ANNEXES

A. THE ROLE OF CBA IN EATMP

A.1 BACKGROUND AND ORIGINS OF EATMP

In April 1990 the Ministers of Transport of the European Civil Aviation Conference (ECAC) launched the “ECAC En-Route Strategy for the 1990s”, a multilateral strategy to increase capacity to meet the expected doubling of air traffic demand over the next decade. This was further developed by the European Organisation for the Safety of Air Navigation (EUROCONTROL) into the European Air Traffic Management Programme (EATMP).

The programme aims at progressively harmonising and subsequently integrating the ECAC member states’ air traffic services. Central management was entrusted to EUROCONTROL.

A.2 EATMP PHASES

The ECAC Strategy was sub-divided into four (at times overlapping) phases:

- Phase I, “Appraisal and Evaluation”, a comprehensive analysis of the then prevailing degree of sophistication of a large number of ATC units, completed in 1991;
- Phase II, “Progress Development”, completed in 1993, resulting in:
  - Convergence and Implementation Programme (CIP) document which defines a number of Objectives which have to be achieved by participating states;
  - EATMP Work Programme (EWP) document which described the common work required.
- Phase III, implementation by states of “local actions” necessary to achieve the initial CIP Objectives. The CIP to be updated annually as progress is made towards harmonisation;
- Phase IV, implementation of the future European Air Traffic Management System (EATMS). Comprising of the:
  - adoption of a common functional model integrating the airborne and ground-based components of the EATMS;
  - implementation in specified zones of advanced systems supported by extensive automation and enhanced data communication available with utilities and the aeronautical telecommunication network;
  - progressive extension of implementation of advanced systems to other zones.

A.3 EATMP WORKING STRUCTURES

For the purpose of managing EATMP two main institutional arrangements have been established:

- the EATMP Project Board, composed of high-ranking officials of participating states, the EUROCONTROL Director General and representation from the Commission of the European Union. This Board's objective is to exercise overall management control of the Programme, as well as to decide upon any extension of the Programme to further European states and upon relations with other countries and international organisations;
- the EUROCONTROL EATMP Team, comprising EUROCONTROL staff from various Directorates under the general supervision of the Senior Director Operations and EATMP, the Project Leader. The Team's objective is to secure implementation of the programme in the agreed time scale, and to perform its day-to-day management under directions given by the Project Board within the agreed EUROCONTROL Agency resources.

Work in EATMP is subdivided into seven "vertical" technical specialist domains:

- surveillance;
- communications;
- airspace management and ATM procedures;
- ATM operational requirements;
- ATM data processing systems;
- human resources;
- navigation.

plus five "horizontal" domains:

- institutional arrangements;
- future concepts;
- safety;
- ATM system engineering;
- planning and control.

Domain teams have been set up, comprising experts from states and from the Agency, to advise the Project Leader on each technical domain. The objective of these teams is to attain a consensus on the development and specification process, as well as on the definition of new objectives to be included in future editions of the CIP (after endorsement by the Project Board).

A.4 ECONOMIC APPRAISAL IN EATMP

In the medium term states participating in EATMP are committed to achieving the Objectives defined in the CIP by the agreed target date. It is their responsibility to decide on the "local actions" necessary to achieve these Objectives and to actually implement them. However, states are strongly encouraged to adopt common solutions, e.g. based on EWP developments, in order to achieve the CIP Objectives.

One of the prime objectives of EATMP is to achieve a uniform level of ATS capability over the whole of the ECAC area (or over parts of it with the same level of ATC complexity). It is therefore essential that, once they are adopted, common objectives are effectively achieved everywhere as required by the agreed target date. If economic justifications are needed to that effect, they should be provided at overall ECAC level before the Objectives are formally adopted. When the Objective(s) is (are) effectively adopted by the Project Board, states may have to conduct a more specific economic evaluation to decide on the actual local actions to be adopted (e.g. separate vs. common development/procurement).

In the long term there will be a variety of ATM concept and system design options integral to the progressive definition and development of EATMS, for which economic appraisal can assist by helping to assess their relative merits. It is vital that such options are generated and assessed from a framework of operational performance and benefits, which economic appraisal can help provide. Without such a framework there is a real danger of an unstructured development programme, with significant risks that it will fail to converge on a solution widely perceived and accepted, by governments and users, as optimal. Subsequently, and in a slightly later timeframe, there will be a number of implementation options including issues of facility sharing and consolidation, where economic appraisal can contribute. Once the design process is complete, with implementation schedules and associated costs being planned, the investment case may at that time need justification at both European and national levels.

A.5 ESTABLISHMENT OF ECBAG

The EATMP Cost-Benefit Advisory Group (ECBAG) was established in 1994 following the recommendations of a Task Force set up by the Project Board as part of the Planning and Control domain. The production of this document represents one of the tasks of the Group.

A.6 EPAC

It is important for the success of EATMP that work is carried out effectively and efficiently. The EUROCONTROL Agency needs to ensure that projects are prepared in a timely and critical managerial manner and that they meet the demands of its customers. Within the Agency, therefore, there are a number of steering committees to ensure this. The EATMP Policy and Allocation Committee (EPAC), chaired by the Senior Director Operations and EATMP, is one such steering committee. It assists in agreeing the priority of projects and the allocation of major tasks and resources within the Agency.

In order for EPAC to appraise projects effectively, guidelines for the drafting of project proposals for appraisal by EPAC have been issued by the Agency. Project managers must follow these guidelines when submitting project proposals to EPAC. The resulting proposal document is used as the basis for a “Go/no Go” decision on the project.

Although the EPAC guidelines discuss briefly economic analysis of projects in a section titled “Cost Benefit Statement“ - Version 1.0 of the ECBAG guidelines is referenced - there is no guidance as yet as to where, when and how in the EATMP project life cycle cost benefit studies could play a role. EPAC guidelines are considered as “live” in that they will be updated at regular intervals as lessons are learnt from their use. It is important that future editions take note of the following ECBAG guidance material:

- the role of CBA in project development and decision making; and
- the level of detail for CBA.

As a general rule for the future the two sets of guidelines must be seen as compatible and complementary.

B. OTHER APPROACHES TO ECONOMIC APPRAISAL

B.1 INTRODUCTION

In addition to CBA, there are two other basic methods of economic appraisal to be distinguished:

- Utility Value Analysis;
- Cost Effectiveness Analysis.

