Cost Efficiency Model for Civil Transport Aviation referring to Operations

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ABSTRACT

The air transport system is the global network of commercial aircraft operators, airports, air navigation service providers, manufacturers of aircrafts and their components, airline operators, ground and flight services, infrastructures. It is responsible for connecting the global economy, providing millions of jobs and making modern quality of life possible, thus strongly supporting the world's gross domestic product (GDP).
The costs of operating such a complex network are a major concern for all the identified stakeholders. Furthermore each of them has a specific paradigm and related control mechanisms to handle cost efficiency issues. They all concur to determine the performance of the overall transport system and improving cost efficiency (linked to competitiveness) requires a deep analysis along all the system life cycle from feasibility to disposal.
One of the highly ambitious goals identified and formalized by the European Commission in "The European Aviation Vision 2050" is the "cost effective transport chains" [44]. The adoption of a rigorous cost efficiency methodology based on analytic/statistical formulation is mandatory. Such approach is the only way suitable to assure the effectiveness of the generic technology innovation on the aviation sector as well as for any other industrial one.
Due to the experience matured within CAPPADOCIA, a coordination support action, funded by EC, devoted to identify gaps and bottlenecks affecting cost efficiency improvement in ATS towards Flightpath 2050 goals, an analytic model has been recognized as a useful tool. Such a framework supports the analytical evaluation of the benefits due to the adoption of new technologies, processes or methods in some specific domains of the ATS life cycle (e.g. airframe and avionics, ATM systems, ground systems, design, production, maintenance, etc).
This paper describes the framework, the assumptions and the considerations derived on a case study.

KEYWORDS: *Cost Efficiency, Civil Transport, Aviation, Operation, Global Network.*

NOMENCLATURE

A3	Aegean Airlines	CL	Lufthansa Cityline
AA	Australasia	DF	Degree of freedom
AC	Air Canada	EN	Air Dolomiti
AC	Aircraft	ET	Ethiopian Airlines
Adj	Adjusted	EU	Europe
ATS	Air Transport System	EW	Empty weight
A&ME	Africa and Middle East	FC	Fuel Capacity
CA	Air China	GDP	Gross Domestic Product

IATA International Air Transport Association
ICAO International Civil Aviation Organization
JP Adria Airways
LH Lufthansa
LX SWISS
MTOW Max take-off weight
MLW Max landing weight
MRO Maintenance, Repair and Overhaul
NA North America
Nb Number
NH All Nippon Airways
NZ Air New Zealand
OEW Operating empty weight
OU Croatia Airlines
Ref. Reference
SA South America
SN Brussels Airlines
SQ Singapore Airlines
SS Sum of Squares
TG Thai Airways International
TP TAP Portugal
UA United Airlines

THE APPROACHED PROBLEM AND PURPOSE OF THE PAPER

Being competitive in the global market is a "must" that every stakeholder in the aeronautics domain pursues. One of the mean to reach this goal is cost efficiency that has become a major issue for all the value chain actors: from airliners and airports to aircraft manufacturers passing through designers and supplier integrators and MRO stakeholders.
It is not by chance in fact that also ACARE (Advisory Council for Aeronautics Research in Europe) has addressed cost efficiency in its Strategic Research Agenda (SRA 2), that has become a guide for future public and private funding programmes. In its future views of the ATS, ACARE has identified five "High Level Target Concepts" (HLTC) addressing different aspects to create pools of technology for deployment to whichever future scenario actually develops. One of these HLTC is "**the highly cost efficient air transport system**" that focuses upon all of the costs that arise in the whole air system design and operation.
These considerations clarify that handling cost efficiency is an issue for which all the aeronautics stakeholders need solutions.
Over the last decades, civil aviation has deeply increased its service volumes due to rapid technological change resulting in a decrease in costs and prices, nevertheless airlines have experienced a low profit in general. The deregulation process of markets and growth of competition have increased capacity causing lower rates, even with its rising costs. Therefore, for airlines the approach to face with price decreasing is to start reducing costs.
Considering all the components of the total cost function, it is challenging to identify the influence of each component on total cost. So it is strategic to analyze such impact [47], though it is a complex matter. The effectiveness of reduction of each item that composes the total cost of airline can change over time, depending on both the business model as well as external factors.
The proposed framework is based on an empirical approach. Starting from public data and using statistical approaches, it identifies the analytic regression laws suitable to estimate the operative cost reduction due a change in the ATS system life cycle. Using specific functions, the proposed framework processes a large amount of data representing the typical aviation life cycle parameters related to costs. Table 1 resumes the input data grouped according to the highlighted categories:

Table 1: Input Data

Costs	Fleet	Traffic	A/C Model	A/C Perform.	Charact. Weights
Fuel consumption	Airlines	Number of flights	Airliner type	Cruise speed	MTOW
Raw material	Number of airliners	Operated airports	Wake class	Climb and descent ratio	MLW
Supplies	Airliner category	Passenger capacity	Seating capacity	Flight range	OEW
Purchased merchandise	Internal seat layout	Passenger load factor	Propulsion system	Specific fuel consumption	EW
Maintenance		Transport capacity	Installed power		Fuel Capac.

STATE OF THE ART

In literature there are few recent studies focused on efficiency analysis of European airlines as most of the related work use data collected before 2000. In general, a function cost is derived thorough the use of different estimation methods (parametric, nonparametric...) and input data. The optimum for this estimation is to have input prices of airlines, which are not usually available [48], [49]. The adopted approach in case of lack of prices data is to estimate technical efficiency based on input and output data, which are easier to access [50].
Another possible approach to derive the most important parameters influencing costs is described in [51]. In this method of decision support AHP (Analytic Hierarchy Process), the weights of the factors were determined through questionnaires sent to experts in the aviation field.
In [52] they measure efficiency and productivity decomposition in European airlines using panel data methods, building on time varying inefficiency specific to each airline and performing an econometric estimation of an airline total cost function. It is a function form for the long run cost function using panel data methods.
The proposed approach will use a mixture of factors, in terms of input data organized in different categories. They represent panel data synchronously ordered to determine co-variances among them and able to support cost reduction decisions.

CONTRIBUTION OF THE AUTHORS

Rational Assumptions

This paragraph describes the framework and the relative assumptions based on a case study. The characterization of the operating costs have been carried starting from the public info provided by LH describing their activities and the associated periodic financial results.
The proposed approach is devoted to build an empirical model able to evaluate the accomplishable benefits due to technological or operative innovations. It identifies the driver parameters affecting costs and derives the regression laws which in the most part of the cases are dimensionless. It does not analyze the financial aspects of the airlines from the economic stakeholder point of view.

