Airline Fuel Savings Estimation Based on Segmented Fuel Consumption Profiles

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Abstract. Fuel conservation programs are instruments used by airlines to improve operational efficiency and trim fuel related costs. Identifying fuel savings to accurately manage these programs has always been an issue due to the operation volatility and lack of reliable data. Advanced data management systems were developed to support these programs, but having means to identify fuel savings is still compelling. A new methodology based on segmented fuel consumption profiles is proposed as a tool to accurately identify fuel savings across periods. This approach allows for a detailed fuel consumption analysis with full operation coverage.

Keywords: airlines, fuel efficiency, fuel conservation, fuel consumption profiles

1 Introduction

Airlines today struggle to survive in a highly competitive market, facing high operating costs and being seriously affected by the global economic and financial crisis. Market deregulation and growth of low-cost carriers have since late 90's reinforced the need to improve and follow operational costs and finding means to reduce them. From the airlines' cash operating costs, fuel represents the highest block of direct operating costs, having had a dramatic increase in the latest years [1, 2]. Additionally, fuel prices constant fluctuation represents a challenge to the airlines.

Besides the high fuel costs, there are emerging global environmental concerns to reduce carbon emissions from the aviation industry. Despite the fact that aviation transport system energy intensity continues to decline due to more efficient aircraft, engines and general procedures, air travel continues to experience the fastest growth of all transport modes. Air transport industry was responsible in 2005 for approximately 2.5% of total anthropogenic carbon emissions [3]. However, aviation's relative contribution to climate change is presumably higher due to the fact that the majority of emissions are produced at high altitudes [4]. If no additional fuel efficiency measures are adopted, this contribution may grow up to 15% if this industry keeps the growth pace at around 5% per year.

Due to these environmental concerns and the need to reduce aviation carbon emissions, there were several commitments from different entities to approach the global warming issue and define strategies to reduce carbon footprint. IATA (International Air Transport Association) proposed a four-pillar strategy for carbon neutral growth from 2020 [5]. Despite the fact that today's aircraft are 70% more efficient than first jet-era aircraft [6], Technology, mainly related to aircraft and engine manufacturers new solution developments, as well as biofuels, has the best prospects for reducing aviation carbon emissions. Infrastructure, through improvements on air traffic management and airport infrastructure, is a major opportunity and may provide 4% emission reduction by 2020. A more efficient combination of air traffic management and airline procedures can reduce by 30% the typical descent fuel burn [7]. Economic Measures can prove to be another mechanism that can contribute to reduce aviation carbon emissions. The fourth and last pillar, Efficient Operations, mainly airline's responsibility, is potentially the one that can result in immediate carbon emissions reductions.

Airlines, aiming at mitigating fuel cost and carbon emissions have developed for several years extensive fuel conservation programs with numerous initiatives covering areas as flight and airport operations procedures, aircraft weight reduction or engine and aircraft washing [8]. These initiatives, all together, have already contributed to a general operational efficiency improvement. As some of these initiatives come at cost, it is critical to properly analyze the impact of such implementation. It is also vital to monitor across time the adherence to these initiatives, as well as perform periodic assessments of fuel burn reductions to continuously evaluate program's operational impact. Airlines soon realized that up-to-date, reliable operational data is imperative to complete these tasks.

2 Problem description

Fuel conservation programs developed by airlines typically integrate all key areas of operations that affect fuel usage having as main objectives trimming annual fuel costs and increasing operational efficiency. Many airlines' fuel conservation programs have failed because of the lack of automated data feeding fuel analysis and dashboards to cross-departmental stakeholders [9]. On cross-departmental programs like these it is fundamental to monitor the implemented initiatives' performances, as well as the overall performance.

In terms of fuel conservation, the lack of useful, readily available and reliable recorded data is a crucial issue. The airline operation, highly dependent on procedures and checklists, usually generates large amounts of data that is typically spread out through the departments. Therefore, data availability has always been one of the biggest issues in the fuel conservation programs.

To solve this data availability and quality issues, airlines, such as TAP Portugal, invested substantial effort in developing complex database systems that could concentrate information from different sources, and could provide means to perform smart fuel consumption analysis.