B.2 UTILITY VALUE ANALYSIS

Utility Value Analysis (UVA) represents a multi-dimensional approach to the economic appraisal of a system without the necessity to quantify in economic terms the different system dimensions. UVA involves:

- the identification of objectives to be served by a system;
- the rating of their relative weight in attaining the overall goal;
- the appraisal of the performance of the various system options with respect to each objective separately; and
- finally with respect to the overall goal attainment.

System performance with regard to the objectives of the interest groups involved is estimated as objectively as possible but is often based on expert judgement. The main difficulties with the application of this methodology are the definition of value functions and point scales, the dependence of utility amongst the measures being set and the interdependence of objectives. However, the key advantages of UVA are the consideration of subjective and qualitative preferences of individual interest groups, and also a system assessment based on a wide range of performance dimensions, not just economic considerations. Various types of UVA are available, each using different weighting/assessment methods and different mathematical analyses to interpret data.

B.3 COST EFFECTIVENESS ANALYSIS

Cost Effectiveness Analysis can be used to assess project proposals when it is not practical to translate the benefits associated with the project options into economic figures. The costs of individual investment alternatives are quantified in present value terms and related to the project benefits which are described as fully as possible - either in physical, non-monetary units or by using qualitative value scales. Similar to the utility value analysis the methodology usually requires a definite hierarchy of goals taking into account the relative weights of the individual goals according to the subjective views and preferences of the various interest groups involved. Cost effectiveness ratios for each project proposal are then computed by dividing the present value costs of the assessed alternative by the measure of its principal impact. Since costs cannot directly be compared with benefits on the basis of a common unit of account the approach cannot indicate in clear quantitative terms whether the main benefits of a project warrant the cost involved. Instead, given defined objectives, it can be used to assist the decision-makers in choosing the option that maximises cost effectiveness.

C. ATM SERVICE PROVIDER COST SAVINGS

C.1 COST ANALYSIS CATEGORISATION

The following is a categorisation (non-exhaustive) of cost components which can be used to track the cost savings to the ATM service providers of a given project or programme. Not all cost elements apply to every project.

Costs and potential cost savings must be considered for the major phases of any project:

- Research and Development (R&D);
- implementation;
- operational.

In addition, expenditures must be broken down into the appropriate ground, airborne or space cost components, as appropriate.

C.2 R&D COST SAVINGS

Research and development expenditure is normally incurred to generate new valuable technologies and assets for ATM projects. Often there is a long “lead time” before the eventual implementation of the developed system.

C.3 IMPLEMENTATION COST SAVINGS

Potential cost savings need to be assessed when comparing the implementation costs incurred for the new project with the reference case. The implementation phase will require one-off investments over an initial period of time as the elements of the new system are installed and certificated.

Investment expenditure shall comprise expenditure on equipment and buildings, including related works services, expenditure on land, basic software and, where appropriate, application software. Interest (financial charges) incurred during the pre-operational phase also needs to be taken into account.

Examples of initial implementation cost elements include: ATC centre, Controller Working Position (station), CNS equipment, ATFM system, ASM system, planning and project management cost, etc.

C.4 OPERATIONAL COST SAVINGS

C.4.1 Introduction

Operational costs must be compared in the following three areas: staff, operations and overhead, to see if there are operational cost savings.

Reduction of service providers' operating costs include:

- decreasing staff numbers;
- introducing new technology (to reduce maintenance costs);
- reducing other overheads (e.g. utility bills, number of buildings used).

C.4.2 Staff

Direct staff required for the operation of a new system include:

- air traffic personnel (specify type according to project) including trainees, supervisors and all other staff directly involved with air traffic operations;
- maintenance personnel (including trainees, supervisors and technical support staff);
- other Operations personnel. This may include staff in central services or technical support personnel (excluding maintenance staff itself).

For staff expenditures, identify, if possible, the different types of project staff (internal, external contractors, civil, military, etc.) if they have different cost implications.

C.4.3 Operating costs

Direct annual operating costs for a project should include:

- spare parts, materials, supplies and operational equipment etc. Those non-staff costs incurred for the provision of maintenance and repair, the equipment used for the maintenance of ATM facilities;
- cost of application software (unless considered as an investment);
- land or facility rental costs;
- utilities expenses (energy, water, fuel etc.);
- communications costs (leased or owned services);
- investment costs (interest charges) and depreciation costs, if appropriate.

C.4.4 Overhead

Overhead costs include those costs which although not directly associated with a project, could arise as a result of its implementation. This category includes management, administrative and training personnel.

D. AIRCRAFT OPERATOR COST SAVINGS

D.1 INTRODUCTION

This annex provides guidance about potential cost savings to aircraft operators which may be associated with a change in the CNS/ATM environment through the implementation of EATMP projects. Individual projects will usually only address a subset of the four categories of cost savings mentioned below. Note should be taken of the fact that the realisation of cost savings may vary significantly between different airlines although they might have the same operating environment.

The four principal categories of potential cost savings are defined below and each is discussed in the rest of this annex:

- reduced ATC charges due to a reduction of ATC investments/operating cost resulting from a project;
- lower investment and operating costs of new airborne technologies or airline ground-systems as a result of introducing new CNS/ATM infrastructure or procedures;
- changes in the CNS/ATM environment allowing a greater number of flights closer to the optimum trajectory;
- reduction in ATM-caused irregularities, i.e. delays.

D.2 REDUCED ATC CHARGES

Assuming that investments in the CNS/ATM infrastructure and operating costs for the provision of Air Traffic Services are fully recovered through ATC user charges, any cost reduction for the ATS providers would be translated into cost savings for the aircraft operators. Cost savings for the ATS providers would need to be distributed to the aircraft operators according to applicable recovery mechanisms.

D.3 COST SAVINGS FOR NEW EQUIPMENT AND AIRLINE SYSTEMS

This category of cost savings would be realised whenever existing airborne equipment or airline ground systems would be replaced by less expensive ones - in terms of investment and operating cost substitute.

A differentiation by aircraft types may be necessary since the equipment standards may vary. Furthermore, different categories of aircraft operations and/or phases of flight need to be taken into account if a project is related to certain operations only (an example would be precision approach and landing systems).

