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Analyzing the effect of aviation infrastructure over aviation fuel consumption reduction

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ABSTRACT

The purpose of this paper is to examine the effect of various aviation infrastructure dimensions over aviation fuel consumption reduction (AFCR) performance. This study is an effort that considers the role of dimensions collectively from all aspects belonging to aviation infrastructure. The relevance of dimensions and constructs for hypothesis development are based on extensive literature review. Exploratory factor analysis (EFA) and Confirmatory Factor Analysis (CFA) were performed in the consecutive purification processes. Also, hypothesis testing was conducted using Structural Equation Modeling (SEM). A customized questionnaire was developed for collecting data from both kinds of respondents: Aviation industry experts and academic experts. Out of 382 approaches through mail survey, a total of 194 valid responses were collected. Analysis of the results shows the positive and significant impact of various factors such as: airport design, airspace management and air traffic control over the aviation fuel consumption reduction. Maximum importance is adjudged on air traffic control (ATC) and airspace route flexibility. The results of this study will encourage airlines and airport development authorities to increase their insight over aviation infrastructure, also to perform deeper analysis and find out precise values for real life implications.

1. Introduction

There was a time when aircraft fuel availability and extraction cost had almost no effect over aviation industry growth. Today, however, the aviation industry is facing a lot of challenges which demands the need for conservation of aviation fuel. Commercial airliners are facing aviation fuel cost as a major expenditure out of their total operational cost. Airline fuel bills have crossed the previously highest labor cost to become 34% of the total operating cost (Lawrence, 2009). The early 1970s made it clear that the time of abundance and cheap fossil fuels was facing its end. Economies of aviation sector started to get affected significantly by fuel prices. After 1973 Arab oil embargo, market prices of fuel spiked, resulted in a prompt 400% increase in fuel price (ICAO, 2009). Over the next few decades, prices of aircraft fuel fluctuated a lot, raising concerns over aviation industry's profitability and sustainability. The increase in the cost of fuel forces airlines to go for higher ticket prices, resulting in pressure on the customer's wallet. Again in 2011, fuel prices severely spiked and reached an all-time high of 140 dollars per barrel in March 2011. Between March 2011, and March 2016, huge instability in aircraft fuel prices was seen in the global market as fuel prices shrunk to almost three times. Though, prices of aircraft fuel dropped from the level of 140 dollars in 2011 to today's level, which is close to 40 dollars per barrel (IATA, 2016). Airbus (2015) suggested prices of fuel will swell to a much higher level considering mid-to-long-term effects. After many consistent efforts by airliners, they are still facing huge difficulties to produce an increase in efficiency and revenue matching instability of fuel price. Top producers of fuel are oversupplying and oil demand of world aviation increased from 1.18 MB/day in 1971 to 4.9 MB/day in 2006 and it's about 11.2% of worldwide overall fuel demand (Mazraati, 2010). Additionally, CO_2 emissions are directly proportional to aviation fuel burning (Airbus, 2015). Concerns related to environmental degradation have increased over rapid escalation in the growth of air traffic. All initiatives and policies have failed to control a net increase of fuel utilization, and this leads to an increase in emissions with environmental impacts (Lee et al., 2001). A saving of 0.3 kg of aviation fuel can save almost a kg of CO_2

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emission, which in return also saves about 1.1 dollars (Tsai et al., 2014). Moreover, fuel reserves are depleting and there is dire need to look into the sustainability of the aviation industry. Supply-demand curves are showing an exponential gap. Tension between Middle East nations and huge demand of fuel from China is making the gap worse (Abdelghany et al., 2005). With this, airliners are confronting a challenge over maintaining their commercial viability, requiring a balance between increased fuel consumption and aircraft fuel cost. Furthermore, passengers mostly like to opt for airlines which have greater environmental consciousness (Hagmann et al., 2015). All these situations have encouraged airliners to explore efficient ways for aviation's fuel consumption reduction (AFCR).

Studies by (Drake, 1974; Linz, 2012; Barros and Wanke, 2015) suggest that the key steps towards this goal would be through socio-economic and political changes, improving alternative fuels (Alonso et al., 2014), improvising technological innovations and change in designs of aircraft (Dray, 2013). But, surprisingly previous studies have always subdued a key element like aviation infrastructure and its detailed impact on aviation fuel consumption. Lack of infrastructure and its operational efficiency leads to delays with congestions (this also works vice-versa). These delays and congestions increase fuel consumption and emissions. According to Eurocontrol (2013) delays at airports will rise from 1 min in 2012 to 5–6 min per flight by 2035, and this is considered a substantial increase and needs to be controlled. ICC (1992) strongly urged airport authorities and governments to make a timely and adequate amount of investment in airports, which is a portion of aviation infrastructure. Failing to do so would result in severe airspace and airport congestions. Large investments by developing nations in aviation infrastructures portray the importance of aviation infrastructure. Sarkar (2012) suggested that by improving the efficiency of aviation infrastructure, we can additionally reduce 4% emissions globally by 2020. This reduction could also be close to 10% for certain regions. Previous studies always lagged behind the precise solo collective effort of all the factors and sub-factors of aviation infrastructure over AFCR. This study attempts to touch almost all the sub-areas of aviation infrastructure in detail. In this article effort had been invested to connect all research gaps for a definitive conclusion regarding the options in the field of aviation infrastructure for aviation fuel consumption reduction.

2. Literature base for constructs and hypothesis development

Studies show that implementation of technologies and design is way behind schedule and fully depends on the wish of carriers, whether to invest on costly equipment's or not. Just as aircraft design, alternative fuels are also constrained by technological developments' timeline. Thus, investing time and money over them may not yield the required results in time. Moreover, there is a need for immediate action. Development and implementation of technology are constrained by its technology life cycle (TLC), which involves rigorous safety testings and also require engineering excellence. All this significantly increases the development cost and decreases implementation rate of technology (Ribeiro et al., 2007). So, the infrastructures emanate out to be the most predictable, and investing over it will produce predictable and satisfactory results with immediate effect. But investing in infrastructure to fill the gap between current and required is a huge one-time investment, so we must go for increasing asset utilization (Adler and Gellman, 2012) by investing in certain parts of infrastructure which will yield the most reduction in fuel consumption. With it comes the need to identify parts of aviation infrastructure which can assist the most in asset utilization.

