A Cost/Benefit Analysis of AFAS Functionalities for a Future ATM-System

Dieter Dey, Hans Schnieder and Dirk Schaefer
AIRBUS

Keywords: AFAS; Cost Benefit Analysis; Future Air Traffic Management

1. The AFAS Concept

AFAS means „Aircraft in the Future ATM System". It is an EC funded Research and Technology Project of 16 partners lead by AIRBUS. Information about the project will be found at "www.euroafas.com"

AFAS aims at the coupling of the on-board Flight Management System with the ATM system on ground via Data Link, to enhance the planning, negotiation, and execution of 4D Trajectories. It is well known, that the management of 4D Trajectories in real time by the involved Air Traffic Servicing Units (ATSU´s) is a big challenge, which needs dedicated Tools and related new Procedures and Responsibilities. Therefore, AFAS will provide central functions and procedures, which are based on and amend the outcome of other projects.

The main idea of AFAS is:

- to plan the intended flight from destination and scheduled arrival time backwards to departure and scheduled departure time
- to calculate the optimal trajectory according to take off weight and actual weather conditions.
- to negotiate this flight plan with ATC
- to consider the negotiated flight plan as a contract, which will be valid as long as the planned 4D position can be kept and no unforeseen event occurs

Flight planning and calculation of the optimal trajectory will be executed by the on-board Flight Management System; data exchange will be supported by Data Link functionalities on board and on ground; AFAS will provide three further functionalities on top of the Link 2000+ functions, see Fig. 1 and [1]:

- Pre-flight Trajectory Coordination (PTC)
- Flight Plan Consistency Check of 4D Trajectories (FLIPCY4D) and
- 4-Dimentional Trajectory Re-planning (4DTR)

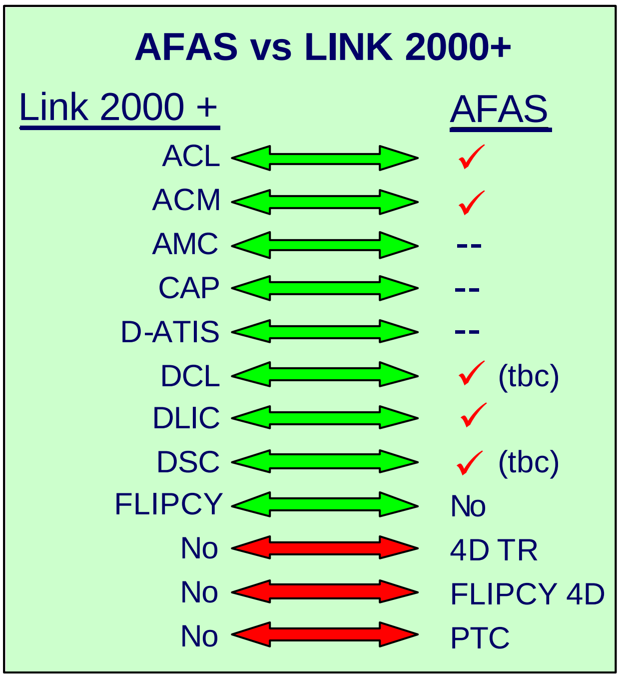

Fig. 1: Link 2000+ and AFAS Functionalities

How these AFAS functions interface with the LINK services:

- ATC Clearance (ACL)
- ATC Communication Management (ACM)
- Departure Clearance (DCL)

- Data Link Initiation Capability (DLIC)
- Down Stream Clearance (DSC)

has still to be worked out in detail.

Pre-flight Trajectory Coordination (PTC):
It is assumed that the trajectory negotiation is proceeded between aircraft and controlling ATSU (C-ATSU), when the aircraft is at the gate. Basis for the negotiation process is a 2D route, which has been pre-coordinated between Airline Operations Centre (AOC) and Central Flow Management Unit (CFMU). The negotiation between aircraft and controlling ATSU has to incorporate intended route, flight profile and landing time, departure runway, Standard Instrument Departure (SID), actual traffic situation, actual weather situation, Standard Arrival Route (STAR); it should lead to an executable Departure Clearance.

Flight Plan Consistency Check of 4D Trajectories (FLIPCY4D):
The FLIPCY4D service is used by the C-ATSU (automatically or on request of the controller) to check, whether the part of the trajectory it is responsible for, is consistent with the trajectory stored in the ground system. If there will be an update, the new trajectory will be distributed to all ATSU´s concerned by the flight. An aircraft guided along an agreed trajectory, will keep this trajectory very accurately. The accuracy of guidance and specially the accuracy of prediction should contribute significantly to the effective use of airspace.