In order to prepare the data for the statistical analysis, all the values relevant to the effects of interest vs adopted parameters have been collected, assuming the adopted parameters as "independent" in the early phase and relevant to the same conditions. In case of correlation between parameters, the data set is reduced. The adopted statistical tools belong to the toolbox "6σ" methodologies. Obviously, different elements of the operating cost are linked between them. The sketch below (Figure 1) shows in an easy graphical way the operating cost structure.

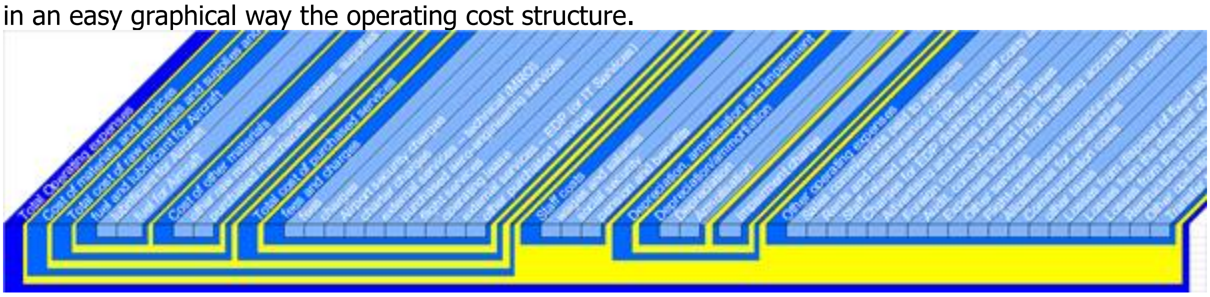

Figure 1: Graphic scheme of the operating cost structure

The reference values of the operating expenses have been retrieved from the periodic financial reports. These reports are yearly published and describe the status typically at December 31st. It is clear that the number of operating conditions is too low for statistical purposes, if compared to the large number of involved parameters. Consequently, it has been preferred a monthly time step with one observation period from December 31st, 1999 up to December 31st, 2016. In this way, the number of different events is equal to 204 at least for one single airlines. The monthly costs value has been calculated by means of linear regression laws starting from the yearly ones. The choice of the monthly time step is also due to the traffic description provided with such periodicity [2].
The framework target is to identify the strongest parameters able to affect the cost-efficiency w.r.t. target values, using the most suitable key performance indicators and specific statistical tools. This

model also allows to perform forecasts at a generic reference year and at a given confident level because it is strongly linked to public official data. The official data have been modified in dimensionless form adopting a common reference value (e.g. relevant to the start date: December 31st, 1999). The adopted time abscissa, which univocally describes the sequence of air traffic conditions, is:

Time = Year + Month/12 (Year = 1999 – 2016 and Month= 1, 2, .., 12)

The next sketch shows the total operating costs trend vs Year in dimensionless form setting the value 100[%] at year 2000. Analytically, the formulation is:

Cost [%] = 100 * Cost (Year) / Cost (Year=2000)

Figure 2 shows the staff costs variation, as well as its contribution terms, assuming it is equal to 100, in percentage, at year 2000. Obviously, a similar description is available for the other costs and with the same detail.

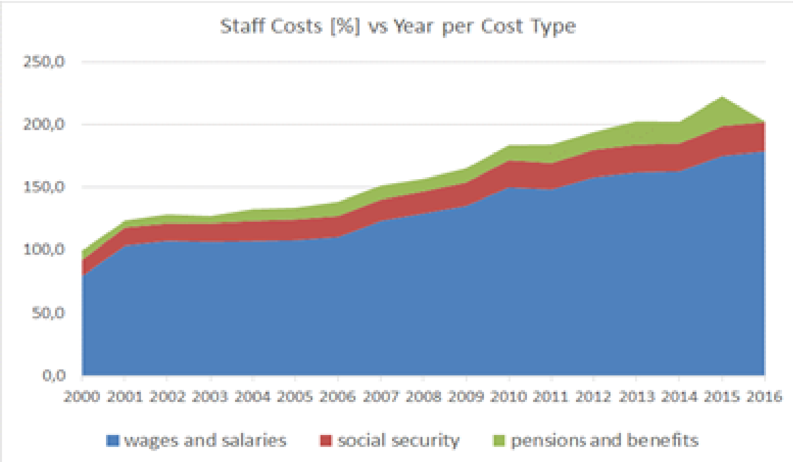

Figure 2: Staff Cost [%] vs Year per Cost Item

Another valuable info source is the monthly reporting of the performed flights. These reports describe in a very detailed way the airline monthly performance in terms of: passenger load factor [%], number of passengers [Kpeople], available seat*kilometre (in millions), revenue seat-kilometre (in millions) and the ration of the last two.

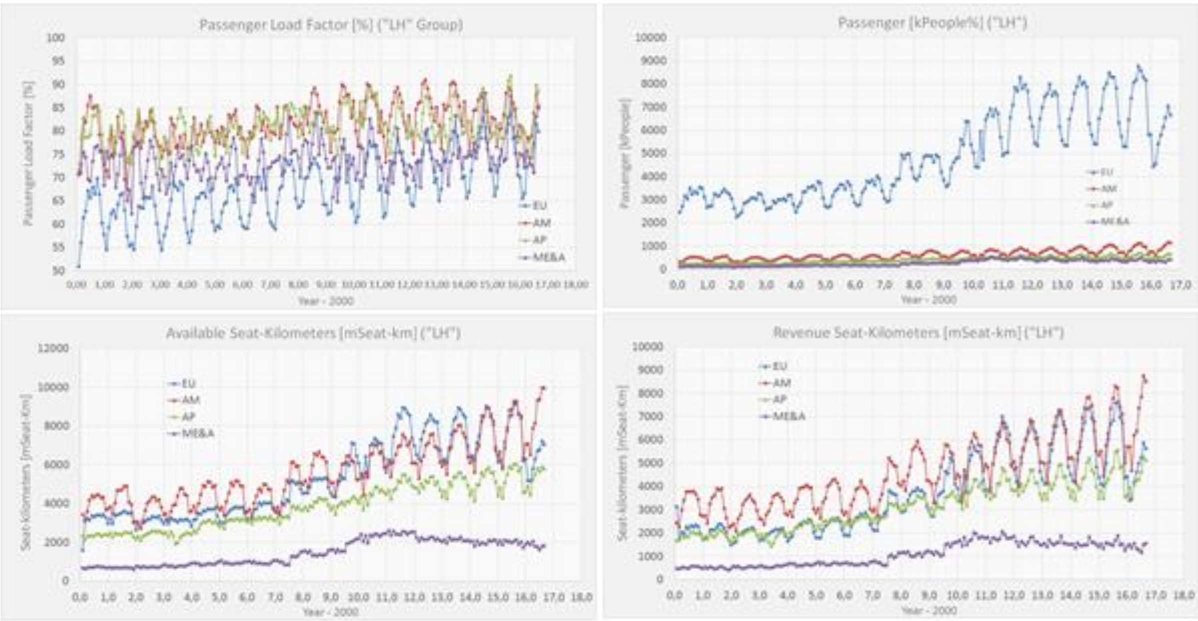

Figure 3: Monthly Operative State

The previous data show the fleet capacity and its effective utilization in the different world regions. Consequently, it is mandatory to include other source data to link the previous performance to the effective fleet composition (see Figure 4) and the performances of each airliner model.