While going through literature, we have to take into account propagation of delay i.e.; delay because of any reason transferred from one area to other areas (like a ripple effect) (Evans and Schäfer, 2011). Construct formation is based on the literature study. The research model of the current study is displayed in Fig. 1 and the development of the hypotheses are described in detail below.

2.1. Taxiway (TWY)

Development in the aviation industry is increasing ground operations complexity and causing problems throughout airport resource distribution. To increase the operational efficiency, we have to pre-plan taxiway paths (Zhou and Jiang, 2015). Research towards simulating a flight movement on taxi routes are going on so that one can predict aircraft movements step by step leading to minimizing conflicts. Conflict leads to delay and fuel burn. Jiang et al. (2013) studied taxiway safety separation for optimizing a path to be conflict free, by allowing one point of taxiway to permit only one aircraft pass at a time. In the case of peak hours, aircraft wait in departure queues for as much as 30 min. Practices breakaway thrusts to proceed, causing unnecessary fuel burn and emissions. Minimizing the taxing distance (Kazda and Caves, 2007) and incorporating rapid taxiways facilitate faster turnaround (Bradley, 2010) in airports; a significant amount of reduction in aircraft fuel burns can be achieved. Geometric component of a taxiway like number of turns and number of stops increases fuel consumption, because of differential thrust and throttle adjustments use in respective cases (Khadilkar and Balakrishnan, 2012). A study by Nikoleris et al. (2011) concludes 18% of fuel consumption is because of stop and go situations. Based on the above arguments, the following hypothesis is made:

H1: Taxiways have significantly positive impact on AFCR performance.

2.2. Terminal area (TMA)

As air transport is highly prone to changes for its efficiency improvement, Baltazar et al. (2014) took indicators, out of which passenger terminal area and cargo terminal area were efficiency indicators. FAA (2013) predicted an increase of 105% in passenger demand and 50% in flight operations for terminals areas from 2005 to 2040. This alarming data projects, how important terminal area infrastructure is for the efficiency of airports. Operations efficiency can greatly reduce fuel use, and what is the operational capacity of that airport will decide an airport's fuel saving capacity. According to Upham et al. (2003), operational capacity of an airport will be influenced by number of terminals and size of terminals in the airport. An increase in taxiing distance and terminal distance from runway lead to more distance to cover, causing more fuel consumption. Schlumberger (2012) found, location of terminal determines the extra greenhouse gas (GHG) emissions and similarly have an influence on fuel consumption. Based on the above arguments, the following hypothesis is made:

H2: Terminal areas have significantly positive impact on AFCR performance.

2.3. Apron (APRN)

According to Bradley (2010) MARS (Multi-aircraft ramping system) centerline and single centerline are very efficient. But, they have their own advantages and disadvantages and depend on the

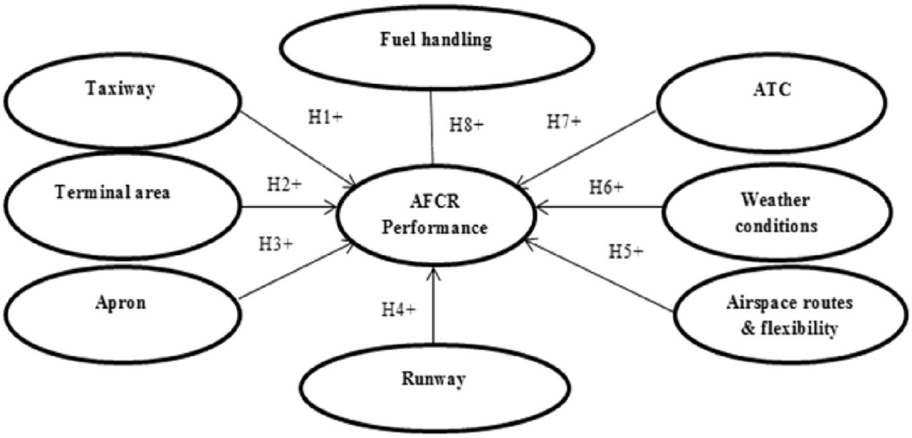


Fig. 1. Research model.

layout of an apron to increase efficiency. To make ground movement work more effective and efficient, apron location from other elements is a deciding element towards minimization of congestion and taxing (ACRP, 2013) Aprons' size is found to be a critical match towards how many aircraft it can accommodate (ACRP, 2013; Hamzah and Adisasmita, 2015), and that will lead to a decrease in congestion by reducing number of aircraft in waiting, i.e; in runway and airspace. Use of push back control reduces departure queue sizes, leading to a substantial amount of fuel saving of 12,250 to 14,500 Kg, CO_2 emissions of 38,700 to 45,800 Kg and a total saving of 8800 to 10,400 dollars. Use of Ground power units than auxiliary power units can save fuel in the range of 11,940 to 14,190 Kg (Simaiakis et al., 2014). ACRP (2013) suggested amount and type of apron markings can drop visual confusion's occurring both to pilots as well as the ground crews and results increase in apron area efficiency. Based on the above arguments, the following hypothesis is made:

H3: Aprons have significantly positive impact on AFCR performance.

2.4. Runway (RWY)

Aircraft consumes a large amount of fuel while running on a runway, during its takeoff and landing. Ball et al. (2007) found runway condition's to be an important parameter for aircraft performance. Smooth and a hard surface will decrease roll distance fuel consumption, as it reduces resistance and hence increases the momentum of the aircraft. Additional parallel runways can decrease fuel consumption significantly, but its construction is suitable for airports with ample area. Baltazar et al. (2014) considered numbers of runway to an important efficiency indicator. Santos and Antunes (2015) conclude an addition of runway can increase the capacity of runways by 200–300 departures per day. Where there is an area constraint involved, one should prefer cross runways over parallel runways to operate independently. But, how much or whether will it save fuel doesn't entirely depend on the cross runway. Rao et al. (2009) found runway slopes can decrease runway length by 15–20% then level runways. Runway length is considered to be an important parameter for deciding the aircraft size that will be in use (Hamzah and Adisasmita, 2015). As bigger the aircraft in use per passenger or per unit cargo fuel consumption will be lesser. Poret et al. (2015) report that big aircraft like Boeing 787-8 can tackle instability of fuel prices because of its range/seat/payload capabilities. Balicki et al. (2014) state that altitude change of runways cause variations in air density, which result into variations in lift, drag, length of runway and fuel consumption. Based on the above arguments, the following hypothesis is made:

H4: Runways have significantly positive impact on AFCR performance.