4-Dimentional Trajectory Re-planning (4DTR):
The 4DTR service is used, to adjust an agreed flight plan in case of severe weather, occupied air space, technical reasons and specially if the Requested Time of Arrival (RTA) can not be reached any longer. The 4DTR service can be initiated either by the pilot or the controller. In the vision of AFAS, this service should not be very often needed.

The paradigm "on-time – first served" combined with early available, reliable and accurate 4D information and predictions should lead to a situation, that AFAS equipped aircraft will follow mainly undisturbed the negotiated flight plan, automatically monitored and controlled by the Air Traffic System. Especially for the landing regime, the paradigm should save a lot of time generally wasted in holding flights. Compared to not AFAS equipped aircraft, which will be tactically controlled according to later available and less precise information, that all should lead to an important reduction of delays for AFAS equipped aircraft.
This vision is very challenging for the ATC systems of today and implies many assumptions. Therefore, it is the intention of the project, to test the concept by operational validations and Fast Time Simulations (FTS) performed by EEC, NLR and AENA.
A prerequisite for analysing single flights is the definition of Metrics with measurable values on which the influence of AFAS should be seen.
The Metrics results will be used for Cost/Benefit Analysis for a single airline and for the European ATC System. The references will be Metrics values and cost of today.

2. The Cost/Benefit Analysis

Within the project one task of AIRBUS is to estimate the effects of the proposed AFAS functionality. The Cost/Benefit analysis (CBA), usually done with the help of the cash flow analysis, should show the economic effects of the new functionalities to the global European Air Traffic System, and to the individual stakeholders involved. Generally spoken, it seems only to be possible to introduce a new technology, which is favourable for all participants involved. The expected advantage per stakeholder will develop individually, following its own rules.
It is the purpose of CBA to show the consequences of these rules, and to demon-

strate, that a possible win/win situation is achievable in a reasonable timeframe.
The method follows the “Technology Assessment Methodology“, described in [2] which is in principal comparable to the CNS/ATM Focus Team (C/AFT) process [3]. It calculates the cash flows and the resulting Net Present Value of the necessary investments and cost benefits associated with the AFAS concept.
In the following you will find a rough description of the way, step by step, how to evaluate the new functionalities of the ganisations (ATC). The aircraft manufacturer is - in this context - of minor importance.
2) For the assessment of the technology - specific functionalities in terms of their effects to the operational scenario, it is necessary to define a limited set of Metrics allowing a comparison of the actual state of the art with the effects of the proposed AFAS environment.
3) Measurements of the expected operational effects will be expressed in terms of Metrics results.