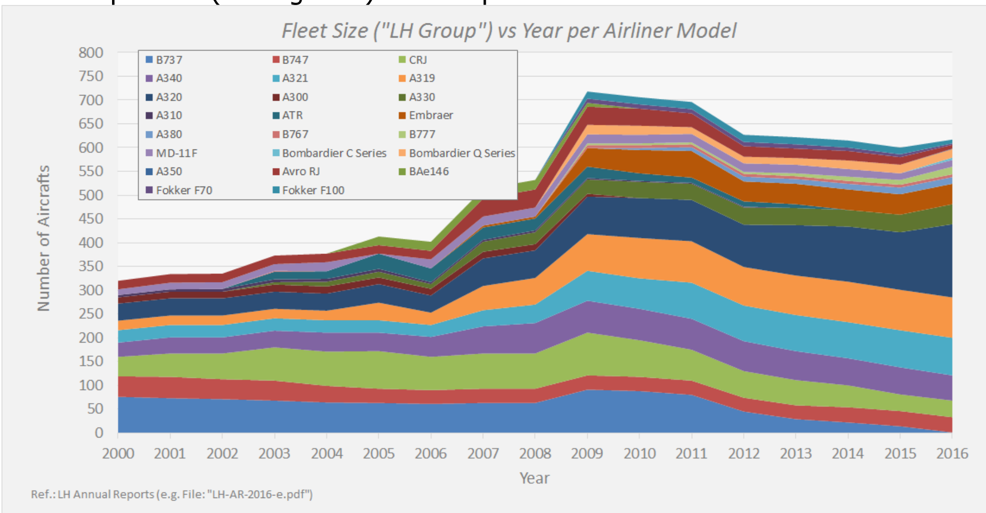

Figure 4: Fleet Size ("LH Group") vs Year per Airliner Model

The LH' timetable form provides for each planned flight an elementary data set including: the origin and destination cities, the associated UTC, departure and arrival airports with the associated code, the days of service, the departure and arrival times, flight number, airliner type and the involved partner carriers (#27). In particular, for each departure airport, the timetable provides a list of planned flights, identified by means of an assigned code. A detailed description may be retrieved from any LH' timetable (e.g. [01]) in its original version.
This database provides a detailed description of the air transport network, for a generic week during the timetable validity period. It is worth noting that the described airline traffic is the scheduled one, it does not see any delays or traffic variations due to force majeure.

The next pie chart shows the flight share vs carrier type (operator or partner). The values appear quite similar and close to fifty-fifty percent.

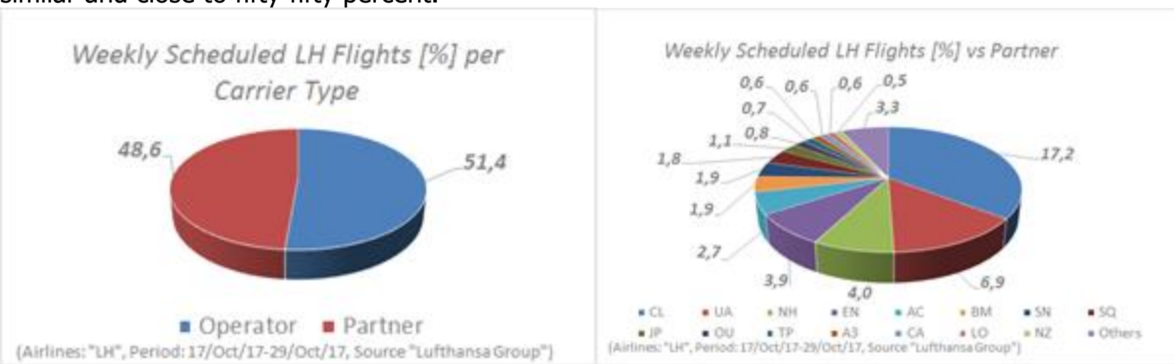

Figure 5: Weekly Scheduled LH and Partner Flights [%]

The total number of airports operated by LH and partners is equal to 252, in the referred period, and they are spread out through the world regions how show in Figure 6. The flight network connects the set of specified airports by means of 1044 distinct routes, labelled using the departure and arrive airport codes (e.g. FRA-MST is the label to identify the route from "Frankfurt" to "Amsterdam").

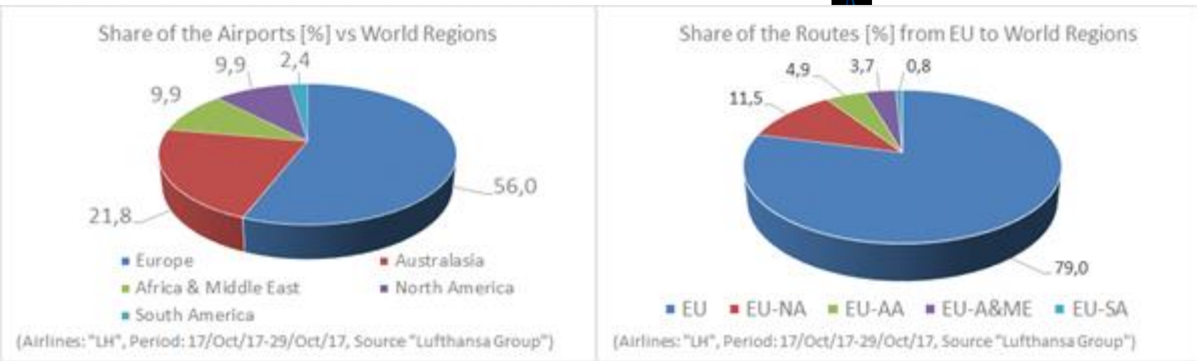

Figure 6: Operated Airports and Flight routes of the LH operator [%] vs World Area

The adopted distance is the minimum distance along the geodetic maximum circle joining the departure and destination airports. These distances have been calculated using an ellipsoidal formulation. So, the calculated distances show discrepancies w.r.t. the same measures made with the ruler in "Google Earth" tool also per intercontinental distances on any couple of latitude or longitude values.
The total number of flights (LH+Partners), from the European airports, is equal to 10821 and their destination airports are spread out through the world regions how showed below as well as for the flights from Australasia (#1137).