2.5. Airspace routes and flexibility (AR_F)

Single European Sky ATM research (SESAR) initiates a performance-based approach, which introduced flexibility over Functional Airspace Blocks (FBA) of Portugal and Spain. Inclusions of free route airspace of direct routes save 2–3% of flight distance, producing around 100,000 Euros of saving per day and tons of emissions and fuel (Nava-Gaxiola and Barrado, 2016). Pham et al. (2010) suggest rerouting flights can be useful in congested flight paths and waypoints can help in reducing emissions from fuel consumption. Redesigning routes will allow choosing most efficient routes followed by a fall in fuel consumption (Sarkar, 2012). According to Vaaben and Larsen (2015) an integration of flexibility in flight trajectories can cause a saving of several million USD for severely impacted airspace congestions. Airspace is mainly divided into two areas i.e.; civil airspace and military airspace. Access to military airspace by civil aircraft can sufficiently decrease congestions. According to Gianazza et al. (2009) number of aircraft and sector volume are a decisive parameter in airspace configuration. Lewis (2013) stated that in a mixed airspace risk of conflicts are high because of the cross and converge routes. This will lead to congestion, forcing aircraft to choose non-efficient routes, resulting in extra fuel burn. An extra airspace access can provide an extra parallel route for avoiding conflicts. Based on the above arguments, the following hypothesis is made:

H5: Airspace routes and flexibility have significantly positive impact on AFCR performance.

2.6. Weather conditions (WR_C)

Efficiency and capacity of air transport are highly affected by severe weather conditions. Concerns pertain about the severity of weather conditions hampering operations of air transport. Zillies et al. (2014) concludes wind optimized routing increases 4.3% of overall efficiency. Savings on a lower wind day will be considerably lower. Icing imposes extra weight to an aircraft leading to decrease in lift and increase in drag resulting extra fuel burn (Bedard, 2003). Bedard (2003) categorized thunderstorm as an aviation hazard, which can cause controls to go haywire and causing delays. Zanni and Ryley (2015) conclude snow as the most disruptive one causing 30% trips to face long delays and over 25% being canceled. Hurricanes affect 40% trips and volcanic ash causes 75% cancellations. Balicki et al. (2014) suggested dust as a key element which will increase fuel burn because of loss of thrust and deposition in cavities and engines, thus reducing speed, deteriorating engine efficiency. Rerouting, ground holding and cancellation of flights, only for 1-h closure of London Heathrow airport costs around 700,000 to 1,250,000 Euros (Pejovic et al., 2009). Yoder (2007) used temperature as a fuel reduction modeling parameter and Balicki et al. (2014) found an increase in temperature affects turbine engines causing more fuel burn. Fog produces low visibility and increases arriving aircraft spacing, enforcing them to lower landing rates. Ball et al. (2007) suggests fog is highly disturbing in the case of operations and control, causing high delays. Based on the above arguments, the following hypothesis is made:

H6: Weather conditions have significantly positive impact on AFCR performance.

2.7. Air traffic control (ATC)

The core purpose of ATC is to maintain a safe separation and efficient control over concerned aircraft. As airports are a bottleneck for air transport, managing operations of the airport can successively reduce congestions and delays. According to Marks and Rietsema (2014) and Roosens (2008), VHF radio communication is one key element for efficient movement and adding more VHF frequencies will increase ease of communication, causing fewer delays (Marks and Rietsema, 2014; Roosens, 2008). Radar is for smooth flow of traffic, FAA spending's on radar facilities decreases costs of delays. Navigational system is for efficient movement of traffic, as the development of satellite navigation system make flights to go more direct and to choose efficient ones. An introduction of 4D trajectory based operations is researched by SESAR in Europe and NEXTGen in the USA. Operations using 4D trajectories can solve the issues of traffic predictability, optimal route, capacity, ATC workload, delay, fuel consumption and emissions (Enea and Porretta, 2012). Importance of ATC skilled personnel's in increasing capacities and effectiveness of a system has been suggested by (Ball et al., 2007). Thus, we proposed the following hypothesis:

H7: Air traffic control has significantly positive impact on AFCR performance.

2.8. Fuel handling (FL_H)

Lack of fuel handling expertise can cause more fuel consumption leading to wastage. Chauhan et al. (2015) suggested pumping equipments should be maintained regularly to get more efficiency, minimizing delays and leakage waste. Chauhan et al. (2015) and FAA (1974) suggests filters to be an important part of refueling as clogging or rust in it can reach turbines through fuel and clog it, causing even more decrease in efficiency. FAA (1974) suggests storage tanks can contaminate fuel causing detrition of aviation fuel quality. Condensed water should be checked and removed on a regular basis. Another type of contamination occurs because of FAME (Fatty Acid Methyl Ester) from biofuel. FAME has an ability to be absorbed by the surface of storage tanks. A joint transportation system of jet fuel and biofuel mixed diesel make a possibility of FAME to mix with jet fuel. FAME's acceptable limit is 5 ppm which is very low and such low amount of the same categorizes fuel as contaminated and unsuitable for use as aviation turbine fuel (Joint Inspection Group, 2008). Thus, we proposed the following hypothesis:

H8: Fuel handling has a significantly positive impact on AFCR performance.

2.9. AFCR performance (PRFM)

AFCR performance is not a singular identity, but comprises of sub-areas which will also be directly influenced by impacting parameters. Simić and Babić (2015) considered fuel consumption reduction and emission reduction as dominant objectives while assessing infrastructure utility. As reduction in fuel consumption will decrease emissions and produce energy savings, we also have to measure revenue savings. Virtual Frontier Benevolent DEA Cross Efficiency model (VFB-DEA) introduced by Cui and Li (2015) studied the energy efficiency over a time-period of 2008–2012 for 11 airlines. Results indicated energy efficiency is greatly driven by capital efficiency, mainly revenue generated. The unit cost of per landing and takeoff (LTO) air pollution depends on the severity of their global impact and are divided into short, medium and long haul. The unit costs are 81, 145 and 700 Euros respectively (Eurocontrol., 2015).

The overall idea about all factors and sub-variables has been provided in Appendix A. Literature review table.