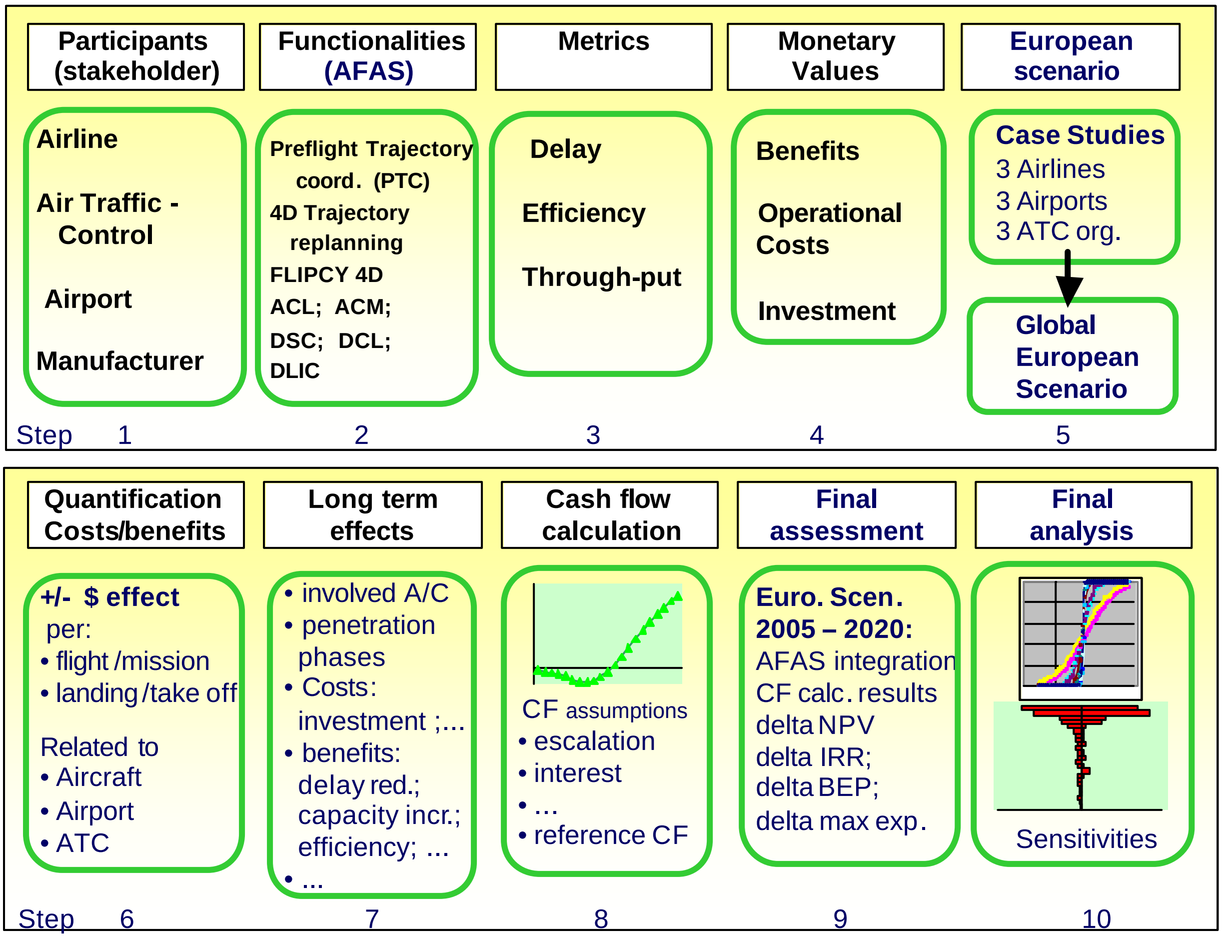

Fig. 2. Roadmap of AFAS CBA

AFAS concept by following the AFAS-CBA roadmap.
1) The initial step is to define the participants, which are involved in the economic analysis. The main stakeholder is the airline, and the CBA will be focused on this participant, but it will address in addition the relation to the other stakeholders, the Airports and the Air Traffic Control Or-

The use of Metrics allows to quantify the individual effects, which are by its own difficult to compare, to weight against each other, or to accumulate.
4) For the CBA the Metrics are translated into monetary values, because the monetary effects of the different Metric’s are open to further calculations. They are comparable to each other, and it is possible

to accumulate or to subtract the effects, so they prepare the way for using the Cash Flow methodology.

5) The AFAS effects will be shown in a reference "net", linking three airports (FRA; MAD and CDG) in the Core European region. Statistical data will be used to give the reference Metrics effects in the reference year. It is obvious, that the main effects of AFAS can be evaluated best in this high-density area of central European air traffic. The results of the three city pair connections will be used at the end together with a translation function to cover the global European scenario.

6) In the step "quantification of costs and benefits" we are asked to quantify the monetary value due to the new functionalities of AFAS in the current scenario to the stakeholders. Some of the costs or benefits are linked to the individual flight (delay reduction; efficiency parameters (fuel-burn; utilization), others are linked to the number of A/C in the system (investment-, training-, maintenance costs) or to the equipage rate of the ATC centres.

All these costs will develop with the individual penetration rate of AFAS related equipment.

7) This leads to the next step, where this penetration phases have to be defined and fixed over the time period, including the fixing of the long-term development of all parameters involved.

8) After having prepared all CF input parameters, the following step aims to define the reference, or baseline cash flow. Part of this step is the definition of some common CF - related figures like interest-, and escalation rate.

9) The following step is the final assessment step. The new technology, in our case the new AFAS functionality, has to be applied to the baseline CF scenario ("do nothing scenario"). This of course will change the cash flow calculation, so that the economic result of the new technology can be expressed as the difference between the two Cash Flows with and without AFAS. By this way, the technology effect can be express by the variation of the economic related results in form of:

- delta Net Present Values (dNPV)
- delta Internal Rate of Return (dIRR)
- delta max. Exposure (dME)
- delta Break Even Point (dBEP)

for the main stakeholder, and in a reduced detailing level for ATC and the European Air Traffic System.