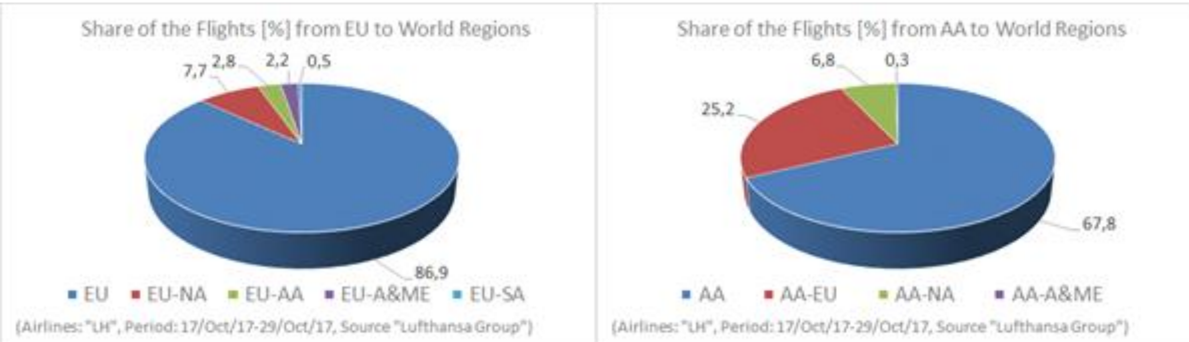

Figure 7: Operated Airports and Flight routes of the LH operators [%] vs World Area

Another aspect to consider is the local level of air traffic, on a specific airport or in given region (e.g. lander or arrondissement). A description of this kind of air traffic is mandatory to set up with adequate detail the daily operations and the associated ground service costs.
The next pie chart shows the movements (departures) vs European Countries.

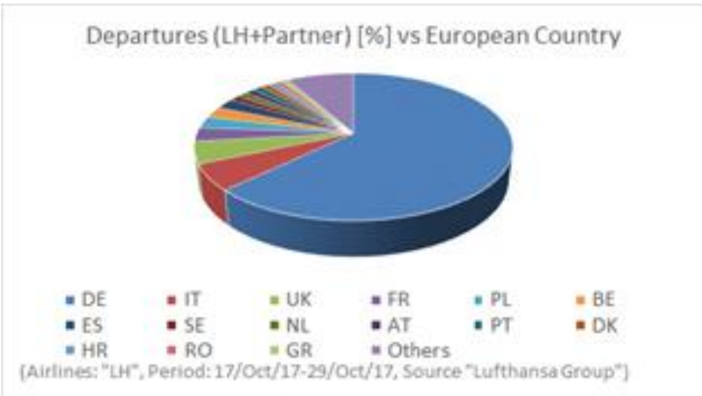

Figure 8: Departures (LH+Partners) [%] vs European Country

The previous data have been complemented with the information about the airliner models involved in the identified routes and the associated share per manufacturer. The sketch below shows, for instance, the flight rate per OEM in the reference period.

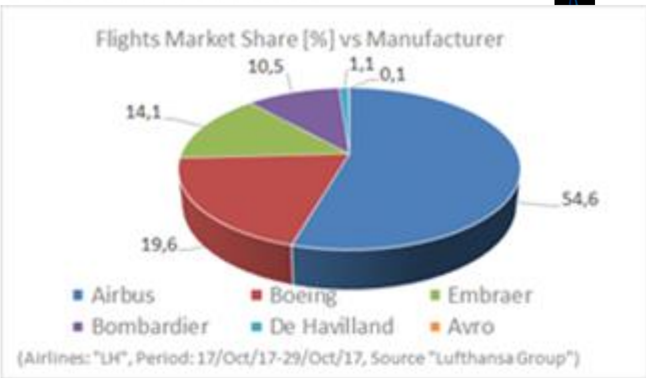

Figure 9: Share of the flights [%] per Manufacturer

By this way the LH's flight share w.r.t. its airliner models has also been characterised. The next two pie charts show the number of flights per model of the two major manufacturer providers: Airbus and Boeing.

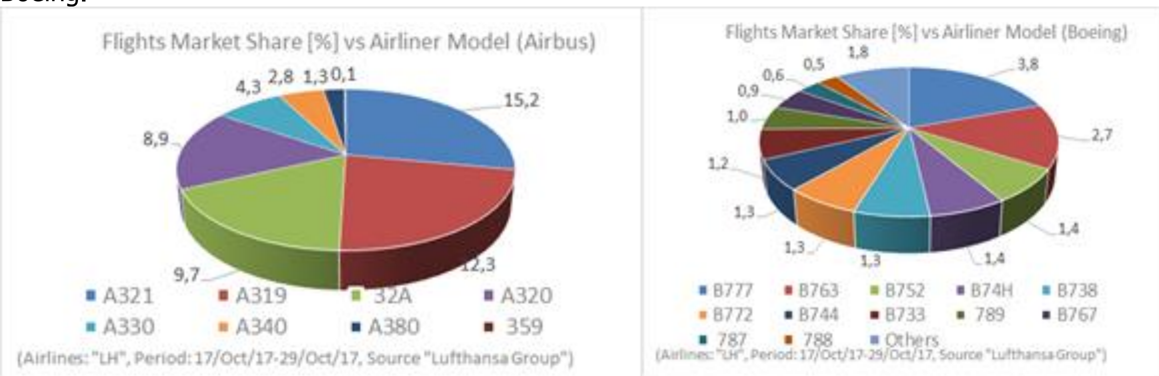

Figure 10: Flight Share [%] vs Airliner

This empirical description has allowed to derive the regression laws existing between the number of flights and the different independent parameters that are: operator, partners, operated airports, used routes, their geopolitical locations (NUTS, Country, World region), used airliners, manufacturers, etc. In other words, all air traffic components have been identified at any node of the transport network in aggregated or non-aggregated form with the identification of the main actors involved.

The same considerations are applicable to other traffic parameters: passenger capability (airliner configuration, number of seats), flown distances as well as "Seat*kilometers". It's worth noting that all the data retrieved from the timetables are related to a scheduled scenario, so they could not describe the real number of further transported passengers.