For aircraft that operate in more than one region, cost savings may only occur if the redundant equipment is not mandated or used anymore in the whole area of operation. If, for example, in Europe the mandatory equipment with ADF and VOR receivers was withdrawn, but this equipment was still required in other parts of the world, there would be no cost savings for aircraft operating inter-regionally.

D.4 FLIGHT OPERATIONS CLOSER TO THE OPTIMUM

Implementation of a project may allow aircraft operators to plan and execute their flights closer to the optimum trajectory and schedule as defined by:

- flight distance;
- speed;
- altitude, including climb, descent and step climbs.

The quantification of these cost savings requires a detailed analysis of the routes concerned and aircraft types operated on these routes. This usually involves complex simulations of the overall traffic flow. Models may be used for such simulations and this is discussed in Annex I.

Ultimately, cost savings arise in this area only when the project yields reductions in one or both of:

- reduced fuel consumption;
- reduced flight time.

Reduced Fuel Consumption

Reductions in fuel consumption usually can be calculated directly from flight planning systems or from appropriate simulations. Aircraft type performance needs to be considered. In certain cases reduced fuel consumption may lead to increased payload of the aircraft concerned which is an additional issue to be considered. Another important factor is whether the optimised flight trajectory is planable by the airline or whether it will only be made available ad-hoc, e.g. by offering direct-routeings to a crew in-flight, based on the actual traffic situation. Planable improvements will yield higher benefits since aircraft can initially be fuelled to lower levels.

Reduced Flight-time

Principally, cost savings as a result of reduced flight-time might occur in:

- flight crew and flight attendants cost;
- aircraft depreciation and associated financial cost;
- aircraft overhaul, maintenance cost etc.

The calculation of flight-time related cost-savings is much more complex because it does not only vary based on aircraft types, but also by operators and type and area of operation. Cost savings often also depend on certain thresholds to determine the magnitude of the flight-time reduction required to realise the above mentioned cost savings.

Flight crew and flight attendants costs may only partially depend on the flight-time since only some of the personnel are paid variably per flight-hour. This may depend on the airline or even on the individual operation. If a certain threshold for flight-time reductions is passed on a certain operation, however, there might be significant savings. Flight-time reductions may lead to a reduction of the number of crew members for an individual operation if the threshold above which additional crew members are required is passed. To give a practical example, if the flight-time for a B767 flight of one of IATA's member airlines could be reduced on a particular route from 8.5 to 7.5 hours, the number of pilots could be reduced from 3 to 2. Some airlines also have different payment schemes for crews depending on the flight-time. One operator, for example, has contracted flight attendants at much lower cost exclusively for flights with a duration of less than 120 minutes: a reduction of scheduled flight-times from 125 to 115 minutes could allow this operator to allocate personnel with lower salaries to this flight. In other circumstances reduced flight-time may increase the productivity of the crew by allowing the execution of another flight within the limits of their duty time regulations.

Similarly the cost for aircraft depreciation and related capital services will only be reduced by flight-time reductions if the productivity of the aircraft can be increased. This may only be the case if the flight-time reductions are individually or cumulatively - within a certain area and type of operation - of a magnitude that additional flights can be performed.

Parts of the aircraft operators' cost for maintenance, overhaul, etc., depend directly on the flight-time. However, there exist different accounting mechanisms and the flight-time dependent parts of these costs may vary for different aircraft and operators. Until now, there have been no representative figures available for this part of the operating cost.

The aforementioned factors highlight the difficulties faced with calculating cost savings. The results of a cost benefit study may be distorted if “cost savings” are calculated by simply multiplying average operating cost per minute with the cumulative time saved by flight time reductions.

D.5 REDUCTION IN ATM-CAUSED IRREGULARITIES

In this context irregularity means a difference in the execution of a flight relative to the published schedule. Principally there are three types of irregularities which may be caused by the ATM-system or by insufficiencies in the CNS-infrastructure :

- delay of a flight (ground or airborne);
- cancellation of a flight;
- diversion of a flight.

The reduction of such irregularities by implementation of a CNS/ATM related project could lead to cost savings to aircraft operators. The quantification of these cost savings depends heavily on the probability that the irregularities will be reduced.

Cost savings related to delays share some of the same methodology as discussed in the context of flight-time reductions. However, there is another set of costs that may apply due to a delay causing a late departure, arrival or excessive block time:

- use of ground-power units;
- parking fees;

- additional services for passengers (meal vouchers, hotel accommodation, etc.);
- late baggage delivery;
- additional fuel stops.

In addition, if the operating environment consistently causes delays, aircraft operators may be forced to secure additional aircraft to ensure punctual services.

The costs of a delay are non-linear if the magnitude of delays increases beyond certain thresholds. However, this threshold will only be crossed in exceptional cases, e.g. as a result of industrial action leading to significant traffic disruptions. Therefore it is felt to be legitimate to neglect this effect for CBA in the field of implementation of CNS/ATM-systems.

Similarly cancellations and diversions of a flight occur in very exceptional circumstances only and usually cannot be considered when analysing a CNS/ATM-system. In particular cases, however, if a system is introduced to cater only for such events, e.g. precision-approach and low visibility landing systems, cost savings associated with reductions in diversions and cancellations would need to be considered.

D.6 SUMMARY

Although a methodology and cost categories may be consistently used for different projects, the discussion above shows that detail within the categories to be considered can vary significantly from case to case, depending on the type of project to be evaluated. Direct involvement of the aircraft operators concerned is essential in order to achieve realistic results.

E. CAPACITY AND REDUCED DELAY BENEFITS

E.1 BACKGROUND

Increasing the capacity of en-route airspace in order to accommodate forecast growth in air traffic is one of the principal drivers for EATMP projects. It is important, therefore, to make an accurate assessment of the increases in airspace capacity that might be brought about by investments and the probable financial benefits associated with such increases. Assessment of capacity must consider the following factors:

- the **capacity** of en-route airspace (and also airports);
- the **demand** for air travel;
- the relationship between capacity and demand, which may lead to a situation of **constrained demand**;
- the **economic costs of constrained demand (**the benefit of increasing capacity would be the avoidance of these costs).

This annex describes each of the above in turn. It also considers a number of approaches that can be taken for the evaluation of capacity benefits.

