel consumption reduction measures and actual implementation of such measures in flight operations. Therefore, it

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[1]https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx

is worthwhile to investigate pilots' opinions and perceptions regarding fuel efficient flight operations as they have hands-on experience and practical knowledge in flight operations, which can contribute significantly to more feasible strategic planning for reduction of fuel consumption.

2. Literature review and theoretical discussions

ICAO recognized the potential of fuel-burn reduction in decisions made by flight crew in its Circular 303 AN/176 document (ICAO 2003). For example, the document mentioned that in the takeoff and climb stage, flight crew can decide whether to use full thrust or less than full thrust to get airborne and climb to cruise altitude. According to that document, fuel efficiency in the cruise stage is already generally optimized by the airlines and there is very little room for improvement for flight crew to take actions in terms of flight speed or altitude. In the landing phase, flight crew can decide whether to reduce speed with reverse thrust with brakes or to use brakes only, and these actions do influence fuel consumption.

Rodriguez-Diaz et al (2019) presented a bi-objective model for landing aircraft to optimize the noise impact and fuel consumption. By utilizing real data from Madrid-Barajas airport, the research showed potential improvements of up to a 4.5% reduction in total fuel consumption (without increasing noise levels) only by modifying the sequence of arrivals, and up to a 43% (without extra fuel consumption) reduction in noise impact over the populations under study.

Jensen et al (2013) asserted that commercial airplanes did not normally operate at a speed that maximized fuel efficiency. They noted that for an airplane carrying some amount of weight, there was one speed that minimized fuel burn. They also insisted that airplanes had an optimal altitude that minimized fuel consumption. This is not always the altitude preferred by pilots. By flying away from optimal altitudes, aircraft experience higher than necessary fuel burn rates. If they try to operate at optimal altitudes when the traffic condition is allowed, airlines could reduce their fuel consumption.

Fuel efficiency schemes, however, must be implemented with caution. Although flights generally carry fuel for contingencies, aggressive efficiency measures can lead to adverse effects that cause excessive inefficiencies and sometimes lead to serious safety hazards. A report by the Spanish Civil Aviation Accident and Incident Investigation Commission regarding an emergency landing due to low fuel on a Ryanair flight stated that Ryanair's fuel policy was based specifically on minimizing fuel uplift for maximum efficiency. The investigation discovered that Ryanair aircraft frequently landed with minimum landing fuel. The report also stated that if several aircraft with minimum fuel on board were forced to arrive at one airport, this could lead to a chain reaction of several simultaneous emergency landings due to insufficient fuel on board. (Civil Aviation Accident and Incident Investigation Commission (CIAIAC), 2010).

3. Research procedures

3.1 Overall scheme of analysis

This study was designed to analyze pilot behavior concerned with fuel saving operational measures during normal airline flights. The study conducted surveys on airline pilots to obtain the required data for analysis. The authors identified the actions that may be considered for fuel efficiency when the pilots control the aircraft during mission flights. These actions were considered to be factors contributing to pilots' perceptions toward potential fuel savings. This facilitated estimates of the importance of each factor for fuel efficiency based on the recognition of pilots. The Analytical Hierarchy Process (AHP) was used to estimate the importance of each factor (Golden et al., 2012). A pyramid hierarchy structure was used for this study in which pilots' perceived potential for fuel savings was categorized with two levels with the first criteria level being flight phases and the second level being more specific fuel saving actions or factors in each flight phase. For simplicity, the specific actions and factors in the second level shall be called 'factors' throughout the study. The AHP generates a weight value for each factor based on scores from the decision maker's pairwise comparison of factors under the same criterion. The higher the score, the more weight is placed with respect to the considered criteria and the greater the weight value, the greater the importance that factor holds. Finally, the AHP combines the scores for each factor using related criterion scores in all criteria levels for a global result including ranks of factors. The global weight for each factor is the sum of normalized scores weighted by the normalized scores of the parent criterion (Saaty, 1980).