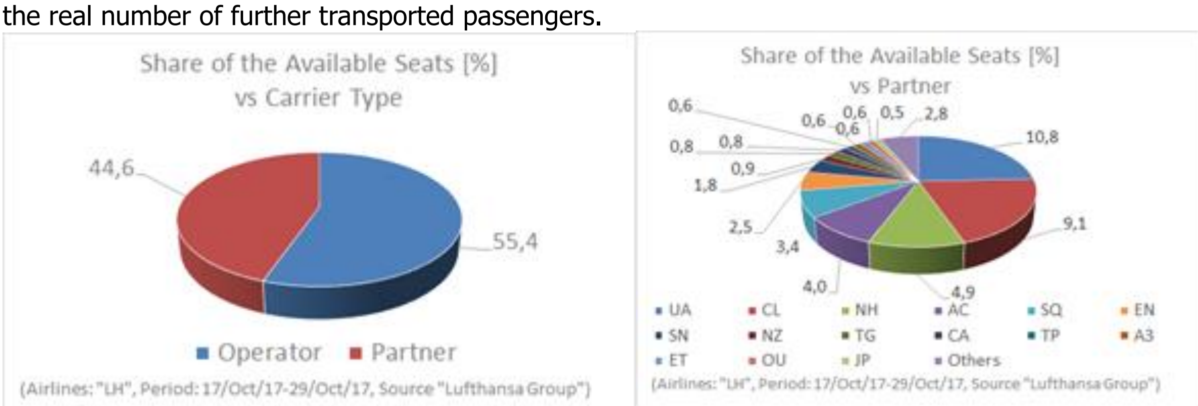

Figure 11: Weekly Available Seats [%] per Carrier Type and per each Partner

It is clear that the integrated set of data collecting the annual and monthly traffic results and the scheduled flights completes the full palette of colors suitable to paint the traffic panorama including its evolution vs time. The graph below shows the variation of the personnel composition vs month, while the pie chart shows the detail at year 2000.

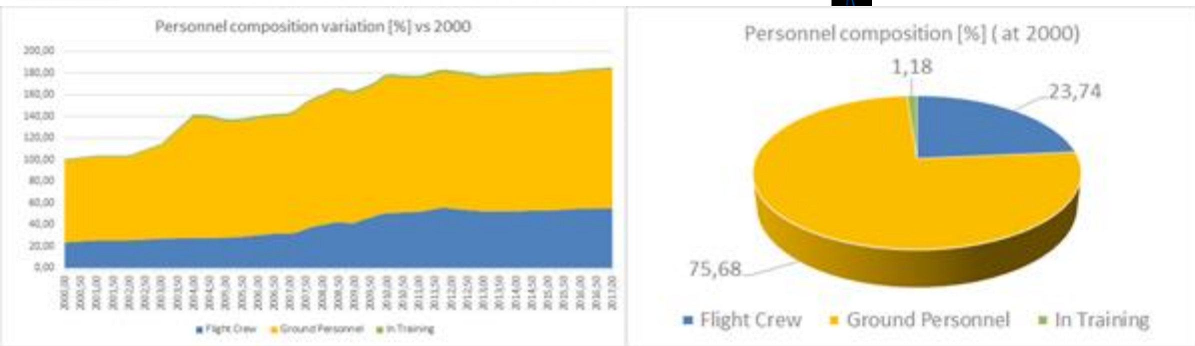

Figure 12: Personnel Composition [%] vs Month and detail at 2000

The geo-politic location of most of the airports have been performed by means of "Google Earth" as well as the route distances. The name of the departure city is linked to the associated airport code and time zone and provides the destination city and the scheduled flights by means of simple sub-roots. Obviously, the destination city includes the airport code and its relevant time zone.

The flights are listed according to the departure hour and a codified alphanumeric string, referring to the operated days. These data fully describe all the flights scheduled by the operator weekly.

Taken into account that one of the most relevant item associated to the flight activity is strictly related to the distance existing between the two airports, the route has been adopted as first driver parameter.

The number of flights between the two airports has been calculated taken into account the listed flights and their week frequency. All flights between couples of airports of the same country, in Europe, are named "National", if one of the airport is located outside, the flight will be named "International" and all flight between airports internal to US will be defined "Domestic".

Statistical Analysis & Results

The aim of the proposed approach is to verify the existence of regression laws between the various parameters described by homogenized values and to weight the related parameter "relevance" by statistics. Time has been assumed as independent parameter because it is fundamental to describe the correspondence of the different values through the covariant parameters. In other words, it assures a common event reference frame for all parameters.

The preliminary actions have been devoted to identify the operative costs structure, which is homogeneously close to the stakeholder assumptions. All costs values have been modified in dimensionless values, using the associated total value at the year 2000.

For instance, in case of the "Staff costs", composed by "Wages and salaries", "Social security" and "Pension and benefits" ([1] - [17]), all values of the previous items have been modified in following way (e.g.): Var19 [%] = 100 * "Wages and salaries cost" / "Staff costs" (Year=2000), similarly for all addends including the totals. It is important to clarify that the monthly costs have been estimated by means of a linear interpolation starting from the yearly values. In other words, the cost rate has been assumed constant in each year.

The primary parameter adopted is the observed passenger request, in kilo-people, (var75) vs year (var69); this data has been considered as the starting one. The residual plots, referring to the best-fitted regression law, show an evident periodic variation of their values.

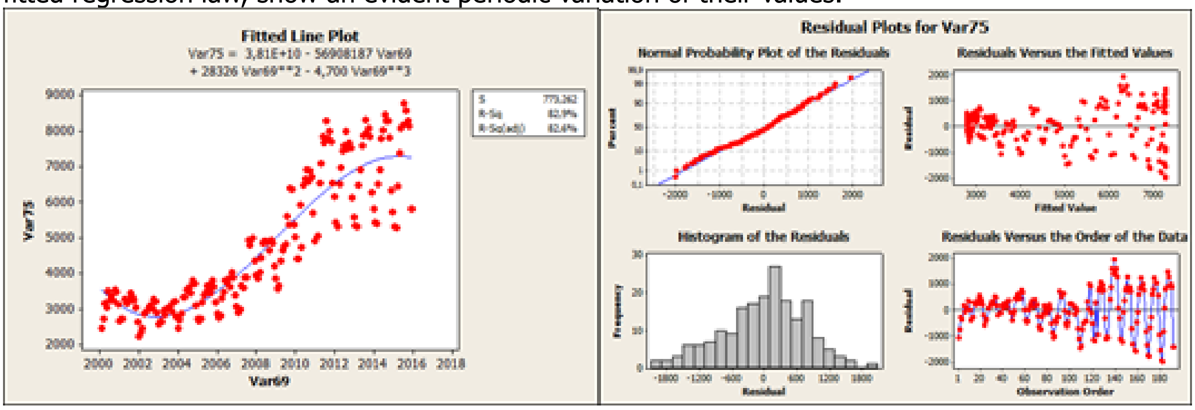

Figure 13: Fitted line plot of the Number of Passengers and related residuals.