E.2 CAPACITY

The term capacity can be used to refer to a number of factors, any of which could be the limiting factor that might place a constraint on the amount of air traffic that can be handled. These factors can be categorised as follows:

- **Airspace capacity:** literally, the number of aircraft that can be fitted into ATC sectors, keeping in mind aircraft separation and safety standards, area navigation direct routeings, etc.;
- **Controller capacity:** the maximum workload of controllers, i.e. the maximum number of aircraft that can be handled by a controller within a certain period of time for a given sector size;
- **Equipment capacity:** the number of flights that can be handled by ATC systems, e.g. there are a limited number of Mode A identification codes that can be allocated at any one time;
- **Airport capacity:** which is increasingly limited by “available concrete” for landing and manoeuvring aircraft. There are interfaces between airports and TMA airspace, which in turn interfaces with en-route airspace. These interfaces may form bottlenecks themselves and must be considered where necessary.

The above definitions necessarily simplify the term capacity to enable an assessment to be carried out: in reality capacity is a complex issue that is affected by all of these as well as other, external, factors.

E.3 DEMAND

Organisations such as EUROCONTROL, IATA, the European Commission and aircraft manufacturers, such as Boeing and Airbus, forecast a steadily increasing level of demand for air travel in the near future. Such forecasts are based on assumptions about economic growth, and European integration, that will lead to increasing requirements for air travel both for commerce and leisure purposes.

The annual growth in demand in flight numbers can be obtained from EUROCONTROL statistics. It is usual for baseline, low and high growth figures to be available. These can be used to bound the calculations of capacity benefits.

Demand is not constant, and any calculations using demand are sensitive to:

- traffic patterns through sectors;
- annual growth in traffic demand;
- seasonal fluctuations;
- fluctuations within the day.

The traffic data used will be dependent on the type of project. For a project based around a specific airport the forecasts required would be different to those used in a project dealing with en-route airspace. If CBA is applied to a large region of airspace some averaging of the traffic statistics is inevitable, but care must be taken to capture the peaks of demand.

E.4 CONSTRAINED DEMAND

The relationship between capacity and demand may lead to “bottlenecks” or **constrained demand** on certain routes at particular times of the day. Three types of constrained demand can be identified:

- **demand generally less than capacity, but exceeding it during peak periods:** Excess demand may be accommodated by allowing delays to build up during the peak period then recovering during the subsequent “quiet” period;
- **demand approaching/exceeding capacity:** If capacity is, on a regular basis, insufficient to meet demand at certain times of the day, airlines may be forced to operate services at less busy times (demand spreading) or to fly non-optimum routeings;
- **unaccommodated demand:** Demand may exceed capacity to the extent that there are simply no available slots for further traffic, and therefore demand spreading and re-routeing are not possible. In this case airlines would be unable to satisfy any additional demand from passengers for further services.

E.5 ECONOMIC COSTS OF CONSTRAINED DEMAND

E.5.1 Demand generally less than capacity

If demand exceeds capacity only during certain peak periods of a day, the excess demand may be accommodated by allowing delays to build up during the peak period and then recovering during the subsequent "quiet" period. The delayed traffic does, however, incur significant costs to the user, including:

- increased operating costs to airlines such as additional fuel burn, crew, costs etc;
- costs to passengers in terms of time.

The benefit of increasing capacity would, in this case, be the avoidance of these delay costs.

E.5.2 Demand approaching/exceeding capacity

If capacity is, on a regular basis, insufficient to meet demand at certain times of the day, airlines may be forced to operate services at less busy times (demand spreading) or to fly non-optimum routeings. In such cases, the constraints on capacity are already known and therefore the incurring by airlines of additional costs would be planned in advance.

Both demand spreading and re-routeing can result in considerable costs to operators and passengers. Airlines may lose revenue by operating services at off-peak times, or incur additional fuel penalties by re-routeing to non-optimum trajectories. Passengers would also be disadvantaged in terms of significant additional travelling time, flying at less convenient times of the day and, possibly, having to travel to less accessible airports.

The costs to airlines can be grouped into two categories, each of which requires a different approach to quantification:

- where planned re-routeing occurs the cost of additional flying time can be expressed in terms of aircraft operating costs;
- in instances of demand spreading the effect is more complex to assess and requires some form of economic model.

E.5.3 Unaccommodated demand

Unaccommodated demand results from a shortfall between demand and airspace capacity. Demand may exceed capacity to the extent that there are simply no available slots for further service provision by the airlines in certain markets, and therefore demand spreading and re-routeing are not possible. Thus demand serves as an indicator of capacity related benefits and costs, respectively.

In the most straightforward approach the problem can be seen as airlines being unable to satisfy any additional demand from passengers for further services. The cost to the airlines would be the revenue lost as a consequence of not being able to provide services to meet passenger demand. The benefits to be quantified would, therefore, simply be expressed in terms of revenue gained by airlines as a result of the extra flights enabled by an increase in capacity (but note this would be partially offset by the additional operating cost of providing these extra flights).

However, the complexity of the nature of system capacity constraints on the demand for, and the provision of, air transport will often require the use of economic metrics. Demand spreading and re-routeing are not the only possible consequences for the air transport system approaching capacity limits.

Services may be provided by larger aircraft, or competition may be heavily constrained through the lack of slots (which is already evident today at some European hubs at peak times) with effects on the ticket price levels offered in a specific market. Ticket price is directly related to demand (as modelled with price elasticity models). A shortage of capacity results in higher ticket prices which acts to constrain demand. The benefit of providing additional capacity is related to the reduction in ticket prices which raises the incentive and affordability, respectively, of passengers to fly.

However, in calculating the monetary benefits for the aircraft operators, the trade-off between higher yields/less passengers and lower yields/more passengers needs to be carefully considered. The increase in potential demand through the reduction or elimination of capacity constraints (capacity benefits) is not directly proportional to the monetary benefit (revenue) of the airline system. In this context it also has to be noted that the revenue diverted from one airline to a competitor due to the reduction in capacity constraints on competition must be isolated from the gross impact on airline revenues.

Modelling the effect of capacity constraints on service quality (provision of flight frequencies in particular) and ticket prices and, consequently, on demand and airline revenue should, in a complete analysis, not be limited to an unimodal perspective, but should integrate an intermodal demand elasticity metric (competition of the air transport system with potential substitute models).

F. RELIABILITY BENEFITS

F.1 INTRODUCTION

This annex describes how CBA can aid in the decision-making process as to whether or not to commit investment expenditure to the replacement of old or unreliable equipment.