10) In conclusion, the final step will cover the sensitivity analysis. Due to the variation of the future related input parameters, the final results will vary in a certain bandwidth. With the help of the probability distribution and the sensitivity analysis, shown as a Tornado diagram, the influence of specific items on the global results can be shown.

3. Metrics Definition

For cost and benefit calculation, Metrics have to be defined,

- which can be calculated from measurable and today available data,
- which are supposed to be effected by the future AFAS functionalities.

According to desired metric characteristics, three categories of Metrics are selected (see Fig. 3.)

Metrics Definition	
Efficiency	
Efficiency = Reference Flight / Actual Flight (%)	**(Time; Fuel)**
Delay	
Arrival Delay = Actual Arrival Time - Scheduled Arrival Time (min)	
Through-put	
TMA through-put	**= Number of aircraft, that can be accomodated in a given time period by the Terminal Area**
En Route through-put	**= Number of aircraft , that can be accomodated in a typical sector**

Fig. 3. Metrics Definition

Three city pair connections (FRA, CDG and MAD) will be evaluated as case studies. These connections are chosen due to their representation of the core European airspace and the expected availability of data.

For the city pair connections, the scheduled flight times (departure and arrival) are available. The internationally defined and recorded “OOOI” data will be used:

- Time Off Blocks (O) will be used as the actual departure time, the time the aircraft is leaving the gate.

- Time Off Wheels (O) will be used as the actual take-off time.

- Time On Wheels (O) is available as the actual landing time and

- Time In (I) will be used as the arrival time, the time the aircraft is at the gate and on blocks again.

Performance data of the aircraft (A320) allow calculating theoretical flight times without ATC restriction as reference flight times. Figures for ATC through-put, aircraft movements (starts and landings) per hour and day, are available for the specified airports. Figures for en-route ATC through-put of typical sectors (number of aircraft under control per hour and day) are also available. Hence, the three connections can be analysed.

3.1 Efficiency

Efficiency is defined as the relation of a theoretically derived flight time of a specific flight (great circle without any ATC restrictions) to the actual flight time. It is assumed that flight time can be transformed into fuel consumption and cost.

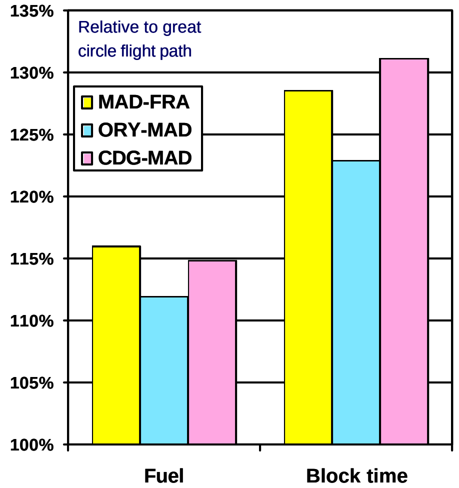

Fig. 4. Fuel- and Block time consumption

Theoretical flight time is used as a reference, keeping in mind, that this value with all its assumptions will not be reached in practical operation, but is a stable reference, representing the potential of the aircraft.

Fig. 4 shows the differences between the theoretical potential of the A/C compared to the statistical analysis of flights in our case study

It is known, that the Flight Management System uses an airline defined cost function for its planning, merging cost of fuel and cost of time. Actual flight time is defined as time from take-off to touch down, calculated from the OOOI-Parameters. Doing this, cost for holding time is not separated from cost of en-route time. The resulting effects have to be evaluated.

3.2 Delay

Fig. 5 shows graphically the relations of scheduled flight times to actual times and the different delays, which may occur.

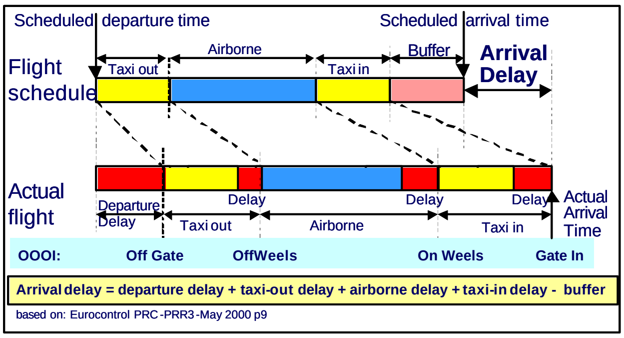

Fig. 5. Definition of: Arrival delay

‘Arrival delay’ is a metric for AFAS. This measure includes several individual delays and is important for the passenger due to its influence on connection and date planning. So, it is of high concern for the airlines.