Most of the observed residuals appear related to "month" (var68), consequently they are not only due to randomize effects but also to seasonal variation of the passengers request (see Figure 14).

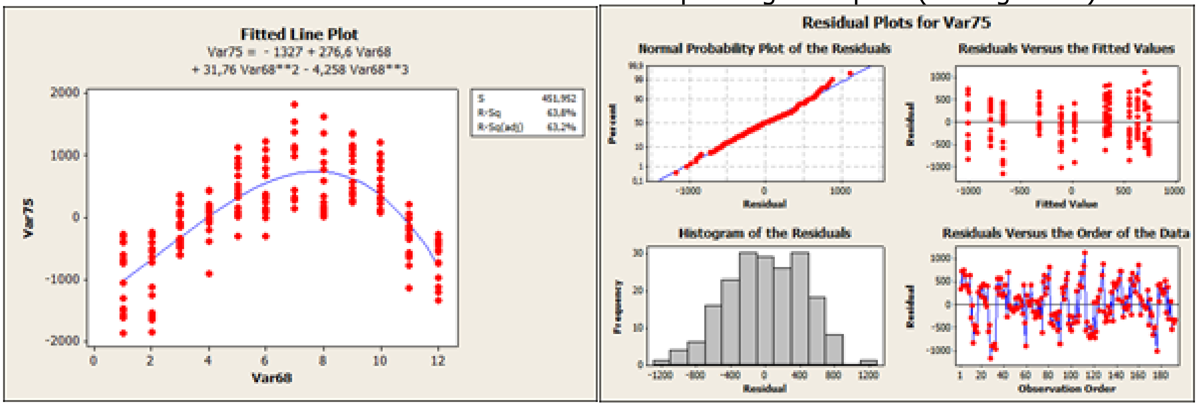

Figure 14: Variation of the Number of Passengers Discrepancies and related residuals.

The plot var75 vs var60 (Figure 15) shows that a polynomial fitted line of 3rd order, on all month range, is able to describe the observed trend, but it is better to make different best fits w.r.t. distinct portions of the month range.
The last residual plot, lower left, still shows the presence of variations. A capability analysis have been performed to verify and identify the possible covariance referring to other variables. Therefore, an analysis has been performed using ANOVA (**AN**alysis **O**f **VA**riance) method. A basic technical description of this methodology may be found in [45] and [46]. The commercial "Minitab" tool has been used to perform the identification of the driver parameters and to verify how these values vary w.r.t. their means.
The last residual variation vs its mean value has been compared to the similar variations observed referring to the parameters: Month, Number of Aircrafts and Time.
Analysis of Variance of the residual of "Var75", using Adjusted Square Sum for Tests, provides the following:

Source Model	DF	Reduced DF	Seq. Sum of Squares
Var68	11	11	72025273
AC_Nb	139	135+	28274770
Var60	191	22+	3293282
Error	-150	23	2343758
Total	191	191	105937083

S = 319,222 R-Sq = 97,79% R-Sq(adj) = 81,63%

Next figures show that the year 2008 is a watershed for the previous highlighted residual as well as for operated fleet. Consequently, it can be observed that the seasonal variations are strictly linked to the number of operated airliners.

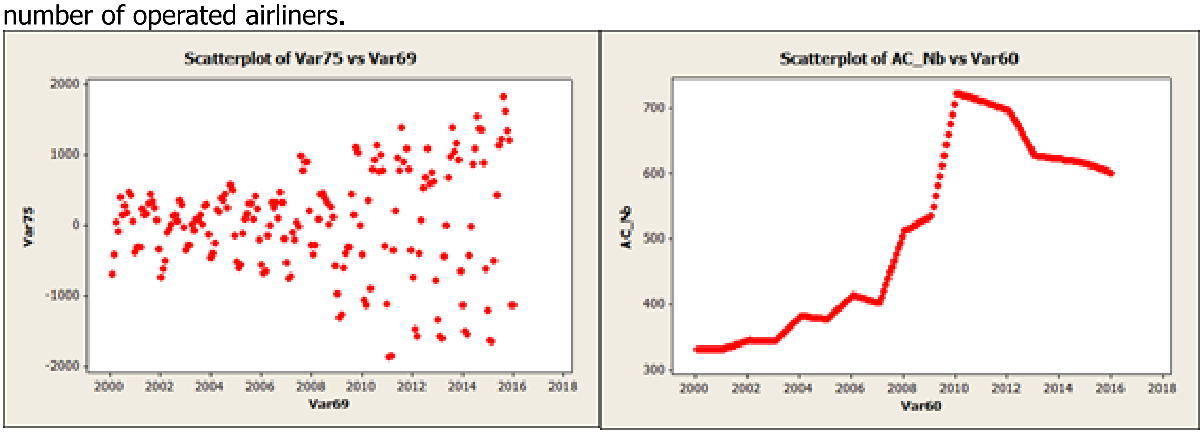

Figure 15: Residuals of the Number of Passengers and Fleet size vs Year.

Taking into account the identified covariant parameters, a reference passenger transport request model has been created for each world area: Europe, America, Asia and Pacific, Africa and Middle East and the overall one (worldwide).
A second step has been focused to identify the effective group of parameters in order to have a more limited number of case studies. The high number of involved parameters and interactions could cause a huge effort in the processing. In this situation, the matrix plot represents a useful tool able to show several scatter plots in a single image:

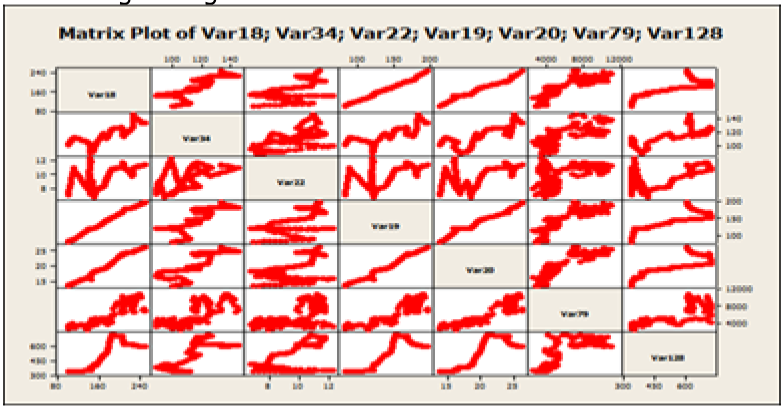

Figure 16: Matrix Plot of a set of possible involved parameters

The staff is a typical important pillar of a generic airline as well as for any commercial organization, it assures with its daily work the flight and support operations. Starting from the staff cost values, the Var08 expressed in percentage has been derived. This value has been assumed equal to 100 at year 2000.