F.2 BACKGROUND

In order to provide a safe and efficient ATC service, it is essential that the systems that supply data and services to controllers maintain a pre-defined level of reliability. Failures of certain types of equipment may necessitate the imposition of constraints on ATC operations for safety reasons. If, for example, one of the key components at a radar station were to fail and the radar display were to be lost, the controller would, by voice instruction, increase aircraft separations to guard against potential accidents - i.e. to maintain safety. The resultant delays to the aircraft affected translate into additional costs to airlines (in terms of additional fuel burn, crew costs etc.) which can be quantified.

Quantifying the benefit of reduced maintenance costs (from purchasing more reliable equipment) and the cost of delays caused by equipment failure forms the basis of the benefits case for investment projects that seek to replace or upgrade old and/or obsolete kit. Assuming that the proposed replacement equipment would achieve the required level of reliability, the project can be said to avoid the delay costs that would be incurred if the existing, unreliable, equipment were retained. These avoided costs constitute the benefits of carrying out the project and are offset against the investment cost of the project to give a net cost or benefit.

This type of analysis indicates to decision-makers how worthwhile investment in a replacement project is likely to be. If the analysis shows a net benefit then the initial expenditure is likely to be recouped within the lifetime of the new equipment. If a net cost is shown, then a judgement has to be made as to whether any unquantified benefits (e.g. safety, environmental) justify the net expenditure.

There may be several proposed options for replacing the existing equipment. Assuming these all deliver the same level of performance, i.e. the same benefits, then a decision will be based on the relative costs of the options. The options may, however, deliver different levels of benefit. In this case the preferred option is likely to be that with the greatest net benefit (or lowest net cost) when the costs and benefits of each option are brought together.

F.3 KEY INFORMATION REQUIRED

Operational effect of an outage: this is the central assumption upon which reliability benefits are based. If the failure of a system has a measurable effect on air traffic operations then the benefit of avoiding such failures can be quantified. In some cases there may be specific guidelines that define the extent to which operations should be degraded if a particular system fails; if there is not, then expert opinion should be sought as to the likely effect on operations of such failures. In the latter case it should be made clear that the benefits are based upon informed judgement, not stated fact.

If there is an operational effect upon which a benefits case can be constructed, then the following information is necessary to enable the benefits to be quantified:

- **analysis period:** this commences from the project implementation date, and is usually taken to be the depreciable life of the replacement equipment;
- **reliability data:** historical documentation of the frequency and duration of failures of the existing equipment and, if possible, highlighting any trends towards an increase in failure rates;
- **forecast traffic:** this would probably take the form of a forecast traffic rate for year one of the analysis period, and a given annual growth rate for the subsequent years;
- **delay costs:** the cost to airlines of flight delays, including extra fuel burn, crew costs, parking charges (if delayed on the ground). An average cost per hour to a typical flight, calculated for use in all replacement projects, can be applied.

F.4 QUANTIFYING RELIABILITY BENEFITS

The information described above can be used to quantify the benefits of the replacement project. Say, for example, that failure of a particular system delays flights by, on average, half an hour. Given the reduced failure time with a new equipment, the number of flights affected and the cost of delays to those flights, the total reduced delay costs over the analysis period can be estimated. A very basic calculation would be:

$$\begin{gathered}\Delta \text{ Frequency of failure} \times \Delta \text{ Downtime per failure} \\ \times \text{ No of flights per hour} \times \text{ Cost of delay per hour}\end{gathered}$$

where Δ = delta, meaning “change in”.

Assuming that implementation of the replacement project results in these costs being avoided, they can be offset against the investment cost of the project to give a net cost or benefit.

Improved reliability also benefits the staff associated with equipment maintenance. Maintenance benefits might be quantified as:

$$\Delta \text{ Frequency of failure} \times \Delta \text{ Maintenance cost per failure}$$

G. SAFETY BENEFITS

G.1 INTRODUCTION

Safety benefits are inherently difficult to quantify directly. This is because they are benefits that result from reducing the risk of an accident where injury and/or loss of life may occur. If safety is to be quantified in financial terms, it may be necessary to estimate a value of a human life.

It is vital that the current level of safety is maintained or improved upon when implementing new technology, operating procedures and airspace design. Accidents are - by design - very rare; this does mean, however, that a lack of data makes improvements in accident risk difficult to measure. This section summarises four approaches that can be used to appraise projects that claim safety benefits. These are:

- the “Constraint” approach;
- the “Qualitative” approach;
- the “Explicit” approach;
- the “Implicit” approach.

In the vast majority of projects safety is a constraint and only qualitative benefits can be provided. However, if the primary benefit is safety it may be possible to provide illustrative examples to support the case.

G.2 CONSTRAINT APPROACH

This approach rests on the premise that a safe air traffic system (meeting a minimum level of safety) must always be maintained. For example, where problems occur due to unreliable ATC equipment, aircraft separations may have to be increased and capacity, therefore, is decreased. Safety is therefore a constraint on the system. The economic dis-benefits of reduced capacity can be quantified in an appropriate way, thus giving an “indirect” measure of safety benefits.

Consider the failure of a Flight Data Processing System (FDPS). Aircraft separations may have to be increased for safety reasons, leading to a reduction in ATC capacity that can be quantified financially via delays and unaccommodated demand. The more often the FDPS fails, the more frequent the reductions in capacity. If the system can be made more reliable by replacement then the benefits can be measured.

In this approach increasing safety does not have a direct benefit. This is because there is a minimum “target” level of safety to be met. If it is not met then restrictions are introduced, but there is no direct benefit in exceeding it.

G.3 QUALITATIVE APPROACH

Capacity, efficiency and reliability benefits can usually be quantified and compared to costs to give a net benefit. If the net benefit is positive, i.e. the quantifiable benefits outweigh the costs, the project may be deemed to be viable without the need for formal quantification of the safety benefits. If, however, the net benefit is negative, a subjective judgement is made as to whether the safety benefits are worth at least as much as the shortfall.

Consider the example of Oceanic clearance delivery by VHF datalink. Pilots who wish to enter North Atlantic airspace from Europe have to request permission from ATC by voice communication. The use of a datalink would enable clearances to be given semi-automatically, enabling the ATC Service provider to re-deploy staff and save money. If use of VHF datalink costs the airlines, say, 50 ECUs per flight, and the cost savings are equivalent to 20 ECUs per flight, then there is a net cost of 30 ECUs per flight.