However, pilots are not always able to control their aircraft in fuel efficient ways because airlines must adhere to strict safety regulations. Even when pilots recognize that a certain factor is important for fuel efficient operations, they may ignore that factor because of safety concerns. In addition, it is possible that pilots may choose to avoid fuel efficient flight operations due to habits or convenience. Thus, the present study carried out a second analysis to determine differences between recognition and actual implementation with respect to fuel efficiency. The Importance-Performance Analysis (IPA) technique, which had been effectively utilized by Martilla et al.(1977) for their marketing research, was employed to help determine the gap between recognition and implementation. With IPA, the study needed to conduct a second survey to inquire into actual behavior when controlling the aircraft.

First, it was necessary to understand the aircraft control situations that pilots are confronted with during each phase of their flights. These phases of flight operation were categorized into five sequences – ground operations, takeoff/climb, cruise, descent/approach, and land/ramp-in (Goblet et al., 2015). Through a few intensive interviews with experienced airline pilots, a few subordinate factors involved in aircraft control at each flight operation phase were finalized. Figure 1 demonstrates the hierarchy structure of the defined and selected components, which was subsequently used for the AHP analysis.

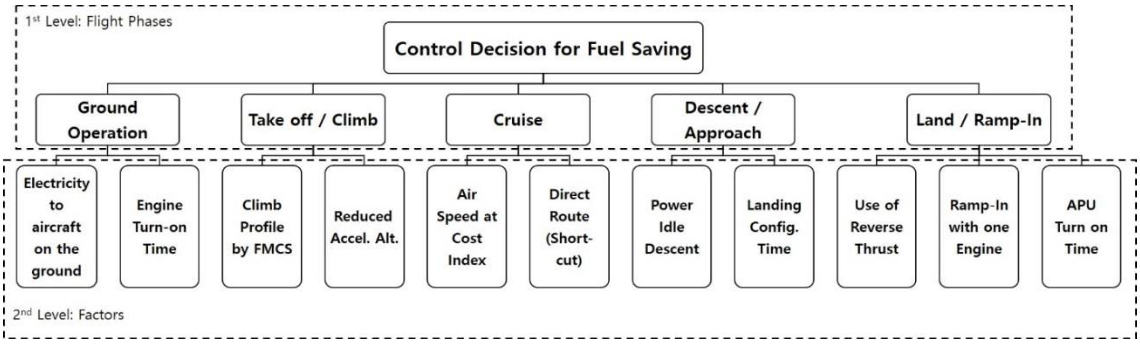

Figure 1. Hierarchy Structure of Flight Phase and Subordinate Factors

A brief discussion follows on the components of the control factors subordinate to each flight phase.

- *Electricity to aircraft on the ground*

Power supply functionality can be adjusted while the aircraft is on the ground. If pilots use the Auxiliary Power Unit (APU) equipped in the aircraft, some fuel is consumed to generate electricity. On the other hand, the utilization of an external electricity supply via a Ground Power System (GPS) does not consume any of the aircraft's fuel. However, pilots may feel it easier and more convenient to turn on the APU rather than request GPS.

- *Engine turn-on time*

Aircraft engines can be turned on to initiate flight operations while the pilots are waiting for clearance to begin moving the aircraft. However, this engine start-up time can be delayed while the airport is utilizing external equipment like tug cars for the initial movement of the aircraft. Pilots may also feel it easier and more convenient to start the aircraft engines earlier rather than rely on external equipment.

- *Climb profile via Flight Management Computer System(FMCS)*

Pilots input surface wind data into the FMCS while on the ground, and they can also input data via the fixed altitude while the aircraft is climbing. Ascending along the profile shown in FMCS can have a great effect on fuel savings. However, most pilots do not follow the climbing profile on FMCS by inputting wind data at fixed altitudes, and they climb the aircraft according to an air traffic controller's instructions.

- *Reduced Accel. Alt.*

Reduced Acceleration Altitude is a best practice for increasing fuel efficiency in the climbing phase. The principle is to accelerate at an altitude lower than what is usually done. By accelerating at a lower altitude, the clean configuration is reached earlier and drag is reduced[2].