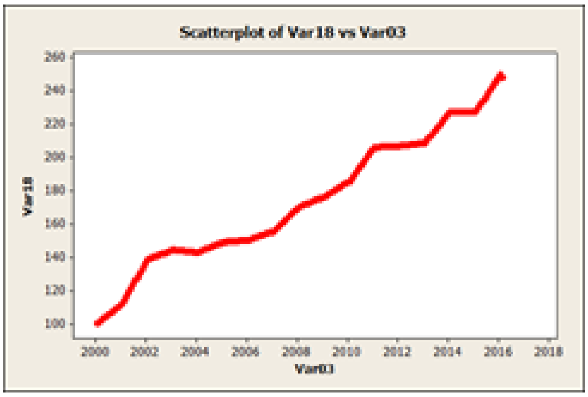

Figure 17: Staff Costs vs Year

A first analysis of variance of the residual of "Var18", using Adjusted Square Sum for Tests, w.r.t., provides:

Source Model	DF	Reduced DF	Seq. Sum of Squares
Var19	161	161	261646,9
Var20	103	9+	92,4
Var21	95	4+	0,2
Error	-170	15	6,9
Total	189	189	261746,5

S = 0,679043   R-Sq = 100,00%   R-Sq(adj) = 99,97%

The previous variance result points out that most relevant covariance of the Staff costs (Var18) is associated to wages and salaries (Var19). Therefore, the analysis of variance of the "Var19", using Adjusted Square Sum for Tests, gives the following results:

Source Model	DF	Reduced DF	Seq SS
Var61	179	179	261379,5

Var57	145	1+	96,1
Var34	170	1+	51,7
Var79	181	1+	16,4
Error	-486	7	202,8
Total	189	189	261746,5

S = 5,38304 R-Sq = 99,92% R-Sq(adj) = 97,91%

The last variance shows that the most relevant covariance of the (Var19) appears associated to worldwide GDP (Var61), while other expected covariance vs the total personnel (Var57), other operating expenses (Var34) and total number of passenger transported (Var79) appear weak.

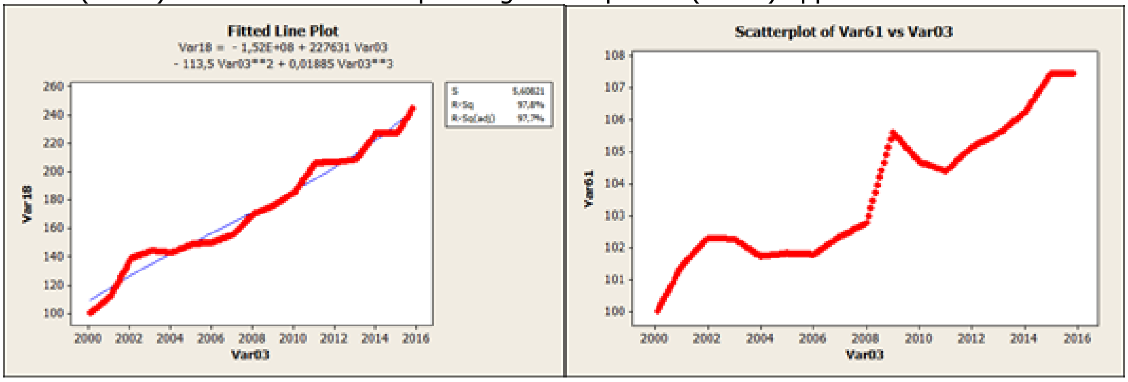

Figure 18: Fitted line plot of the Wages and .. [%] (=100 at 2000)

PREDICTION ANALYSIS CASE

To verify the added value of the approach, it is worth to perform estimation of unknown values relevant to the future. Consequently, we assume as working hypothesis, that the final date of available data is December 31, 2008. The repeated analysis of variance of the "Var19" in the time frame (January1st, 2000 - January 1st, 2008) set of data, using Adjusted Square Sum for Tests, gives the following results:

Source Model	DF	Reduced DF	Seq SS	
Var61%		57	57	8536,641
Var57%		36	11+	147,657
Var79%		93	14+	128,880
Var34%		95	5+	7,775
Error		-186	8	0,432
Total		95	95	8821,385

S = 0,232289 R-Sq = 100,00% R-Sq(adj) = 99,94%

This confirms the previous covariance dependences and assures preliminarily good confidence to create a model with good level of accuracy. The regression line of Var19% vs year, working on the only selected data from January1st, 2000 to January 1st, 2008), has been identified with associated residuals as shows below. The identified relationship has been used to perform the forecast for the next period (February 1st, 2008 – December 1st, 2016). The obtained results are compared to the real values for the same period.

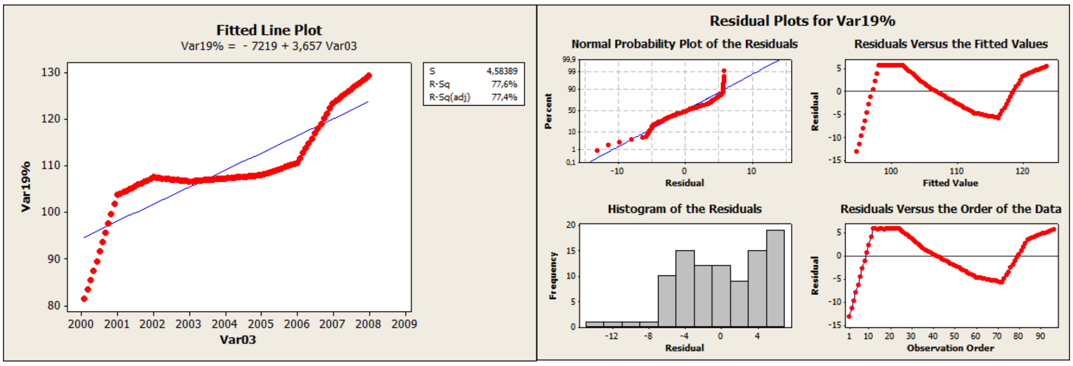

Figure 19: Fitted line plot of the Wages and .. [%] (Staff Cost =100 at 2000)

Similarly, the same analysis has been repeated about the discrepancies vs Var61% and then vs Var57%.