3. Research methodology

3.1. Measurement instrument and sampling technique

All the questions were proposed on the basis of extensive research of more than 140 articles of previous studies. Questions in questionnaire were tested for their validity. For its betterment academicians and experts in the field of aviation gave their invaluable suggestions, towards its refinement and testing. As suggested by Sekaran (2006) both pre-test and pilot study was conducted to decrease questionnaire's inexactness and validate instrument through feedbacks. A five-point Likert scale had been used. In the scale, 1 represent strongly disagree and 5 represent strongly agree. The data's from Likert scale should not be treated as ordinal data but intervals. In the study, the questionnaire was conveyed by a covering letter, which described the goal and significance of the research study, then ensured confidentiality for the filled data. Respondents were described that the study was being conducted to investigate their opinion on fuel consumption through aviation infrastructure, and that the involvement in the study was voluntary. They were additionally informed that any time they have the right to withdraw from the study and there is a necessity of at least 5 years of experience to contribute in the study. Furthermore, the respondents were provided with the contact info of the researcher (i.e., Name, designation, contact number and contact address) so that they can do related inquiries and if they wish, they can obtain the results of the study. Questionnaires were of 2 parts, first, to measure demographic characteristics using a nominal scale and second to measure constructs using the ordinal scale i.e., Likert scale. A sample copy of the questionnaire is given in Appendix B. Orders of the questions of the questionnaire were varied with each respondent to counter possible order bias.

For distribution of the questionnaire, we used a non-probalistic method of convenience sampling (as the cost of the survey was low and easy to approach to the responders). Gathering of a substantial share of data was accomplished through self-administered method. The self-administered survey has many advantages such as: ample time for respondent to provide well thought out responses; conveniently approachable respondents, a lesser amount of interviewer bias and low cost. Central Industrial Security Force (CISF) and Airport authorities of Agartala Airport (IXA), Indira Gandhi International Airport (DEL), Netaji Subhas Chandra Bose International Airport (CCU), Raja Bhoj Airport (BHO) and Jaipur International Airport (JAI) helped in reaching marked personnel's and to collect completed survey data. We targeted senior academicians and experts as they have greater knowledge in the field. The questionnaire had 8 factors consisting a total of 38 measures for AFCR performance evaluation. The questionnaires were distributed to 382 respondents through mails and hand to hand. After one week we sent another copy with some follow up only to those who didn't respond via mail to increase chances of a reply. Every step had been taken to make the respondents comfortable with replying.

A response rate of less than 20% stands to be highly objectionable (Yu and Cooper, 1983). Out of 382 respondents, we got 122 responses within 21 days as early wave and 83 responses after 21 days regarded as late wave, totaling to 205 responses. Out of them, 11 responses were incomplete, and were discarded. We are now left with 194 valid responses, with a response rate of 50.78 percent. The number of responses is above the lower threshold (prescribed to be 5 times of the number of items) (Hair et al., 2006). The response rate is much above the objectionable and prescribed level. So it's satisfactory to proceed with the current number of responses. Out of 194, 137 were from aviation industries and 57 from academics. The data collection was conducted from 10th October 2015 to 24th November 2015 i.e.; 55 days. Respondent's detail is provided in Table 1. However, the recognized categories only differ significantly in working experience and in position between research scientists and pilots. This suggests that with experience, views on certain issues change and there is a perception difference between persons with theoretical knowledge and with practical on-field knowledge. This furthermore puts forward that other socio-demographic individualities, including gender, education level, type of working organization don't significantly influence perceptions, underpinning the study. However, working positions may somewhat vary individual perceptions.

The kurtosis and skewness values are −1.337 to 1.187 respectively, which is between the acceptable limit of −2 to +2 (George and Mallery, 2012). To check for the non-response bias, we considered the study of Narasimhan (2001). Here, we considered the late wave as non-respondents and the early wave as respondents. We calculated mean, using *t*-test of randomly selected 20 questions from both groups. In comparison, we found they had a non-significant difference. The results confirmed the absence of response bias.

To counter common method bias, the best way is to use CFA and compare the non-centrality index of two different models (Lowry and Gaskin, 2014). We used Harman's one-factor-test (Podsakoff et al., 2003). One was proposed model with 9 factors and another was 1-factor model having all observed variables loading on it. The values without rotation came as 0.735 for proposed 9-factor model and 0.314 for the 1-factor model. The value of the 1-factor model is below 50% of the 9-factor model. Thus, confirms no common method bias. Other than CFA we also gave consideration to study procedure. By cautiously constructing constructs and confirming responders anonymity for excluding a possible bandwagon effect (Linz, 2012) we minimized chances of common method bias. As suggested by Nowack et al. (2011) we made sure that comment of one respondent reaches other respondents for better response quality.

3.2. Research procedure

In this study, we will use quantitative research approach. Quantitative approach simplifies complex study problems by breaking them into simpler elements. It offers statistical proof for relations among endogenous and exogenous constructs. In addition, the quantitative approach also gives solid validity and reliability. Lastly, it provides prospect aimed at cost-effective data collection and approves clear theoretical focus with easily comparable data. (Amaratunga et al., 2002).

Research steps for this study comprise of three step improvement procedure. Firstly, EFA then CFA and at last structural model's analysis. Many other studies successfully applied factor analysis and SEM modeling for their detailed research in various fields of air transport industry. For example, in the field of relational management of air transport industry, Chao et al. (2015)

Table 1
Respondent's profile (Sample description: N = 194).