- *Air speed at cost index*

The cost index is a number used in the Flight Management System (FMS) to optimize the aircraft's speed. It gives the ratio between the unit cost of time and the unit cost of fuel. With this number, and knowledge about the aircraft's performance, it is possible to calculate the optimal speed for the aircraft, which results in the lowest total cost.

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[2] https://blog.openairlines.com/what-you-need-to-know-about-reduced-acceleration-altitude

- *Direct route (shortcut)*

During the cruise phase, pilots can request a direct route to the air traffic controller to fly the shortest distance to their destination. However, most requests are made only after bypassing and vacating from bad weather. In general, they fly according to the route in the flight plan.

- *Power idle descent*

Power idle descent is a control that allows the aircraft to descent through airflow without power control. Pilots can execute power idle descent by considering the current altitude, target altitude, distance, etc. Most experienced pilots can check the exact power idle descent point with a quick calculation.

- *Landing config. time*

The landing configuration refers to the landing gears and flaps being lowered for landing. When in landing configuration, drag increases due to air resistance, which causes a lot of fuel consumption. Pilots can save fuel by delaying use of the landing gears and flaps.

- *Use of reverse thrust*

Reverse thrust is the temporary diversion of an aircraft's engine thrust so that the engines act against the forward travel of the aircraft, providing deceleration. Pilots can reduce the landing distance by using reverse thrust with auto brakes. It is especially used when landing on an ice runway. However, for safety reasons, it can also be used with auto brakes on dry runways.

- *Ramp-in with one engine*

Once the aircraft has exited from the runway after landing, the pilots may turn off the power for all but one engine so that they can taxi in with minimum power. Out of convenience, some pilots may not choose partial engine turn-off when moving on the ground.

- *APU turn-on time*

When the aircraft is standing still with all engines off, it may need to have electrical power supply during ground handling. The APU is normally turned on after vacating the runway. After landing, pilots can save fuel by turning on the APU as late as possible. Some airlines turn it on two to three minutes before ramp-in.

3.2 AHP analysis

The survey to obtain data for the AHP analysis was conducted with three hundred and two airline pilots. It was designed to investigate the recognition of pilots regarding feasible fuel savings potential of each factor and flight phase. The demographic characteristics of the sample for the AHP survey are shown in Table 1. The respondents were mostly captains in their 30s and 40s with over 3,000 flight hours of experience.

Table 1. Demographic Characteristics of the Sample

Class		Frequency(N)	Percentage(%)
Sex	Male	300	99.3
	Female	2	.7
Age	30s	49	16.2
	40s	102	33.8
	50s	120	39.7
	60s	31	10.3
Airline (Business mode)	FSC (Full Service Carrier)	176	58.3
	LCC (Low Cost Carrier)	126	41.7
Experience (Flight Time)	below 3,000 hrs	26	8.6
	3,001-10,000 hrs	135	44.7
	over 10,000 hrs	141	46.7

Position	Captain	230	76.2
	First Officer	72	23.8
Flight Training Background	Military Unit.	74	24.5
	University, College	76	25.2
	Private Flying School	78	25.8
	Government or Airline Institute for civilian pilot train	74	24.5
Total		302	100.0

The results of the AHP analysis for each level of hierarchy are as follows. Table 2 shows the relative importance and priority of the first level of the AHP structure, the Flight Phase. As shown in the table, the respondents recognized that the *Cruise Phase* has the most significant potential to contribute to fuel savings, followed by Descent/Approach and Takeoff/Climb. Because the Cruise Phase is the longest and most fuel-consuming phase, pilots recognized greatest opportunity to save fuel even though there had already been considerable achievements in fuel efficiency during this phase along with the existence of constraints in making fuel efficient control decisions due to safety regulations (refer to ICAO 2003, and the Section 3.3 of this paper). The Descent/Approach Phase was considered to have second largest potential for fuel savings. Pilots with sufficient flight experience were well-versed in shallow descents/approaches to achieve fuel savings.