3.3 Through-put

The metric ‘Through-put’ is defined as the number of aircraft in a typical ATC area per hour during the day. It is basically subdivided in En-Route Through-put and TMA Through-put.

An idea of possible positive peak and levelling effects is shown in Fig. 6 and Fig. 7, which may raise the capacity of ATC sectors or TMA.

4. Evaluation of City Pair Connections

The AFAS effects are related on the airline side to single flights and on the ATS side to the number of movements per time. In the description of the CBA methodology, it was pointed out, that the evaluation of the

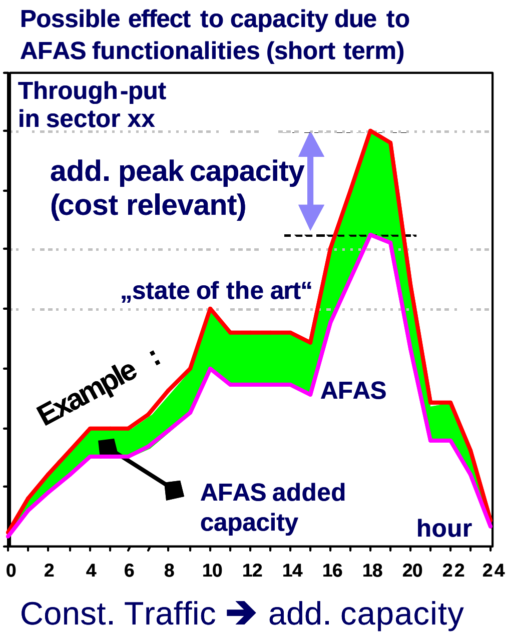

Fig. 6. Through-put (short term eff.)

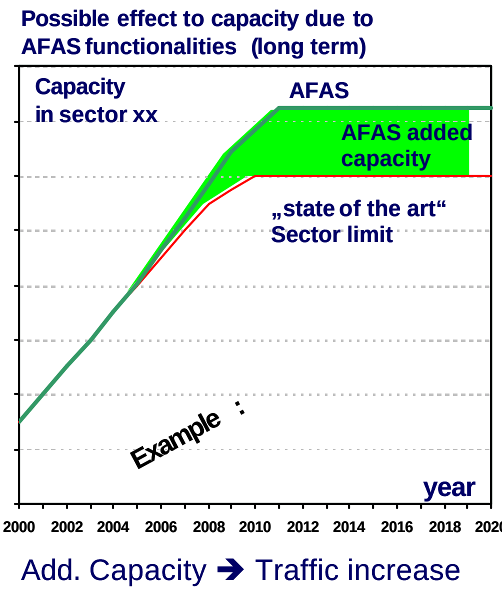

Fig 7. Through-put (long term eff.)

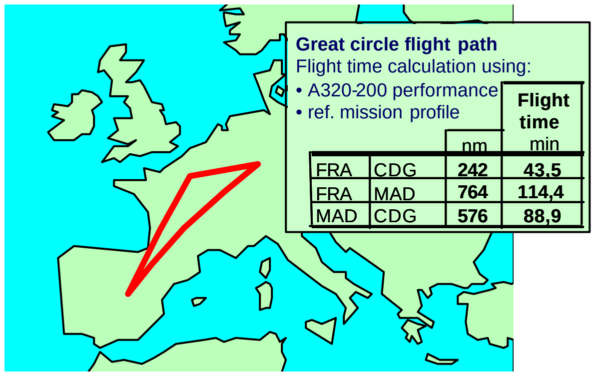

Fig. 8. Case Studies

AFAS effects can be quantified by calculating the differences of the selected Metrics.

To do this, it is essential to define the "state of the art" Metrics and the nowadays traffic as a reference. This is done in Case Studies with 3 city pairs, see Fig. 8.

Data are analysed for a period of half a year, to get stable mean values and distributions, and to eliminate to a certain extend the influence of special events and weather.

In the following some example analysis will show the way how to fix the reference Metrics. This work is still going on.

Fig. 9 shows the distribution of Flight Times and Block Times for the Madrid-Frankfurt connection. The difference of both times is the Taxi Time. Based on this statistics the efficiency factor can be analysed on the basis of more than 1300 connections. The resulting "state of the art" factor is 83% - in terms of fuel, and 77,8% in terms of time –consumption.