Samples	Category	N	Approx. percentage (%)
Gender	Male	163	84
	Female	31	16
Working experience related to aviation field (years)	5–14	87	45
	15–24	61	31
	25–50	46	24
Education level	Doctorate	89	46
	Post-graduation	79	41
	Graduation	26	13
Type of organizations	Academics	57	29
	Aviation	126	65
	Research & development	11	6
Position in an organization	Professors	47	24
	Research scientists	11	6
	Operations	47	24
	Maintenance	28	14
	Aircraft pilots	19	10
	Engineer	42	22

conducted a study between Taiwan's airlines and travel agencies. They validated their relationship marketing model using CFA then SEM. Similarly, Wang (2014) leads a similar research procedure for his study over perceived relationship investment and relationship bonds. Incorporating study on the field of behavioral science for the air transport industry, Davison et al. (2014) conducted a study over household behavioral intentions and air travel behavior. In it, EFA was used to cluster psychological constructs into attitude-based segments. Then, SEM was used for analyzing their path of action. In another study, Wang and Ngamsiriudom (2015) conducted a study on worshipping of celebrity over constructs of purchase intentions and Theory of Planned Behavior's (TPB is a principal staple of behavioral study). In it researchers employed EFA to check any notable deviation from the adapted construct structure, then, CFA was used to evaluate validity. Then, path analysis using SEM was conducted to examine research hypotheses. A study of Ku and Chen (2013) was focused on the use of self-service technology (SST). The investigation was to show how service processes fit facilitates customer's behavior to use SSTs. In the research, CFA was used to check the validity of the constructs and after that SEM for hypothesis testing. In the field of service, Nameghi and Ariffin (2013) conducted their study over full-service carriers of Malaysian airline industry to propose airline hospitality dimensions and their measuring scales. In it firstly, EFA was employed to identify underlying construct structure and then, CFA to verify the structure of factors. Similarly, in the same field of research Hussain et al. (2015) used CFA then SEM for path analysis. Their study was on UAE-based airlines, to investigate linkage among customer satisfaction and service quality. Liedtka (2002) conducted a study to measure airline industries non-financial performance. In here, required factors emerged using EFA and then to scrutinize the factor structure CFA was employed. Jenatabadi and Ismail (2014) used the same procedure of CFA then SEM. The study was on estimating airline companies financial and non-finacial performance. In another study, Evans et al. (2007) used the same procedure of EFA followed by CFA to develop a scale for aviation safety climate, which include initial development of scale using EFA and then used CFA to check posted prior model to fit the data. In brief, EFA will help us to propose a model or to check the structure of any literature model. Mainly, EFA is used for data reduction. CFA facilitates verifying the model given by EFA and to check the fitness of the model for proceeding to SEM. SEM is an empirical technique to test relations between constructs. As the technique is multivariate (Hair et al., 2006) in nature, it can work with multiple equations at a time. Above examples works as a foundation for the research procedure, we are going to follow and portray the appropriateness of our study procedure.

4. Results and discussions

4.1. *EFA results*

The values of Barlett test (BT) and Kaiser-Meyer-Olkin (KMO) showed all constructs were homogenous and adequate. Barlett's test (BT) of sphericity value indicated statistical significance and its value was less than 0.05. Kaiser-Meyer-Olkin (KMO) indicated sampling adequacy and for that, it should be more than 0.5. Therefore, suitable for performing principal component analysis using varimax rotation. Factor loading for each item should be greater than 0.5 (Nameghi and Ariffin, 2013). At first run, we checked pattern matrix, we found the loading of TWY1, AR_F2, WR_C3, WR_C5, ATC2 and performance measuring items were not clean and faced cross loadings. But, considering the literature importance of the performance measures and insignificance of this study without considering them, we proceeded to other checks without deleting the performance measures. TWY1, AR_F2, WR_C3, WR_C5, ATC2 were removed from the pre-developed model. For each construct, we checked Eigen-values and found them to be greater than 1 (Lu, 2014). All cumulative percentages of variance were more than 60% as suggested by Hair et al. (2006). Then we opted for a reliability check with Cronbach alpha value (α), which should be greater than 0.7 (Hussain et al., 2015). All values for constructs were more than 0.7, thus showed their reliability. Finally, we were left with an instrument having 33 items and 3 AFCR performance indicators. The results in detail are shown in Table 2.

4.2. *CFA results*

CFA was used after EFA as a second-degree refinement. The model used was the resulting model after applying EFA. We checked for construct validity and then unidimensionality. As EFA checks only theoretical basis, on the other hand, CFA can check factor correlations, common variable loading on multiple factors.

4.2.1. *Construct validity*

Construct validity involves fulfilling both convergent and divergent validity.

4.2.1.1. Convergent validity. Convergent validity indicates the extent to which items attempts to measure a single construct. Ahire et al. (1996) suggested the use of CFA to assess convergent validity. If the values of average variance extracted (AVE) are greater than 0.5 and composite reliability (CR) greater than 0.7 indicate the validity of the model (Fornell and Larcker, 1981).

Detailed results are shown in Table 3.

4.2.1.2. Discriminant validity. Discriminant validity measures the discrete characteristic of construct's measures. It is desirable that each measure should not correlate too much with a measure from another construct to maintain personal distinct identity. To support the validity, the square root of AVE should be greater than all the correlation between constructs. In another condition maximum shared squared variance (MSV) and average shared squared variance (ASV) should be less than AVE (Fornell and Larcker, 1981). From Table 3 we can see the model fulfilling discriminant validity.

4.2.2. *Unidimensionality*

Unidimensionality indicates whether a set of items represents one or more than one factors. Multiple indicators weaken unidimensionality which is not preferred. For the study, we followed the study of Chong et al. (2011). We checked measure of fit using $\chi^2/\text{df} = 1.248$, which should be less than 3 indicating a good model fit. For unidimensionality, we considered the study of Hart (1994) and Katos (2010), who suggested that if CFI and GFI are above 0.8, the factors are considered to be unidimensional. Fit indices values for the measurement model are GFI = 0.840, CFI = 0.969, RMR = 0.031, SRMR = 0.048, RMSEA = 0.036, TLI = 0.964. For an additional assurance to proceed, we considered the additional parameters of the study Bollen (1989). This included SRMR, RMSEA, and RMR. Values were below 0.1. The value of TLI is above 0.9 (Erkmen and Hancer, 2015). So the proposed model was acceptable and proceeds to SEM analysis.

Table 2
EFA results.