Table 3 shows the relative importance, in terms of fuel savings potential by pilots, of each factor in the second level of the hierarchy, the aircraft control factors subordinated to each phase of flight. During Ground Operation, the respondents recognized that the potential of fuel savings earned from avoiding the use of the APU was slightly greater than the savings earned from delaying the engine turn-on time. During the Takeoff/Climb Phase, fuel savings potential was given in the order of Climb Profile via FMCS and Reduced Acceleration Altitude, and the respondents put greater weight in the Direct Route factor rather than the Air Speed by Cost Index factor during the Cruise Phase. The relative importance of the factors during Descent/Approach ranked in the order of Power Idle Descent and Landing Configuration Time. For Ramp-In, the importance was given in the order of Ramp-in with One Engine On and APU Turn-on Time.

It may be useful to have a further statistical discussion on the results of AHP analysis. Attachment-A is to provide statistical information which could be helpful in estimating statistical confidence in the results.

Table 2. Weight of Importance for Fuel Saving Controls during each Phase of Flight

1st Flight Phase	Weight	Rank	Confidence Interval (95%)	
Ground Operation	.133	5	.127	.149
Takeoff / Climb	.182	3	.176	.202
Cruise	.298	1	.279	.0311
Descent / Approach	.250	2	.227	.253
Land / Ramp-in	.136	4	.128	.148
CR	.001			

Table 3 Weight of importance of control factors at each phase

Phases of Flight	Factors	Weight	Confidence Interval (95%)	
Ground Operation (0.133)	Use of APU, GPU, ACU	0.574	.539	.592
	Engine Turn-on Time	0.426	.408	.461
Takeoff / Climb (0.182)	Climb Profile via FMCS	0.597	.561	.610
	Reduced Acceleration Altitude	0.403	.390	.439
Cruise (0.298)	Air Speed by Cost Index	0.354	.344	.393
	Direct Route (shortcut)	0.646	.607	.656
Descent / Approach (0.250)	Power Idle Descent	0.566	.532	.587
	Landing Configuration Time	0.434	.413	.468
Land / Ramp-in (0.136)	Use of Reverse Thrust	0.281	.273	.309
	Ramp-in with One Engine On	0.429	.398	.436
	APU Turn-on Time	0.291	.276	.308

The results of the combined weight of Level 1 (flight phase) and Level 2 (factors) are shown in Table 4. According to the table, the respondents recognized that there was a higher potential for fuel savings with Direct Route operations during the cruise phase, Power Idle Descent during the approach phase and Climb Profile via FMCS during the climbing phase compared to other factors. As pointed out earlier, because the Direct Route factor during the cruise phase takes place during the longest of the flight phases, pilots think that reducing the overall flight time using a more direct route would result in significant fuel savings. Power Idle Descent was considered the second most important due to its ability to save fuel without frequent power controls in the approach phase.

Table 4 Combined Weight of Factors with Flight Phase Importance

2nd Factors	Combined Weight	Rank
Direct Route (shortcut)	.192	1
Power Idle Descent	.142	2
Climb Profile via FMCS	.109	3
Landing Configuration Time	.109	4
Air Speed by Cost Index	.105	5
Use of APU, GPU, ACU	.077	6
Reduced Acceleration Altitude	.073	7
Ramp-in with One Engine On	.058	8
Engine Turn-on Time	.057	9
APU Turn-on Time	.040	10
Use of Reverse Thrust	.038	11

3.3 IPA analysis – comparing recognition and implementation

It was also necessary to investigate the actual decisions made by pilots and comparing those decisions with their recognition. Aside from constraints for safe flight, the aircraft control factors related to fuel savings might not be implemented due to company policy, practices in air traffic control, weather conditions, airport restrictions, or labor management conflicts. Sometimes, pilots might choose not to attempt to carry out fuel efficient activities for reasons such as convenience if there are no incentives for fuel efficient flight operations. The following are the constraints related to the fuel efficiency factors in each phase of flight operation.

Constraints on Implementing Each Factor according to Pilots

(1) Use of APU, GPU, and ACU

The use of such equipment is rarely made at the discretion of the pilot because it is frequently controlled by a ground handler who has been contracted by the airlines. Some airports that are focused on environmental pollution have specific procedures that they adhere to when utilizing ground support facilities such as GPU and APU.