Despite the significant improvements in data availability, historically, the evaluation of fuel savings within the airlines has always been a tough task due to the constant changes in the airline's operation. Airline's operation is highly dynamical not only in terms of operated routes, but also in operated aircraft or aircraft types. Different aircraft within a fleet have different fuel consumption profiles due to distinct aerodynamic and weight characteristics, but also fuel performance degradation. Also, different aircraft operating in different routes have distinct fuel consumption profiles. As the operation constantly changes between periods, one needs to look at various aggregation levels to properly compare the fuel consumption between periods, ensuring that all the flights are being taken into account.

2.1 Fuel Efficiency parameter

To identify airlines' fuel consumption reductions, one needs to compare typical fuel consumption profiles between periods. As there isn't a single fuel efficiency parameter that is suitable to all applications, airlines need to identify the one that best suits its aircraft operations and available data. Aircraft fuel consumption varies significantly with flight time and aircraft performance degradation, but is also influenced by carried weight, en-route winds, flown route profiles or en-route and airport congestion. Generically commercial aviation fuel burn is function of two key factors: aircraft fuel efficiency – which stands for the amount of productivity delivered by the aircraft through the usage of fuel energy and; operational factors – that comprises mass load factors, airline and air traffic control inefficiencies [10]. While this could be translated as Fuel Burned per ASK (Available Seat Kilometer) or Fuel Burned per PKU (Passenger Kilometer Used) for passenger airlines, Fuel Burned per TK (Tonne Kilometer) may be most appropriate to cargo carriers. On aircraft design stage one of the most popular parameters if Fuel Burned per ATK (Available Tonne Kilometer) [11].

However, when the objective, more than representing an efficiency parameter, is to quantify the fuel savings obtained by the initiatives under the fuel conservation program, one needs to identify a variable or set of variables that corrects fuel burn from quantifiable effects that influence fuel consumption and that are not linked with fuel conservation program initiatives. The fuel efficiency parameters above mentioned depend on the great circle distance (GCD) between two airports that is constant throughout time. Therefore the effect of different routes flown by aircraft between two airports is not properly taken into account. To adequately evaluate the fuel savings between periods, instead of using GCD, it is recommended to use flown hours to normalize fuel consumption. Additionally, as a flag carrier's typical operation is not only carrying passengers but also cargo, and as carried weight also plays an important role in the aircraft's fuel consumption, it is necessary to correct fuel burn from differences on carried weight between periods. Therefore, on top of normalizing the fuel consumed by flown hours, one can use the payload variable to additionally correct fuel burn.

In order to adequately compare consumed fuel differences between periods it is required to identify the quantifiable parameters that can be used to define a fuel efficiency profile illustrative of the operation.

2.2 Information architecture

The data analyzed in the fuel consumption analysis has the granularity of a single flight. For every single flight, numerous parameters are recorded and collected, each having its own source. Flight duration can be reported automatically by the aircraft systems or by airport ground handling agents but can be also reported by flight crews in their debriefing procedure. Additional flight information, as carried passengers or payload are reported by crew or ground handling agents in different formats and timings. Fuel figures are logged by the flight crew members in the debriefing procedure. All these figures may be reported by a totally different process when the flights are operated in a wet-lease basis from another operator.

The diversity of data sources available (associated with a multiplicity of processes to obtain the same data) can cause gaps in each individual measure, making that flight unusable (despite the fact that several other measures associated with that same flight can be available). This means that it is understandable and acceptable that the information produced from this data uses a sample size usually above 90%, but away from the complete set.

The operational systems are the core data source, where all processes, being automatic or manual, end up providing values. Some values are critical for the operational system (precise weight estimates are crucial to feed the flight plan generator) and others are just statistical (fuel consumption).

An important part of transforming data into information is related to the building of a standard data warehouse (DW), where data from several sources is collected and made available as a single record, like schematically described in Fig. 1.