But the VHF datalink also has “safety” benefits. For example, it is expected to lead to a reduction in Gross Navigational Errors, reduce pilot workload and reduce communication errors. This benefit is difficult to quantify, so it is left to the decision-maker to decide whether the safety benefits are worth the additional 30 ECUs per flight. Being able to quantify some of the benefits of a project does clarify the nature of the decision to be taken, and thus enhances the decision-making process.

G.4 EXPLICIT APPROACH

This approach requires a monetary value to be placed on a “statistical human life” - it is termed the “Value of Life” (VoL) and can be a controversial approach. Safety benefits can be evaluated, based on the VoL, following which the approach for a “normal” cost-benefit study can be taken.

As an example, assume that the “cost” C of an incident such as a Mid-Air Collision (MAC) can be estimated, where N_d lives are lost, and all other financial consequences are denoted by O_{fc}. An explicit estimate of the VoL is required. It can also be assumed that the reduction in the risk (ΔR) of a MAC afforded by a particular project can be estimated. The potential safety benefit offered by the project would be as follows:

$$\text{Benefit} = C * \Delta R,$$
$$\text{where } C = N_d * \text{VoL} + O_{fc}$$

This approach seems simple in concept, but there are a number of problems, for example, who decides what the VoL is for aviation accidents? Estimates for other industries have produced a very large range of results. Such a range may be inevitable, and the uncertainty should be emphasised when conveying the results. Any improvement in collision risk - ΔR - is similarly very difficult to estimate.

One suggestion is that a “weighted average” of the cost of a MAC could be used. With relatively frequent events such as road traffic accidents this is probably justifiable, but with “High Consequence Low Probability” events - such as MACs - this is not always a useful approach. This is because there is no such thing as an average collision - there are too few MACs for the word “average” to be meaningful. The consequences of two B747-400s colliding over the centre of Paris and two small jets colliding over open countryside would be very different. The analysis also ignores the potential reduction in air travel demand that bad accidents could cause.

It is true that the lack of a definitive VoL, collision risk and accident scenario ensures that the “margins of error” in any explicit calculation of safety benefits will be large. However there is still merit in performing the analysis. The key point - as with CBA in general - is that such information is valuable to the decision-maker.

G.5 IMPLICIT APPROACH

This approach is more flexible in dealing with the VoL, combining some elements of the qualitative and explicit approaches. For a project concerned primarily with improving safety the cost of implementation over a given period is estimated, as are any directly quantifiable benefits. An estimate is made of how many lives would be expected to be saved over the same period as a result of implementing the project. The expenditure necessary to “save a life” - the “implicit” value of life - can be calculated.

This “implicit” VoL will vary from project to project, and should be regarded as just one of many factors to be considered by the decision-maker.

H. ENVIRONMENTAL BENEFITS

H.1 INTRODUCTION

Environmental issues, which in the aviation industry are primarily to do with noise reduction but also increasingly with engine emissions, can also be difficult to quantify. This section describes three approaches to appraising projects that involve noise. These are:

- the “Constraint” approach;
- the “Qualitative” approach;
- the “Quantitative” approach.

H.2 CONSTRAINT APPROACH

This approach is similar to that described for safety in Annex G, and rests on the premise that a certain noise limit, however defined, should not be exceeded. However maintaining this limit - or reducing it - may have economic dis-benefits. For example, if airport noise is deemed to be too high, capacity may have to be reduced. The economic dis-benefits of restricted capacity can be quantified in the usual way.

H.3 QUALITATIVE APPROACH

This approach is similar to that described for safety in Annex G. Capacity, efficiency and reliability benefits can usually be quantified and compared to costs to give a net benefit. If the net benefit is positive, i.e. the quantitative benefits outweigh the costs, the project may be deemed to be viable without requiring any consideration of environmental issues.

If, however, the net benefit is negative, a subjective judgement is made as to whether the environmental benefits are worth at least as much as the shortfall. That is, would aircraft operators/ATC service providers be prepared to pay this amount in order to maintain the quality of the environment?

H.4 QUANTITATIVE APPROACH

A generic approach can be taken to quantifying noise. Such an approach is described below, although the specifics may vary.

First, the noise “footprint” - the area affected by noise - must be identified. This can be done with a model that permits the noise of different aircraft types on specified flight paths to be measured. The most common measures usually deal with two characteristics of noise, namely:

- the number of noise events that occur in a given time interval and;
- the noise intensity.

The measures can be combined to form an index - the Noise Exposure Index (NEI). Any NEI will be scaled in decibels and will typically represent the cumulative impact of aircraft noise over a 24 hour period, weighted for the time of day. It is therefore possible to measure the noise that currently exists and to estimate the noise that would exist after a change in the aircraft type mix, flight path, or other variables.

The effect of noise can most readily be seen in the change in property values in a noise-affected area. Studies have been undertaken that measure the impact of noise - or its reduction - on the value of property. The NEI can be linked to property prices. For example, an increase of 1 unit in the NEI may result in a decrease in property values of, say, 1.5%. The aggregate decrease in property values represents the dis-benefit of the increased noise. A decrease in the NEI will result in an increase in aggregate value.

This approach has further been developed by academia. The benefits of noise reduction can be viewed as equal to the maximum amount all impacted parties would be willing to pay to avoid the noise. The method described above can therefore be refined by linking the change in aggregate property values to how much the affected parties would be willing to pay to avoid the noise. This amount is usually approximated as half of the noise-produced decline in aggregate property values. However the calculation described above is likely to have a fairly wide margin of error, so the merit in taking the analysis this far is probably limited.

I. SIMULATION TOOLS

I.1 INTRODUCTION

The discussions in Section 3.4 of this document and in Annex E note that simulation models and other supporting tools may be of use in the estimation of capacity benefits. This annex describes the types of models available and their applicability to different types of analysis, and gives details of two specific models developed by the EUROCONTROL Experimental Centre (EEC), Brétigny.

I.2 REAL-TIME SIMULATIONS

In general, the goal of real-time simulations is to observe the performance of a controller when using a particular type of human-machine interface to control a simulated air traffic scenario. Such simulations are designed to evaluate the benefits, in terms of capacity, efficiency or safety, of at least one of the following:

- a new human-machine interface;
- a new airspace organisation;
- new controller procedures.