(2) Engine Turn-on Time

The engines should be turned on as late as possible for fuel savings at the discretion of the pilot, but it is common to turn on the engines at the time when the ground operator so advises.

(3) Climb Profile via FMCS

Due to heavy traffic, airspace separation criteria, military activities, and so on, most airline aircraft are unable to be assigned (or receive) an FMCS optimum altitude.

(4) Reduced Acceleration Altitude

The airport may require inefficient procedures in consideration of avoiding noise-sensitive areas.

(5) Airspeed by Cost Index

The cost index set by the company should be maintained as much as possible, but speed changes due to weather, on-time rates, and structure damage happen frequently.

(6) Direct Route (Shortcut)

In general, pilots may request a direct route after making a detour caused by bad weather conditions on the route, but they do not request a direct route to their destination away from a planned air route to achieve fuel savings.

(7) Power Idle Descent

To carry out this procedure, the pilot must descend from the point indicated by the FMCS, but it is often difficult to do so due to air traffic conditions.

(8) Landing Configuration Time

Due to speed limitations and air traffic conditions in the airport control area, there are limited opportunities for optimized landing configurations.

(9) Use of Reverse Thrust

Depending on the length of the runway, this procedure is limited, and in some cases, appropriate training for the pilots may be recommended to use reverse thrust in consideration of over-run.

(10) Ramp-in with One Engine

Pilots prefer to use two engines when they when ramping-in because it eases taxiing control. Some airports restrict single-engine taxiing, and company policy may prohibit the process.

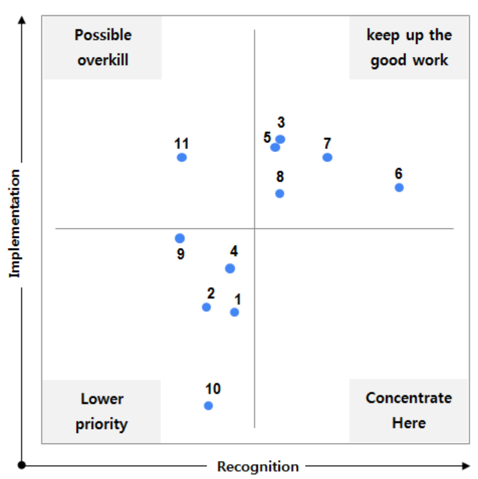
(11) APU Turn-on Time after Landing

The decision to turn on the APU after landing is at the discretion of the pilot. They generally turn it on two minutes before entering the ramp. Some pilots may not put much care into when they turn it on out of operational convenience.

Though airline pilots generally recognize the importance of fuel efficient flight operations and have some knowledge of the techniques related to fuel conservation in aircraft control, they do not implement this knowledge because of environmental constraints on flight operations (as mentioned above) and other personal reasons. The present study conducted an IPA analysis to compare their recognition and implementation in real conditions on fuel efficient factors in aircraft control. For the IPA analysis, the study used the second survey to ask how frequently they implement - fuel efficient methods of operation associated with the factors involved in the first survey. The data collected through the first and second surveys had been linked in the IPA analysis.

The results of the IPA analysis comparing the weight of recognition and implementation for each element considered in fuel efficient aircraft control are shown in Figure 2. As indicated, the elements belonging to the category of “Keep up the good work” that had high significance in both recognition and implementation were 'Climb Profile via FMCS', 'Airspeed by Cost Index', 'Direct Route (Shortcut)', 'Power Idle Descent', and 'Landing Configuration Time'.

The category of “Possible overkill” had a high implementation rate but was recognized as having low potential for fuel savings, and it included ‘APU Turn-on Time’. The category of “Lower priority,” which had low value in both the potential of fuel savings and the implementation rate, included 'Use of APU, GPU, and ACU', 'Engine Turn-on Time', 'Reduced Acceleration Altitude', 'Use of Reverse Thrust', and 'Ramp-in with One Engine'. It was also worth pointing out that there were no control elements belonging to the high value in recognition and low value in implementation rate category.