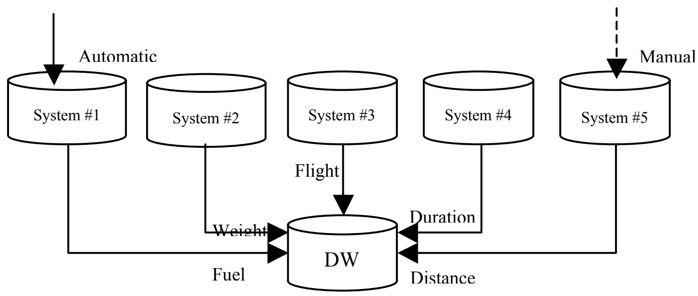

Fig. 1. Data flow, from users and systems to corporative data warehouse

The diversity of processes also implies that information will be produced based on data with different quality levels. Automatic processes are usually more reliable than manual ones, since manually recording (in a paper document) and further reading might more likely lead to insertion errors (when no feedback is given to the user about the correctness of the value) or interpretation errors (namely calligraphy issues or unclear values). Data quality can be checked while loading data into the DW, searching physically impossible values, or values that fail expected correlations between several measures (for instance, fuel consumption per flown hour on a single flight should be coherent with the used aircraft average value). These checks can lead to two distinct consequences: the identification of flights that need to be further examined, or identified as having "no good" information that are rejected on the analysis process.

The data quality process should mainly focus on the data input processes of the operational systems, both in manual and automated scenarios. This continuous evolution, involves migrating manual processes into automatic ones, providing users immediate feedback on entered values, creating simple boundaries for data input and providing systems or forms that are clear and less error prone.

These systems continuous improvement is mandatory to proficiently analyze fuel consumption, identify improvements on fuel savings and pinpoint areas that require additional work.

3 Fuel savings model

As previously stated, quantifying fuel savings within airline's operations has historically been a demanding task, not only due to the dynamic airlines' operations, but also to the lack of required data, both in quantity and quality. While this latter hurdle has been addressed by investments in capable information systems, the comparison of operation and fuel consumption profiles still represents a challenge. The proposed solution attempts to minimize the potentially misleading effects of computing fuel savings between two periods that have distinct sets of flights.

The proposed model is based on the identification of fuel consumption profiles that are representative of consumed fuel in distinct periods. These period-characteristic profiles are the basis to recognize equivalent fuel consumption amongst periods. When pinpointing the fuel savings for a period compared with a reference, pre-computed reference period profiles are used to extrapolate what would be the fuel consumption if the operational reference period characteristics would still rule.

In a nutshell, the solution explores the process described here briefly. **Error! Reference source not found.** provides an example of operation data, for two consecutive years. The different values obtained in the variation of each parameters shows distinct change rates, meaning that changes from one year to the other are not linear.

Table 1. Basic example data, set with two years for comparison

Year	# Flights	Distance Flown (km)	Avg Flight Distance (km)	Fuel Burned (ton)	Fuel Burned per Distance (kg/km)
N – 1	100	350,000	3,500	1,100	3.14
N	150	585,000	3,900	1,500	2.56
Variation(%)	*+50%*	*+67%*	*+11%*	*+36%*	*-18%*

In a simplified approach, as an example, if the fuel profile function is defined as fuel burned per distance, it would produce the values presented in the last column of **Error! Reference source not found.**. When the year N fuel profile is applied to the Year N flown miles, as expected, the result is 1,500 ton. If the year N – 1 fuel profile is applied to the Year N operation flown miles, the value 1,838.5 ton is obtained. This value can be read as the Year N fuel consumption, if the consumption profile had not change from year N – 1. The delta between both values (+338.5 Kg) represents the additionally spent fuel from one year to the other. This methodology enables the comparison of equivalent fuel consumption profiles characteristic of different periods and by using this, allows the identification of differences in fuel efficiency. This example tries to set the path for the two major improvements that this process can benefit from:

- **Fuel Profile Function** – In the example, the distance was used, but other flight information can be used to define a profiling function that reflects the fuel consumption behavior in the compared periods.
- **Flight Segmentation –** In the example, an overall profile was used, applied to both periods. But knowing for instance, that long haul flights have different fuel consumption behavior when compared with medium haul flights, can lead to flight segmentation, originating two segments with distinct fuel profile functions.

The fuel consumption calculation using the generated fuel profile functions is a two-step process: firstly identify for each flight the applicable segment and fuel profile function for the considered periods; secondly, with flight information as flight time, carried weight, aircraft performance, compute fuel consumptions for each period using the applicable fuel profile functions. The difference between the extrapolated reference period fuel consumption and the actual period calculated fuel consumption represents the amount saved or additionally burned compared to the reference period. A schematic representation of the process is found on Figure 2.