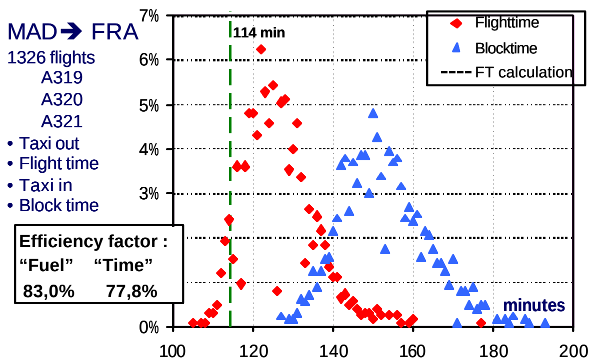

Fig. 9. Statistical analysis of "Efficiency"

in terms of Flight Time and Block Time distribution

Fig. 10. shows the actual statistics of the Metrics "Delay" on Madrid airport. The percentage of aircrafts delayed versus the amount of delay can be used as a reference for non-AFAS aircraft.

The Metrics "Through-put" will be analysed in two ways, en-route – related and airport – related. The corresponding figures are Fig. 11, which additionally shows the workload, measured in PUMA, and Fig. 12 respectively.

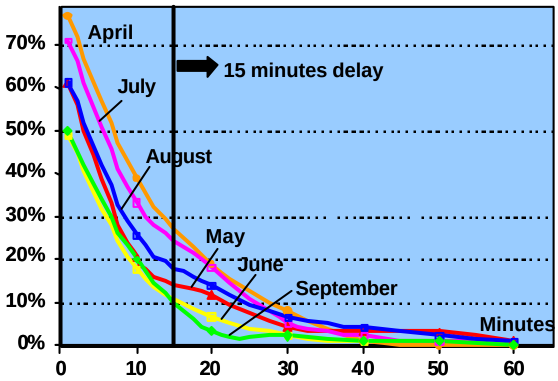

Fig. 10. State of the art Metrics: Delay

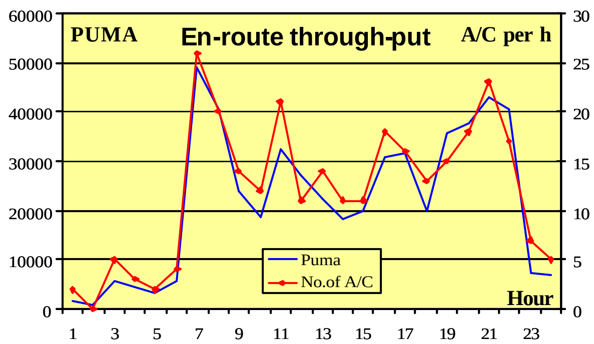

Fig. 11. Example Through put (En route) Including the workload

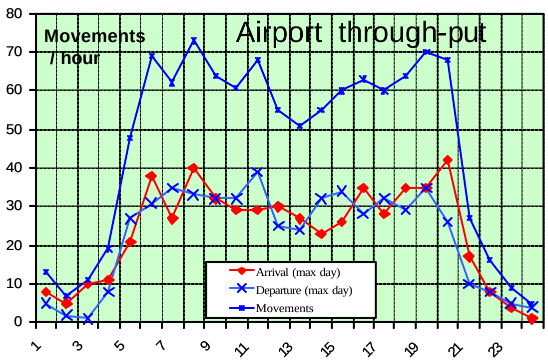

Fig. 12 Example Through put (airport related)

The reference results of the Case Studies, will be used to adjust Fast Time Simulations (FTS) and Real Time Simulations (RTS) to evaluate the intended effects of the AFAS concept in the Case Study – environment.

The AFAS related variation of the Metrics is the output of the FTS, and will be used, after transforming into monetary values, as an input to the CBA evaluation.

In the actual (nowadays) scenario the relation between single city pair connection results and global European data can be worked out, by comparing the above mentioned "Case-Study Metrics" with the "global" European Metrics.

It is assumed, that this relation can be kept constant over the time, to give the resulting future AFAS effect in the European scenario.

5. The Future European Scenario

The European scenario has to be defined in terms of

- number of A/C involved,
- number of ATC centres involved

in – at least – two time periods, the actual, nowadays scenario, and the proposed future scenario in the year 2020.

The expected global future European air traffic development, based on Eurocontrol data and Airbus marketing data, will reach about 15 million movements and nearly 8000 A/C (dependant on A/C size) in the year 2020, see Fig. 13.