Keep up the good work	3. Climb Profile via FMCS(3) 5. Airspeed by Cost Index(5) 6. Direct Route(1) 7. Power Idle Descent(2) 8. Landing Configuration Time(4)
Possible overkill	11. APU Turn-on Time after Landing(10)
Lower priority	1. Use of APU, GPU, ACU(6) 2. Engine Turn-on Time(9) 4. Reduced Acceleration Altitude(7) 9. Use of Autobrake instead of Reverse Thrust(11) 10. Ramp-in with One Engine(8)
Concentrate here	-

Figure 2. Results of IPA Analysis

4. Discussions and Conclusions

The AHP analysis showed that the most important flight phase for fuel savings was the Cruise phase, which takes the longest duration of the flight phase. This was followed by Descent/Approach and Takeoff/Climb. Among the elements of aircraft control, the sample pilots answered that they might save fuel consumption most significantly by flying Direct Route during the Cruise phase.

The second and third elements of aircraft control that can contribute to fuel savings were Power Idle Descent, Climb Profile via FMCS, and Landing Configuration Time during the Descent/Approach phase. Those control elements had been tried for fuel efficient flight operations by the pilots. However, there were quite strong constraints in implementing fuel efficient aircraft control during commercial flights. Lots of these constraints were related to air traffic control (ATC) practices, which are provided by the air navigation service provider (ANSP). Accordingly, upgrading the air navigation system and thereby improving ATC could yield effective results (Daley, 2010).

Airlines pursuing additional advantages from fuel savings in flight operations via the CORSIA implementation need to develop policies that can motivate their pilots to enact fuel efficient flight operations. The airlines should provide sufficient information and instruction to their pilots with effective incentives. The results of this study may offer basic information useful for understanding pilots' recognition and implementation of fuel-saving methods in aircraft control. The airlines may utilize the results of this analysis for the development of fuel saving policies in flight operations as well as in methods of motivating pilots to participate in fuel efficient operations of the aircraft. The ANSPs can also refer to the results of this research when they consider improving infrastructure for fuel efficient flight operations.

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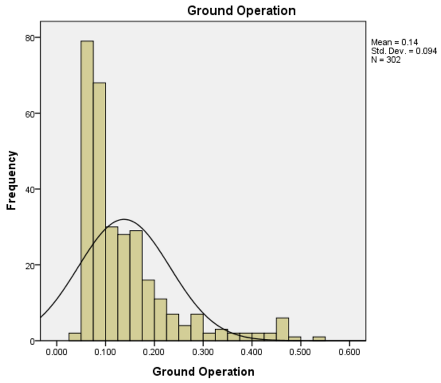
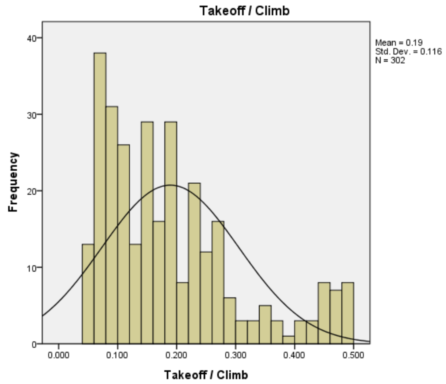
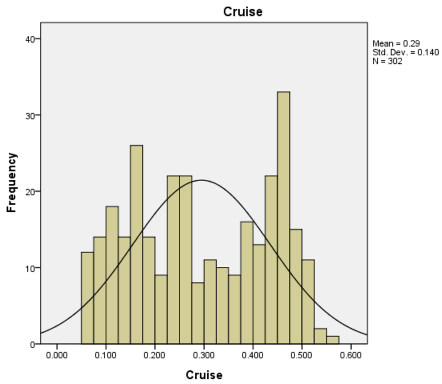
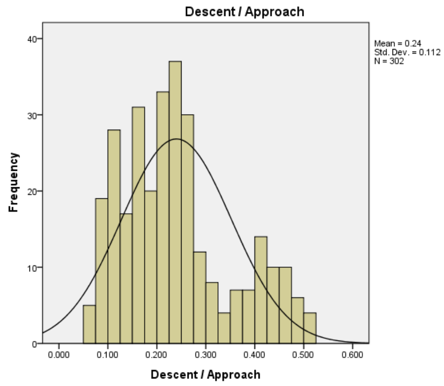
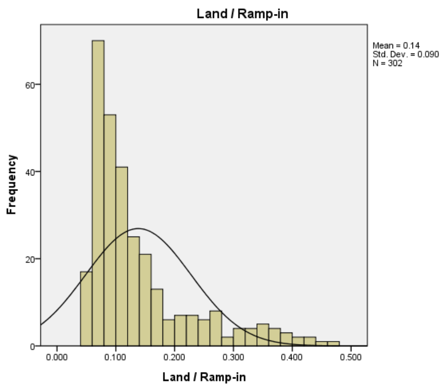
Attachment-A Statistical Information for the results of AHP analysis