Items	Factor loadings	SMC	KMO	Eigen-value	Variance explained (%)	Cronbach α	Mean	SD
H1. **Taxiway (TWY)**			0.775	2.746	68.661	0.844	3.869	0.721
TWY2	0.792	0.467						
TWY3	0.781	0.522						
TWY4	0.901	0.839						
TWY5	0.834	0.539						
H2. **Terminal area (TMA)**			0.735	2.368	78.926	0.866	3.811	0.901
TMA1	0.880	0.658						
TMA2	0.902	0.731						
TMA3	0.884	0.666						
H3. **Apron (APRN)**			0.831	2.951	73.775	0.880	3.709	0.818
APRN1	0.850	0.604						
APRN2	0.821	0.537						
APRN3	0.885	0.760						
APRN4	0.879	0.706						
H4. **Runway (RWY)**			0.852	3.317	66.339	0.869	3.944	0.723
RWY1	0.741	0.403						
RWY2	0.880	0.779						
RWY3	0.856	0.684						
RWY4	0.764	0.452						
RWY5	0.822	0.601						
H5. **Air routes & flexibility (AR_F)**			0.854	3.346	66.916	0.875	4.087	0.719
AR_F1	0.889	0.747						
AR_F3	0.830	0.601						
AR_F4	0.797	0.540						
AR_F5	0.802	0.543						
AR_F6	0.777	0.518						
H6. **Weather conditions (WR_C)**			0.925	4.529	75.484	0.934	3.898	0.967
WR_C1	0.826	0.602						
WR_C2	0.879	0.732						
WR_C4	0.848	0.642						
WR_C6	0.900	0.788						
WR_C7	0.872	0.714						
WR_C8	0.886	0.758						
H7. **ATC (ATC)**			0.746	2.465	82.182	0.891	4.122	0.779
ATC1	0.902	0.716						
ATC3	0.899	0.681						
ATC4	0.919	0.802						
H8. **Fuel handling (FL_H)**			0.742	2.437	81.235	0.884	3.514	0.963
FL_H1	0.904	0.704						
FL_H2	0.887	0.645						
FL_H3	0.913	0.806						
AFCR Performance (PEFM)			0.710	2.297	76.554	0.846	3.942	0.784
PRFM1	0.900	0.706						
PRFM2	0.890	0.701						
PRFM3	0.833	0.563						

Table 3
Convergent, discriminant validity.

	CR	AVE	MSV	ASV	FL_H	TMA	TWY	APRN	RWY	AR_F	WR_C	ATC	PRFM
FL_H	0.884	0.718	0.151	0.074	**0.848**								
TMA	0.867	0.685	0.246	0.121	0.273	**0.828**							
TWY	0.851	0.592	0.240	0.083	0.088	0.179	**0.769**						
APRN	0.882	0.652	0.298	0.144	0.388	0.270	0.211	**0.807**					
RWY	0.874	0.584	0.450	0.170	0.253	0.359	0.239	0.422	**0.764**				
AR_F	0.878	0.590	0.588	0.223	0.250	0.390	0.285	0.440	0.454	**0.768**			
WR_C	0.935	0.706	0.329	0.150	0.373	0.317	0.224	0.352	0.405	0.409	**0.840**		
ATC	0.891	0.732	0.546	0.191	0.087	0.399	0.393	0.299	0.337	0.576	0.350	**0.856**	
PRFM	0.851	0.656	0.588	0.348	0.298	0.496	0.490	0.546	0.671	0.767	0.574	0.739	**0.810**

Note: Diagonal elements (in bold) denote the square root of the average variance extracted (AVE).

4.2.3. Coefficient estimates in the measurement model

For the measurement model, all the standardized factor loadings are significant and above 0.5 and squared multiple correlations (SMC) were above 0.4 (Choi and Park, 2015). Their t-values are greater than acceptable limit of 1.96 (Lowry and Gaskin, 2014), representing coefficient estimates to be reasonable. For TWY, 'stops in taxiway' have the highest standardized factor loading of 0.916, representing greatest describing power. For TMA, 'number of terminals' has the highest standardized factor loading of 0.855, representing greatest describing power. For APRN, 'size of apron' has the highest standardized factor loading of 0.872, representing greatest describing power. For RWY, 'runway configuration' has the highest standardized factor loading of 0.883, representing greatest describing power. For AR_F, 'direct routes' has the highest standardized factor loading of 0.865, representing greatest describing power. For WR_C, ‘wind direction’ has the highest standardized factor loading of 0.888, representing greatest describing power. For ATC, ‘skill of personnel has the highest standardized factor loading of 0.895, representing greatest describing power. For FL_H, ‘storage tanks’ has the highest standardized factor loading of 0.898, representing greatest describing power. For PRFM, ‘Fuel consumption reduction’ has the highest standardized factor loading of 0.840, representing greatest describing power.

4.3. Hypothesis testing using SEM

Path coefficients of SEM shown in Fig. 2 indicate the ranking of impact by infrastructure dimensions. The rankings are in the order ATC ($\beta = 0.480$, $p < 0.001$), AR_F ($\beta = 0.444$, $p < 0.001$), RWY ($\beta = 0.408$, $p < 0.001$), TWY ($\beta = 0.244$, $p < 0.001$), WR_C ($\beta = 0.236$, $p < 0.001$), APRN ($\beta = 0.187$, $p < 0.01$), TMA ($\beta = 0.112$, $p > 0.05$) and FL_H ($\beta = 0.014$, $p > 0.05$). Table 4 shows the path coefficient of ATC, AR_F, RWY, TWY, WR_C are positive as well as significant at a level smaller than 0.001. The path coefficient of APRN is positive as well as significant at a level smaller than 0.01. The path coefficient of TMA and FL_H is positive but non-significant at a level greater than 0.05. Above results represent that if authorities and experts exert their focus majorly towards development and synergy between ATC, AR_F, RWY and TWY respectively, then, a significant amount of reduction in aviation fuel consumption can be achieved. For further benefits, experts can focus on other areas like WR_C, APRN respectively. Investment on TMA and FL_H may produce some positive results, but it may not be as worthy as other parts of aviation infrastructure. In PRFM measure, fuel consumption reduction leads the pack with a value of 0.734 signifying maximum benefit on the reduction of fuel consumption. The increase in revenue was lowest on performance ground. A model proposed by Daniel (2002) can be used to estimate benefits of different parts of airport infrastructure based on traffic pattern changes.

Table 4
Results of SEM analysis.

Hypothesis	SPC	t-value	Results
H1: TWY → PRFM	0.244^{***}	3.630	Supported
H2: TMA → PRFM	0.112	1.746	Not supported
H3: APRN → PRFM	0.187^{**}	2.883	Supported
H4: RWY → PRFM	0.408^{***}	5.881	Supported
H5: AR_F → PRFM	0.444^{***}	6.272	Supported
H6: WR_C → PRFM	0.236^{***}	3.713	Supported
H7: ATC → PRFM	0.480^{***}	6.699	Supported
H8: FL_H → PRFM	0.014	0.217	Not supported

Note: ** denotes $p < 0.01$; *** denotes $p < 0.001$; SPC – Standardized path coefficient.