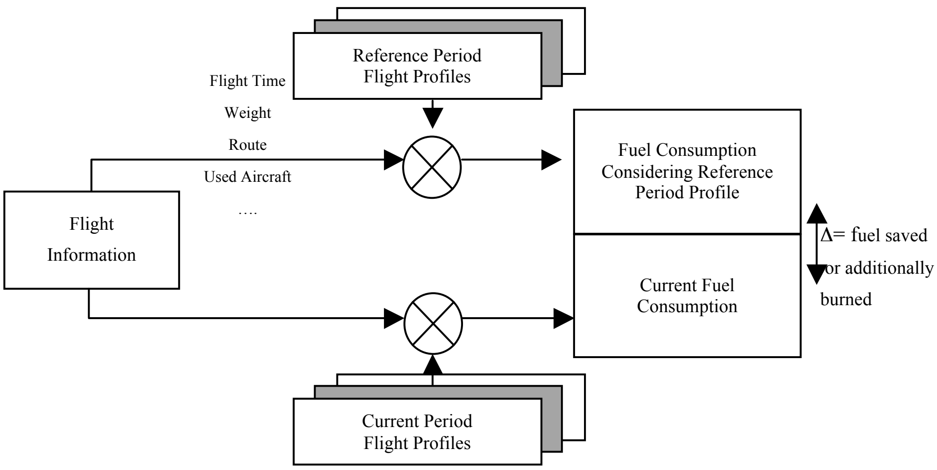

Fig. 2. Fuel savings calculation process

3.1 Fuel Profile Function

Flight fuel consumption varies with the aircraft used, but also depends on physical variables like flight duration, carried weight, wind speed and direction, and other daily features like weather, used routes and both airport and en-route congestion. Although all these variables have an impact on the aircraft fuel consumption, their contribution to the final figures is different. Flight duration, for instance, has a much larger contribution than aircraft performance. On top of this there are variables that are harder to estimate and to quantify their impact on fuel consumption.

In order to properly evaluate the fuel consumption savings, it is mandatory to identify a fuel efficiency parameter that can best represent the operation. The selection of variables used in this parameter should be the ones that have larger impact on fuel consumption and have available data.

Considering the profile function as the ratio between fuel consumed on a flight and a variable, or a set of variables, the accuracy of several different considered alternatives is presented on Table 2. In this table the absolute error is the difference between the real fuel consumption and the estimated fuel consumption, calculated on a flight-by-flight basis, using the calculated fuel profile functions.

Table 2. Average absolute error using several possible parameters

Variables Used	**% Absolute Error (Average Flight Fuel)**
Carried Weight	22.34%
Airport Distance	7.17%
Flown Hours	5.47%
Flown Hours × Carried Weight	3.49%
Flown Hours × Carried Weight × Aircraft Performance	3.35%

As expected, when considering using one variable profile function, the smallest error is obtained when using flown hours, since it is the parameter with larger impact on fuel consumption. The combination of flown hours and carried weight reduces further the error, as the weight also has also a significant impact on fuel consumption. On top of this, when considering aircraft performance, the error is minimized, as the actual aircraft and engine performance is taken into account.

When quality data is available, the selected fuel profile function should be the one that provides the minimum error in estimating aircraft fuel consumption. Although the model is flexible to use these, or any other parameters, as on the current model there is reliable data available to calculate the fuel burned per flown hours per carried weight per aircraft performance, this will be the fuel profile function used since it is the one with minimum error. This fuel profile function will be then computed for each considered flight segments representative of the period's operation.

Flight Segmentation

The amount of segments to be used is a difficult decision. When the number of segments used is increased, the profile calculation quality is also enhanced, as it describes a more specific type of flights. On the other hand, a higher number of segments mean a smaller sample of flights used for each profile calculation, leading to a greater impact caused by outlier flights. Table 3 provides a comparative analysis for several segmentation approaches taking into consideration one year of operation.

Table 3. Comparative analysis of flight segmentation

	All	**Haul**	**Model**	**Aircraft**	**Model Route**	**Aircraft Route**	**Aircraft Route Quarter**
# Segments	1	2	12	90	900	6,000	17,000
# Elements /Segments	100,000	53,000	9,000	1,200	120	20	6
Outlier Weight	3%	3.6%	3.9%	4.1%	4.7%	4.9%	6.3%

On segments with a lower sample size, outlier's weight can be more misleading, so defining a minimum required sample size can help to exclude segments that may cause distortion on the final figures. On the current model a minimum of 10 elements per segment is required.