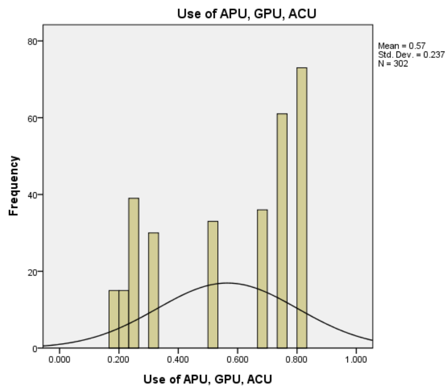


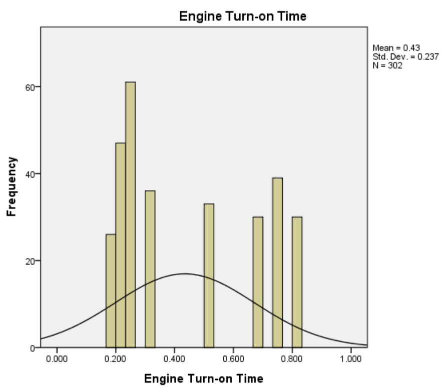


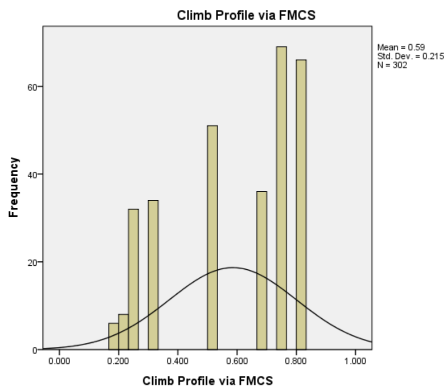


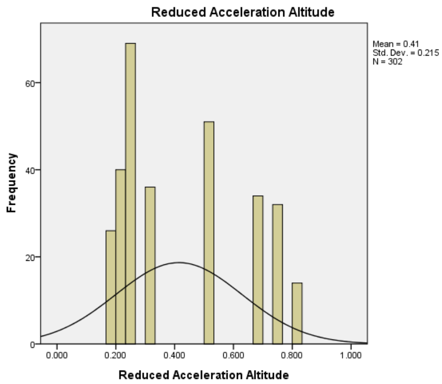


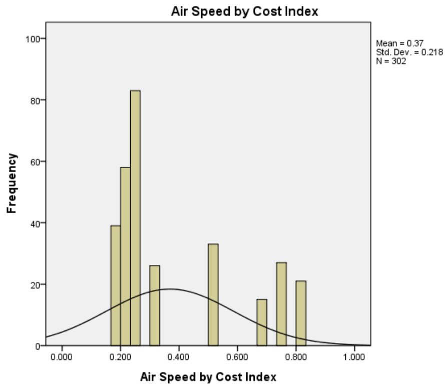


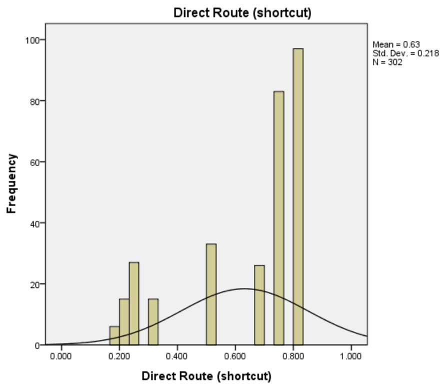


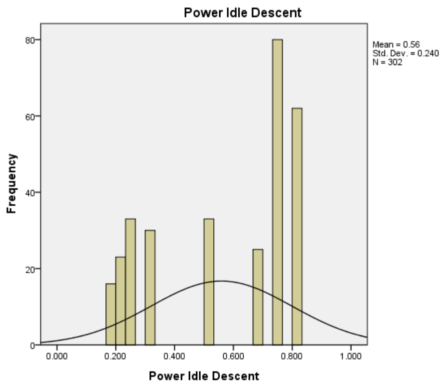


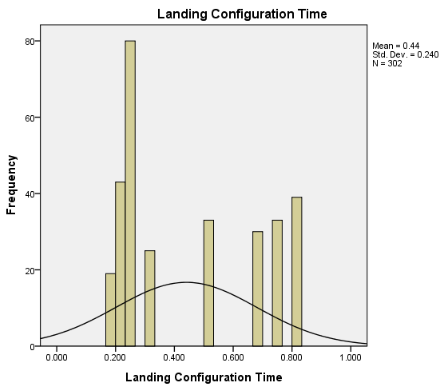


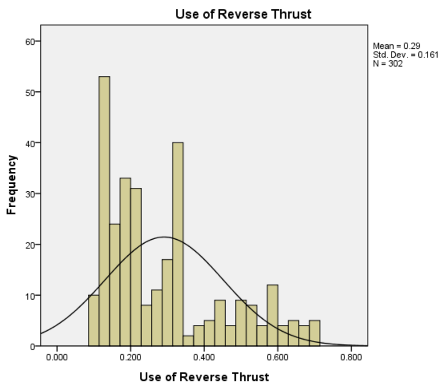

Reduced Acceleration Altitude
Mean = 0.41
Std. Dev. = 0.215
N = 302
Frequency
Reduced Acceleration Altitude

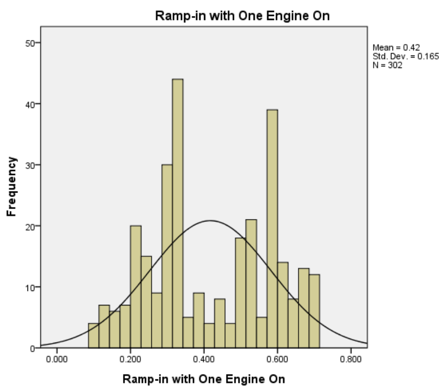

Air Speed by Cost Index
Mean = 0.37
Std. Dev. = 0.218
N = 302
Frequency
Air Speed by Cost Index