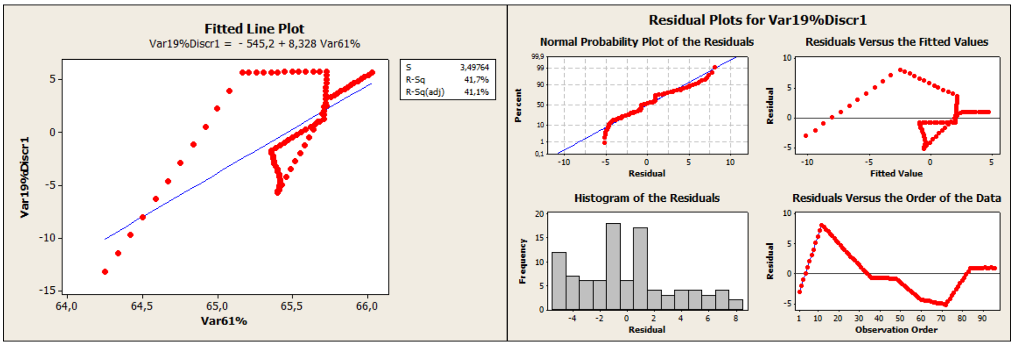

Figure 20: Fitted line plot of the VAR19%Discr1 vs Var61% [%] (Staff Cost=100at 2000)

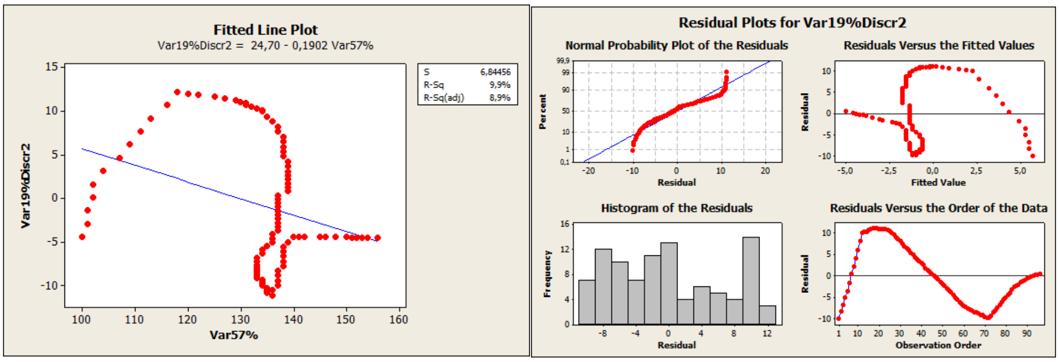

Figure 21: Fitted line plot of the VAR19%Discr2 vs Var57% [%] (Staff Cost=100at 2000)

The combination of the previous three laws is suitable to provide the cumulated value of Var19% referring to the used variables (Var19, Var61 and Var57), so its law is:

$$Var19\% = 3{,}657 * Var03 + 8{,}328 * Var61\% - 0{,}1902 * VAR57\% - 7739{,}5 \pm 3{,}69\ (1\sigma)$$

The figure below shows the forecast from December 31st, 2008 up to December 1st 2016 performed with the model using the available information of this last period. The cyan solid line shows the forecasted values ascribing the known values to Var61% (GDP [%]) and Var57% (Total Staff [%]). While, the dashed curve and dot one, also cyan, shows the forecast in case the known Var61% and Var57% are affected by an error assumed equal to ±5% at December 1st, 2016 and 0% at January 1st, 2008 where the value is known.

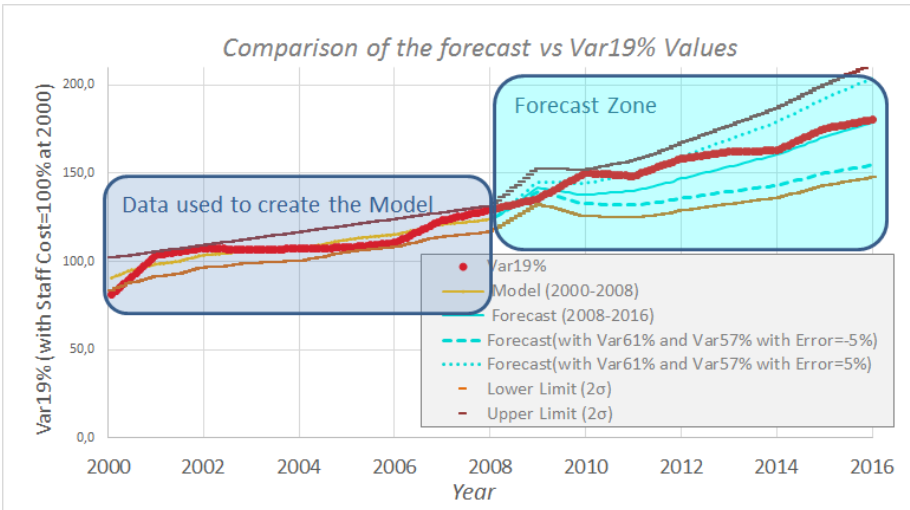

Figure 22: Comparison forecast vs Var19% Values (Staff Cost=100 at 2000)

The previous calculation approach assumes that if eligible and reliable data sources exist, they may be taken into account or preferred to perform different independent estimations. In other words, it is possible to perform a sensitivity analysis vs data source.

Note: The lower limit (light brown) and the upper limit (brown) are respectively associated to dashed curve (-5%) and point curve (5%).

CONCLUSIONS

Aim of this paper is to support decisions on cost efficiency increase, using an analytical tool based on statistics, independent on the specific domain expertise, as the model driver is the covariance of parameters. The defined empirical model type has been adopted to preserve a strong link with the available public information. Such methodology provides estimated cost values in fast and slender way referring to any subset of elements in the operations framework.
The level of detail of the input data, in terms of granularity and quantity, is a necessary starting point to evaluate the impact associated to an implemented research innovation or a new technology.
It can also be an alternative and useful tool to perform forecasts with known accuracy.
It is possible to extend the model with further details and increase the robustness with upgraded database including different airlines and type of operators (e.g. Low cost airline).
The system will be verified in realistic conditions (taking into account change implementations, time dependency of choice consequences,..) with different input data, in terms of time reference and possibly by different airlines. Another future activity will be the validation of the framework. It will be performed by a twofold approach:

1. due to the interaction with an airline, who will be in charge of providing the most relevant parameters to work on to increase cost efficiency.
2. analyzing the measured cost values and identifying the covariance of the related parameters.

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