The results of a simulation are gathered by observation of the controller, and by recording and measuring the events and aircraft movements that occurred. Results of interest might include total controller workload, or a subset of workload such as the frequency and duration of voice communications to aircraft. Real-time simulations are expensive to run since they rely on the use of operational staff and, because they operate in real time, it is difficult to explore a wide range of scenarios. Real-time simulators are operated by most civil aviation authorities.

I.3 FAST-TIME SIMULATIONS

Fast-time simulations differ from real-time simulations in that the operations performed by the controller are also included in the model. Fast-time simulators do not therefore require the direct involvement of controllers and operate many times faster than real-time simulations. This enables a statistically significant number of runs to be performed for a particular set of input parameters. In addition, fast-time simulations can be used to test the sensitivity of the system to the variation of a particular parameter.

In general simulations are performed using real operational data as input conditions. Fast-time simulations are often used to evaluate the impact of future developments in, for example, ATC procedures prior to more detailed investigations using real-time simulations .

I.4 ANALYTICAL MODELS

Analytical models are analogous in concept to fast-time simulations, but use a set of analytical equations rather than a complex numerical model. Analytical models can, in general, be implemented using a simple computer program or spreadsheet, and have the advantage that they are fast to run and can therefore be used to perform sensitivity analyses on particular parameters, prior to the use of a more complex fast-time simulation.

Another significant difference between analytical and fast-time models is in the type of input data used: statistical averages (e.g. average flow rates) tend to be used for analytical models, whereas fast-time simulations use actual traffic samples.

I.5 MODELLING DELAYS

While the occurrence and length of delays could be predicted using modelling techniques such as those described above, there are a number of potential difficulties with this approach:

- the duration of a delay depends on a range of parameters such as number of aircraft in the queue, aircraft position in the queue, aircraft type, etc.;
- values for many of these parameters vary depending on local conditions and are difficult to estimate;
- the effect of knock-on delays is difficult to predict and quantify;
- the policy used by operators to accommodate delays is uncertain: for example, some operators would prefer to incur the cost of delays in the air rather than on the ground because air delays are perceived as more acceptable to customers.

I.6 EUROCONTROL MODELLING TOOLS

As an initial step towards identifying appropriate tools to support cost benefit studies, members of the ECBAG reviewed two simulation models, RAMS and NASPAC/CASA, developed at the EEC, Brétigny. The review assessed the extent to which these models could be applied in CBAs of EATMP projects, recognising that it would be unlikely that a single tool would be appropriate for all sizes of project, types of benefit and levels of analysis.

Reorganised ATC Mathematical Simulator (RAMS)

RAMS is a fast-time simulation tool that models airports, airspace and operating procedures. RAMS can be used to measure the impact of changes to the airspace structure on controller workload, enabling some estimate of the capacity increases associated with a reduction in workload. It also has the flexibility to support other types of studies into, for example, direct routeings or fuel burn penalties incurred due to delays at airports.

The RAMS baseline scenario utilises information from the Data Bank EUROCONTROL, and includes details of airports, airspace, routeings, traffic samples and aircraft performance data. A database of controller tasks (planning, routine and conflict) enables flexible controller workload modelling.

These characteristics can be amended and tested, e.g. the airspace can be redrawn, routeings amended, separations altered, length of controller tasks adjusted and the traffic sample grown.

Cost/benefit-related statistics produced include changes in controller workload (which can be converted into increases/reductions in capacity), extra distances flown, delay times, fuel burn and penalty of not achieving requested level. Graphical displays of traffic distribution, workload times, etc., can be extracted by sector and over any specified time period.

The resource required to use the model can be very large. A decision would have to be made as to whether the size and importance of a particular project warranted the anticipated amount of resource to be used. Using RAMS to assess a large project that requires international co-ordination might produce a large body of information about the impact of likely scenarios on ATM in the ECAC area, but this has to be weighed against the amount of time required to set the parameters of the scenario.

National AirSpace Performance Analysis Capability/Computer Assisted Slot Allocation (NASPAC/CASA)

NASPAC measures the effects of changes to airspace restrictions (e.g. sector capacities) and expresses these in terms of time delays to flights. NASPAC is intended to be of value in long-term macroscopic studies, such as major route or sectorisation changes. The EEC has developed the interface of NASPAC with the slot allocation facility, CASA, to produce an integrated simulation environment.

The input required includes a traffic sample from one or more 24-hour period; files for route networks, flight profiles and sectors, airports and, if necessary, arrival and departure fixes; details of aircraft types and their performance levels; and the values of the capacity restrictions to be applied.

NASPAC runs the simulation based on the slot allocation determined by CASA and produces the output statistics for analysis. CASA computes the take-off time for regulated flights within the defined region based on the traffic sample and airspace restrictions fed into it by the interface with NASPAC. CASA calculates the “best” departure slot for each flight, i.e. the slot with the minimum number of restrictions, and measures delays in terms of the difference between the requested and allotted slot time, or in terms of additional flying time if re-routeing is deemed necessary.

In general the amount of detailed information that can be extracted after the simulation is not as wide-ranging as with RAMS. Fuel burn and other delay costs can be ascribed to the calculated delay times and split by sector and aircraft type but, in general, the main use of NASPAC/CASA would be to achieve a high-level estimate of the magnitude of overall benefits for a future airspace scenario.

Conclusions

Because NASPAC/CASA does not model so many aspects of the airspace in as much detail as RAMS it is likely to be better suited to high-level scoping studies where the impact on traffic flow of large-scale changes in the structure of the airspace are measured in terms of ground or airborne delays to flights. Sector capacities have to be set in advance, therefore a clear vision of what a project is intended to achieve is essential. Similarly, as noted above, the type of results produced by the model are better suited to high-level studies.

For assessment of smaller projects under the EATMP umbrella, RAMS enables particular aspects of the ATM system to be “picked off” for detailed study, with the parameters being easily changed so that different options can be investigated. It may be useful to adopt an iterative approach to the two models: the general magnitude of benefits could be scoped using NASPAC/CASA, followed by focusing on specific areas of potential benefit using RAMS to achieve a more precise assessment.