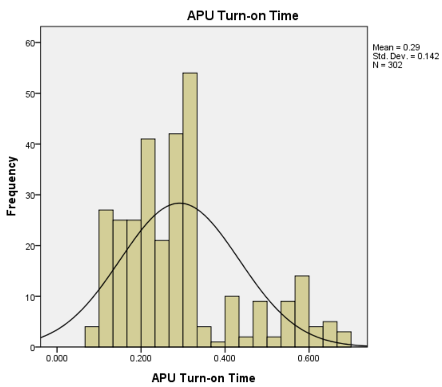

Direct Route (shortcut)
Mean = 0.63
Std. Dev. = 0.218
N = 302
Frequency
Direct Route (shortcut)


Power Idle Descent
Mean = 0.56
Std. Dev. = 0.240
N = 302
Frequency
Power Idle Descent


Landing Configuration Time
Mean = 0.44
Std. Dev. = 0.240
N = 302
Frequency
Landing Configuration Time


Use of Reverse Thrust
Mean = 0.29
Std. Dev. = 0.161
N = 302
Frequency
Use of Reverse Thrust


Ramp-in with One Engine On
Mean = 0.42
Std. Dev. = 0.165
N = 302
Frequency
Ramp-in with One Engine On


APU Turn-on Time
Mean = 0.29
Std. Dev. = 0.142
N = 302
Frequency
APU Turn-on Time