One of the biggest issues concerning this subject is the fact that there are many variables, as aircraft or routes changing from one period to another. When lower aggregation levels are used, finding common segments in the analyzed period can be challenging. For instance, when an aircraft-route aggregation level is selected, if a route is operated in one period, but not on the other, a comparison at the same level is not feasible. In such circumstance a higher aggregation level that enables a comparison between the two periods must be used. Table 4 provides a comparative analysis of the flight coverage rate between two distinct periods. For example, when using a model segmentation approach, a flight is considered uncovered when the aircraft model used in one period was not operated in the other one.

Table 4. Flight segmentation comparative coverage rate

	All	**Haul**	**Model**	**Aircraft**	**Model Route**	**Aircraft Route**	**Aircraft Route Quarter**
Profile Coverage	100%	100%	99.7%	97%	93%	89%	85%

Since the solution should provide a comparison between all the operated flights (and not only the ones that share a similar profile with the reference period being used), an extra qualifying step is needed on the segment selection. This extra step requires the computation of more profiles, not only on the considered detail level, but also on upper aggregation levels. This way, when a profile is missing on a more detailed level, a less detailed profile can be used to ensure that all the flights are covered, like shown on Figure 3.

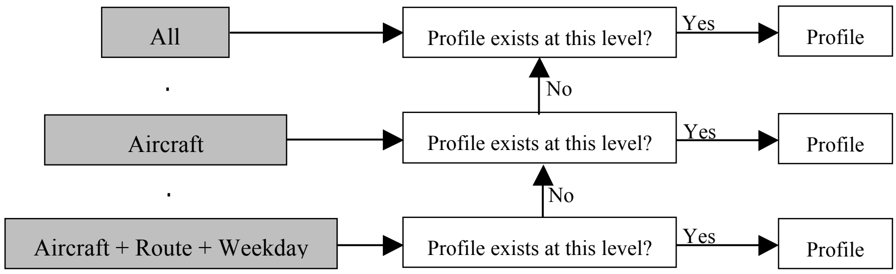

Fig. 3. Flowchart for profile match

On the current model, the lowest segmentation used is obtained by splitting the set of flights by aircraft and route.

4 Information Analysis and Visualization

One of the main purposes of this fuel savings calculation method is to be able to calculate fuel savings on a per-flight basis. This means that, at the bottom line, it is possible to identify how much fuel would have been consumed on the same flight if reference period's conditions were still valid, being the difference between actual and estimated reference period values, the amount of fuel saved or additionally burned. Having information at this level, provides the ability to give a greater insight on how, when and why fuel consumption changes are happening. Table shows some of the potential analysis that can be performed from the generated information.

Table 5. Possible analysis for data visualization

Aircraft	• Changes in airline fleet configuration • Aircraft / engine performance degradation
Route	• Changes in airline network configuration • Flight planning routing (planned and flown) • En-route and airport congestion
Calendar	• Low season / High season operation • Operational fuel saving measures (before and after) • Operational unexpected events (namely, weather condition, volcanic eruption, strikes)

5 Conclusions and Future Work

Quantifying fuel savings has been a challenge that airlines face as they seek new ways to improve fuel efficiency. The proposed methodology ensures that an adequate comparison between periods is achievable through the usage of a multi-stage aggregation levels approach. Defining a suitable fuel efficiency profile varies from airline to airline and greatly depends on the available data. This methodology provides total flexibility on the fuel efficiency profiles used as well as the aggregation levels considered in the calculation. Obtained results demonstrate that full coverage of operation is feasible, allowing a complete fuel efficiency comparison across periods with distinct operation. The generation of fuel savings data on an aircraft, or aircraft-route basis provides a step change in the typical fuel savings analysis, giving room to identifying trends and spotting changes in the airline's operations.

The described solution is generic enough to be easily adapted to other domains where the problem of comparing performance needs to be calculated over changing operational scenarios.

The solution is sensible to data volume and quality. As described, when segmentation goes to a more detailed level the average size of each of the segments drops, making outlier records more relevant in the profile function definition, causing larger deviations. All the improvements that benefit data quality will also benefit the quality of the fuel savings estimates.

A systematic and reusable analysis process still needs to be defined over the obtained set of information, in order to increase the visibility of emerging problems and provide correct savings for specific measures decided by the company.

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