5. Conclusion and suggestions

The contribution of this study can be listed as follows:

1) The study emphasizes on the importance of aviation infrastructure elements in fuel consumption.
2) The aviation infrastructure literature shows the scarcity of empirical research on the determinants of AFCR performance in the aviation sector. This study examined the viability of the model, and thus, the results of the present research contribute by filling the important gaps, by taking on a theory-based empirical investigation of the determinants of AFCR performance in the context of aviation infrastructure.

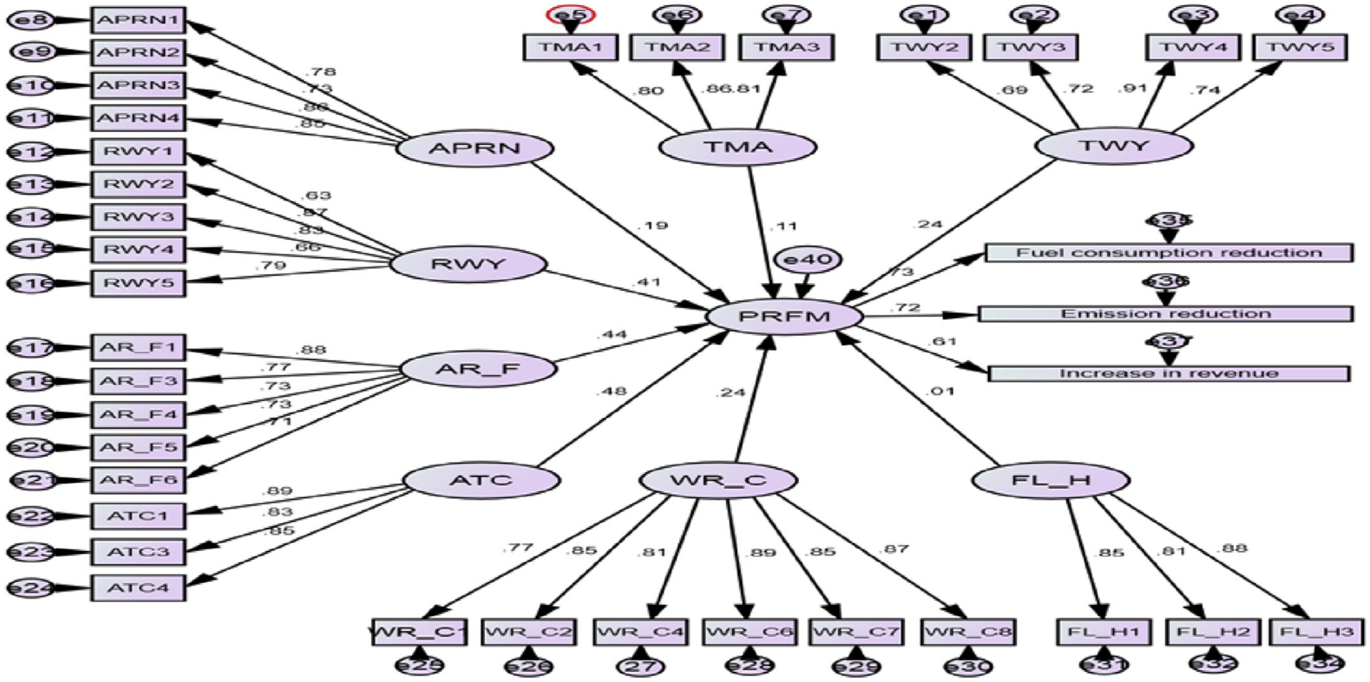


Fig. 2. SEM analysis path coefficients.

3) The understanding of relations between variables can facilitate producing country or situation specific equations.
4) This study yields the results which denote the foundation for the optimal solution of fuel consumption on which future researches can be built.
5) Another contribution of the research on AFCR in the aviation sector is the identification of some important determinants for fuel consumption reduction, emission reduction, and increase revenue.

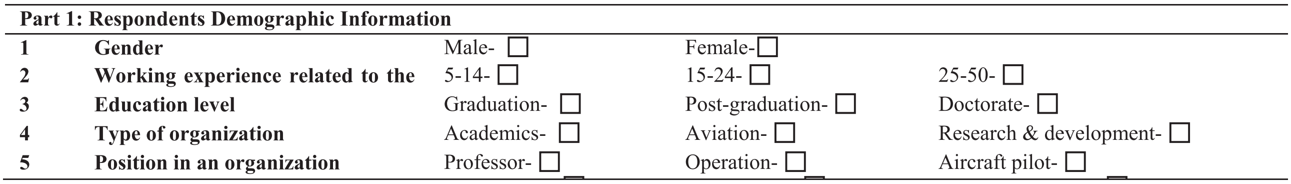
On the basis of above conclusions, some suggestions are provided below for practical management. The significance of the above results should not be considered as the final list. Their performances in real life implication depend on their inter-collaboration and many other external elements. As air traffic control helps controlling airspace routes and delays over aviation infrastructure, but it can't control weather conditions causing forced delays and congestions. Airport design elements like runway, taxiway and apron depend on one another for their operational efficiency. Thus, a decrease in efficiency of one element can affect other elements, though the extent may vary depending on the over elements priority. Terminal areas and fuel handling infrastructure may not be a worthy area to invest. When looking at a perspective of how to proceed with our asset utilization strategy than going with the ranking would be a suitable option. Fundings should be based on their priority and availability. Investments in infrastructure slowly facilitate the release of pressure from the aviation industry. Fuel consumption and emissions will be less in immediate effect by the above measures, but, for gaining profits and revenue on investments, the industry may have to wait a little longer.

Researchers of this field can further work on considering some extra aspects which this study didn't cover such as; this study used non-probabilistic convenience sampling for sending questionnaires. In future studies one can choose probabilistic sampling techniques with much more accurate distributions, to collect a uniform number of respondents as required by study type. As, Person administered survey can be conducted in a place of a self-administered survey. Full data collection by Person administered survey for future studies can increase the response rate, monitor circumstance of responder both social and physical; the complexity of questionnaires can be increased (Clarke and Dawson, 1999; Hair et al., 2006). Sample space considered under this study is below 200 and covers only lower threshold limit, which can be increased to the upper threshold of 10 times for raising the precision of outcomes. The variables that didn't pass through the purification process i.e., TWY1, AR_F2, WR_C3, WR_C5, ATC2 and any other important variable, which this research didn't consider can be added to future studies for broadening the area of research. For industrial application and to extend outcome effectiveness of the above results, one can optimize variables using different optimization tools.