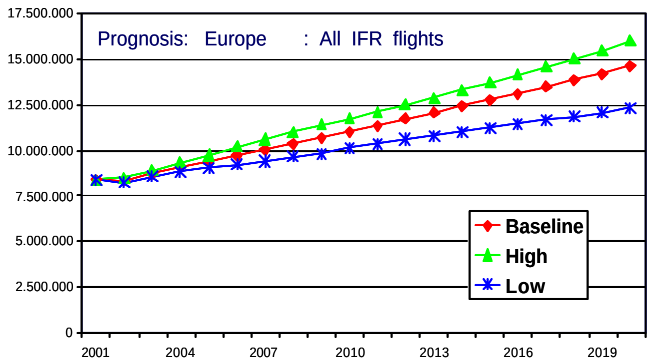

Fig.13. Prognosis of future European Air Traffic movements

It is obvious that the resulting demand could not be accommodated in the nowadays ATC system. The introduction of new Technologies to increase the capacity will be mandatory.
The main objective of AFAS is to reduce delays and increase capacity. The principal functional relationship between Capacity and Delay together with the intended effect of AFAS is given in Fig. 14.

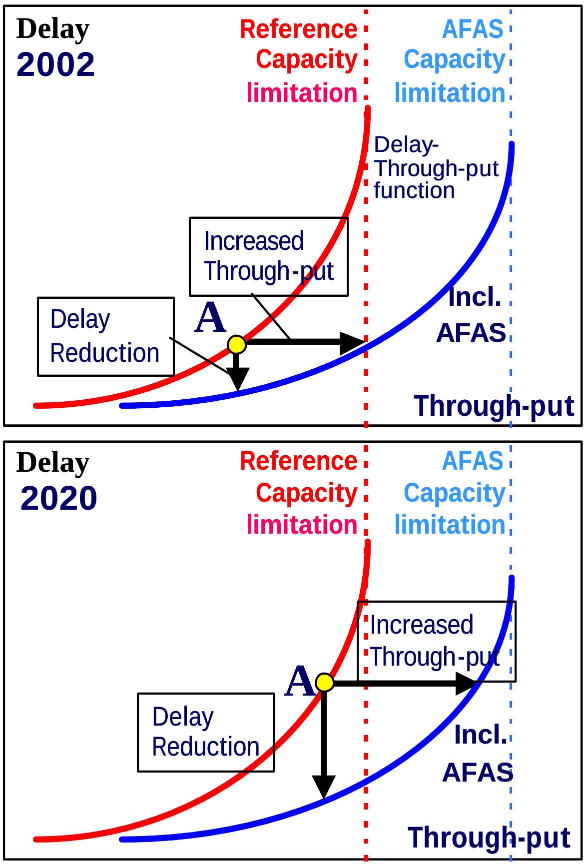

Fig. 14 Intended AFAS Influence on Capacity and Delay

The necessary aircraft related investment is based on the number of AFAS equipped A/C. To evaluate this equipage rate, it is essential to define and to fix the time schedule of the expected AFAS introduction for ATC respectively for an Airline. The introduction time frame will vary, dependant on the stakeholder. One example is given in Fig.15 of an assumed penetration level in a proposed penetration phase. These assumptions are related to the specific stakeholders. In the example, the Airline will start to equip 20 % of its fleet with AFAS in the year 2010, when the ground equipage rate may have reached 50 %, while the total European fleet might be at the 30 % mark. The airline is fully equipped in year 2013 in the given example.
The different time scales of both stake holders might lead to the situation that the Airline will wait until ATC is well equipped, which in turn will defer the ATC capacity increase.
The fixing of this penetration phases has to be worked out, and will have an important effect on the final CBA result.