Appendix A. Literature review table.

Factor/Construct	Key variables	References
1) Taxiway (TWY)	Taxing distance, Rapid exits, Number of turns, Number of stops, Taxiway separation	Kazda and Caves (2007); Bradley (2010); Khadilkar and Balakrishnan (2012); Nikoleris et al. (2011); Jiang et al. (2013); Zhou and Jiang (2015)
2) Terminal (TMA)	Size, Numbers, Location	Upham et al. (2003); Schlumberger (2012)
3) Apron (APRN)	MARS centerline, Location, Size, Markings	Bradley (2010); Hamzah and Adisasmita (2015); ACRP (2013)
4) Runway (RWY)	Condition, Configuration, Longitudinal slope, Length, Altitude	Ball et al. (2007); Santos and Antunes (2015); Hamzah and Adisasmita (2015); Balicki et al. (2014)
5) Air routes and flexibility (AR_F)	Direct routes, Redesigning, Rerouting, Traffic density, Conflicts, Sector volume	Sarkar (2012); Pham et al. (2010); Gianazza et al. (2009); Lewis (2013)
6) Weather conditions (WR_C)	Temperature, Icing, Thunderstorm, Snow, Hurricane and Volcanic ash, Wind, Fog, Dust	Yoder (2007); Balicki et al. (2014); Bedard (2003); Zanni and Ryley (2015); Ball et al. (2007); Balicki et al. (2014)
7) Air traffic control (ATC)	ATC skilled personnel, Radar system, Navigational system, VHF radio system	Marks and Rietsema (2014); Roosens (2008); Ball et al. (2007)
8) Fuel handling (FL_H)	Filters, Pumps, Storage tanks	Chauhan et al. (2015); FAA (1974)

Appendix B. Measurement of latent variables



Part 1: Respondents Demographic Information

1	**Gender**	Male- ☐	Female-☐	
2	**Working experience related to the**	5-14- ☐	15-24- ☐	25-50- ☐
3	**Education level**	Graduation- ☐	Post-graduation- ☐	Doctorate- ☐
4	**Type of organization**	Academics- ☐	Aviation- ☐	Research & development- ☐
5	**Position in an organization**	Professor- ☐	Operation- ☐	Aircraft pilot- ☐

Part 2: Survey Questionnaire

Part 2: You are requested to kindly weight these variables on a five point Likert scale for exploring importance rating in fuel consumption reduction of the air transport sector.
Key: (1) Strongly disagree (2) Disagree (3) Neither agree nor disagree (4) Agree (5) Strongly agree

Measuring items	**Strongly disagree → Strongly agree**
Taxiway (TWY)	
TWY1. We decrease taxing distance to reduce fuel consumption.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
TWY2. Inclusion of rapid taxiways significantly reduces congestion.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
TWY3. Decrease in taxiway turns decreases the use of differential thrusts.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
TWY4. Reduction of taxiway stops reduces the use of differential throttle.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
TWY5. We use taxiway separation to minimize conflicts causing congestions.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
Terminal area (TMA)	
TMA1. Larger terminals have swift boarding facilitating aircraft to wait less.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
TMA2. Increase in number of terminal's increase operational capacities of terminals.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
TMA3. We minimize the distance of terminal from other constituents of airport to reduce fuel consumption.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
Apron (APRN)	
APRN1. Multi-aircraft ramping system (MARS) increases apron's operational efficiency.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
APRN2. We minimize the distance of apron from other constituents of airport to reduce fuel consumption.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
APRN3. Larger apron decreases congestion by accommodating more aircraft.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
APRN4. We use apron markings to decrease confusions and increase efficiency.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
Runway (RWY)	
RWY1. We make runway surface smooth & hard to reduce fuel consumption during roll distance.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
RWY2. Airport's with ample area use additional parallel runway to decrease	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
RWY3. We provide runway's with longitudinal slopes to reduce takeoff and landing roll.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
RWY4. We create longer runways to encourage use of larger aircraft causing lesser seat-km per gallon of fuel.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
RWY5. Less altitude runways with dense air have more lift for flight.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
Air routes and flexibility (AR_F)	
AR_F1. We use direct routes to reduce fuel consumption.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
AR_F2. In a planning phase, we choose more efficient routes by redesigning routes.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
AR_F3. While in air, rerouting flights evade congested flight routes.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
AR_F4. We decide whether to switch airspace or not based on sector's traffic	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
AR_F5. Flight change airspace to minimize risk of conflict.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
AR_F6. Airspace configuration is decided by an airspace volume.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
Weather condition (WR_C)	
WR_C1. Increase in ambient temperature decreases turbine engine efficiency.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
WR_C2. Icing increases drag and decreases lift for flights.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
WR_C3. Severe thunderstorm increases delay by messing up with controls.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
WR_C4. Snow blocks ground paths causes delay.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
WR_C5. We choose non fuel optimum routes to avoid severe hurricanes and volcanic ash.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
WR_C6. We prefer optimal wind routes to reduce fuel burn.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
WR_C7. Fog causes delays by disturbing operations and control.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
WR_C8. Dust deposition in cavities and engines decreases thrust.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
Air traffic control (ATC)	
ATC1. Skill of ATC personnel decide how efficient whole system manevourity will be.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
ATC2. Radar system decreases delay by smooth flow of traffic.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
ATC3. Navigational systems help flights to choose more efficient routes.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
ATC4. VHF radio systems increase ease of communication, minimizing delay.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
Fuel handling (FL_H)	
FL_H1. Lack of maintenance of filters causes clogging of turbines, increasing fuel burn.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
FL_H2. Lack of maintenance of pumps increases delay on airports.	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
FL_H3. Preventing contamination of oil in storage tanks reduces fuel quality	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
Combined Performance (PRFM) of all the above variables	
PRFM1. Fuel consumption reduction	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
PRFM2. Emission reduction	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐
PRFM3. Increase in revenue	(1) ☐ (2) ☐ (3) ☐ (4) ☐ (5) ☐

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