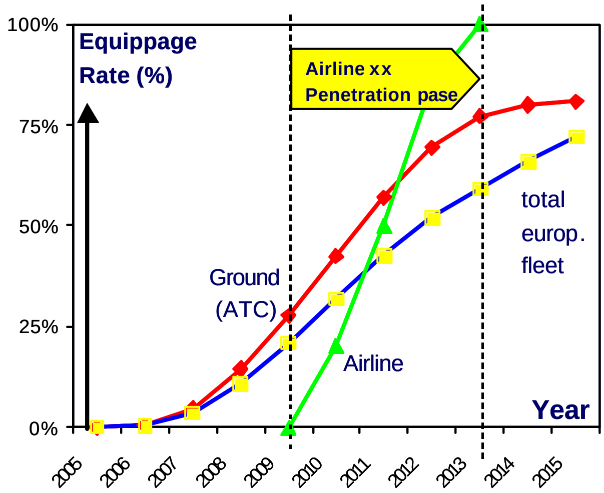

Fig. 15 Example AFAS penetration phases

The benefits and costs of AFAS for the individual stakeholder depend on this equipage rate. This is easy to calculate for the investment costs of the example airline, but a bit more complicated for the evaluation of the global European delay development, because the beneficial effects are a function of traffic increase and a function of time. The varying effects of delay reduction capability and the increased capability to handle the demand can be seen in Fig.14. showing the principle situation nowadays and in 2020, and thus demonstrating the time dependant variation of the Metrics.

The CBA will be performed with a computer-based model incorporating values for the different parameters and their relations. With the model further evaluations in form of sensitivity studies, expressed in a tornado diagram or additional probability analysis, to show the risk of that future investment, will be possible, see Fig. 16. The way of analysing these was introduced by C/AFT [3] and will show the implications of the results.

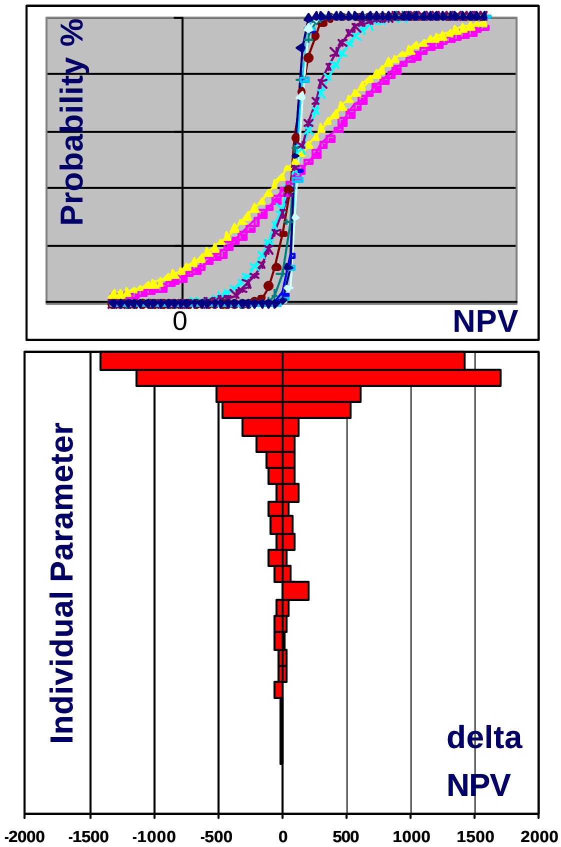

Fig. 16. Tornado-diagram and Probability Analysis

6. Discussion of final work

As mentioned before, the CBA of AFAS is still going on. The results will be expected in about one year timeframe.
That is why this presentation can only show how to evaluate such a complex analysis.
It is the intention of the CBA, to show the bandwidth of possible future situations and to support decisions to be made for the European ATM system.
To do this, all input parameters will be evaluated as “low”; “average” and “high” valued parameters form the beginning.
Without any question, the value of any CBA is directly linked to the quality of input data. Therefore AFAS partners like DLH; AENA; EEC and NLR are involved.

In addition, other supporting initiatives allowing enhancement of the financial aspects, will be considered such as Incentive conditions for early equipped Airlines and guaranteed equipage rates for ATC

7. References

[1] WP1.4 AFAS OSED (Operational Services and Environment Definition
Internal project report
31.05.2001

[2] Schnieder, Hans: *„Methode zur Bewertung von Projekten und Technologien im zivilen Flugzeugbau“*
DGLR–Workshop “Bewertung von Flugzeugen“; TU München ILR
26. / 27. October 1998.
and
DGLR–Jahrestagung 1999; Berlin
27. / 30. September 1999.

[3] C/AFT: *’European Data Link Investment Analysis”*
CNS/ATM Focused Team
led by B. Berends (KLM) and
K. Pirotte (Boeing)
August 22, 2000.

We like to thank the project coordinator Pierre Depape for his support of our work. Jean-Luc Bersat from AIRBUS has supported the work by his connections to the C/AFT group. Volker Rothmann from Deutsche Lufthansa and Marifé Antón Cruz from AENA supported the work by making available necessary data.