The data records of RAMS and NASPAC/CASA, once fully validated, should be adapted to the needs of the EATMP CBA database, as described in Section 3.5.

J. NET PRESENT VALUE (NPV) METHOD

J.1 INTRODUCTION

To calculate the NPV for each project option the following must be determined:

- Analysis period: Benefits cannot be claimed to accrue indefinitely, otherwise they could be infinite. Therefore an analysis period must be set which covers the project lifetime. The analysis period will vary from project to project. For example:
  - in the case of a project that will deliver new operational ATC equipment, it might be assumed that the equipment would need replacing after 10 years. This would be a reasonable lifetime and analysis period for CBA purposes;
  - in the case of a new building for housing ATC facilities, the lifetime and analysis period would probably be longer - of the order of 40 years.

  All similar projects and project options should be compared over the same analysis period. In general:

  - the analysis period should cover the first year in which there will be expenditure on the project and should not be a past year;
  - previous expenditure should be regarded as sunk cost, unless a product of that expenditure could be used for another purpose outside of the project;
  - the end of the analysis period should be such that the operating life of the project falls just within the analysis period. If circumstances dictate that this is not possible, e.g. lack of input data forces the end date to be well within the operating life, then the analyst has to ensure that the shorter time period does not favour one project option at the expense of another.
- Constant price year: This should be the most current year for which equipment (and other) prices are available and should ideally be the first year of the analysis period. Price levels in this year are termed constant prices. Cases may arise where it is not ideal for the constant price year to coincide with the first year of the analysis. In such cases, the constant price year must be stated explicitly.

J.2 DISCOUNTING

Before an NPV value can be derived the costs and benefits must be “discounted”. Investment projects differ in the time patterns of their costs and benefits. Some require a great deal of initial investment, show no returns for a number of years, but have long periods of productivity thereafter. Others yield benefits more quickly but may have only brief useful lives. The differences between the time patterns are important when making investment decisions.

The value of a future sum as seen from the base year (also known as Year 0 - usually the current year) is known as its Present Value (PV). The present value of an amount of money, M, to be received (or paid if it is a cost) in n years' time is obtained by the following formula:

$$\text{PV of M} = M * (1+r)^{-n}$$

where r is the (real) discount rate.

Discounting allows the analyst to calculate **Present Values (PVs)** of streams of costs and benefits over a project's lifetime and to compare them with reference to the base year. The cash flow becomes a **Discounted Cash Flow (DCF)**. The NPV is simply the sum of discounted benefits minus discounted costs. The projects and project options with the highest NPVs are the most financially beneficial. Negative NPVs indicate that the PV costs are greater than the PV benefits.

J.3 INFLATION

It is important to draw a distinction between *discounting*, to allow for the time-value of money, and *inflation* which causes changes in price levels. The method described above uses a base reference year to compare streams of costs and benefits, using "real constant prices" - that is, ECUs of the base year in this case. This ensures that different projects' cash flows can be appraised within the same terms of reference. All inflationary effects must be removed before this can be done. For example, if costs and benefits are expressed in "nominal" (or out-turn) Year 5 prices, they must first be deflated to "real" Year 5 prices before being discounted to "real" Year 0 prices.

J.4 EXAMPLE

An example presentation of the costs and benefits for a project, together with a cash flow and NPV calculation is shown below in Table J-1.

Table J-1 ***Example of discounted cost flow analysis***

Option 1	**in MECU**							
Project A	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**
COSTS								
Radar Ground Station Investment	5.4	8.7						
Radar Ground Station Operating			0.2	0.2	0.2	0.2	0.2	0.2
Transition (ie Parallel Operation)			1.0	1.0	1.0			
BENEFITS								
Reduced Maintenance					7.2	7.2	7.2	7.2
NET VALUE (REAL)	-5.4	-8.7	-1.2	-1.2	6.0	7.0	7.0	7.0
Discount Factor (8% per annum)	$(1.08)^{0}$	$(1.08)^{1}$	$(1.08)^{2}$	$(1.08)^{3}$	$(1.08)^{4}$	$(1.08)^{5}$	$(1.08)^{6}$	$(1.08)^{7}$
NET VALUE (DISCOUNTED) or PV	-5.40	-8.06	-1.03	-0.95	4.41	4.76	4.41	4.08
NET PRESENT VALUE (NPV)	2.22							

K. SENSITIVITY ANALYSIS

K.1 KEY PARAMETERS

Sensitivity analysis represents a systematic variation of key parameters within a specific range and is aimed on studying their effects on the economic measures of the project viability - such as NPV, Benefit/Cost Ratio, IRR, or pay-off period. The sensitivity analysis needs to examine the sensitivity of the project's (economic) performance to the variation of individual parameters in order to identify the most critical issues and the degree of their impact, as well as to define "pessimistic" and "optimistic" scenarios that, in addition to the NPV analysis results of the "baseline" scenario, have to be integrated into the final assessment of the CBA.

Sensitivity analysis can also be considered for qualitative benefits, although this will not affect the economic analysis.

The most significant parameters to be considered in the conduct of a sensitivity analysis will vary from project case to project case. However, the following list contains factors generally important for such an impact analysis:

- projected traffic growth in absolute terms and with respect to the traffic mix;
- capacity increase achieved by the project;
- efficiency improvement in terms of average delay, lateral and vertical flight profiles;
- ATM system costs (ground and space), particularly investment costs (purchase prices, installation/introduction) and staff costs;
- unit costs of avionics;
- user direct operating costs;
- financial parameters, such as discount or interest rates;
- project time scales (transition time, implementation/introduction and decommissioning schedule, project life).

After calculating the economic indicators (NPV, B/C Ratio, IRR, etc.) for the "baseline" scenario, the sensitivity analysis begins with the selection of the key parameters to be analysed. Next, the economic performance measures are determined by varying the individual parameters. This should initially be done for each parameter separately, with all other parameters remaining constant. The range will need to be chosen according to the accuracy of the input data.

Table K-1 illustrates a range of 10% in steps of 5% from the baseline scenario.

The parameter variations in relative terms should apply to the whole project life cycle. The ranges of relative parameter variation may be chosen as equal for each factor to be analysed or may be individually set depending on the assessment of the specific data reliability. Independently, experience has proven that a sensitivity analysis usually only leads to realistic conclusions if relatively small percentage variations in the key parameters are applied.

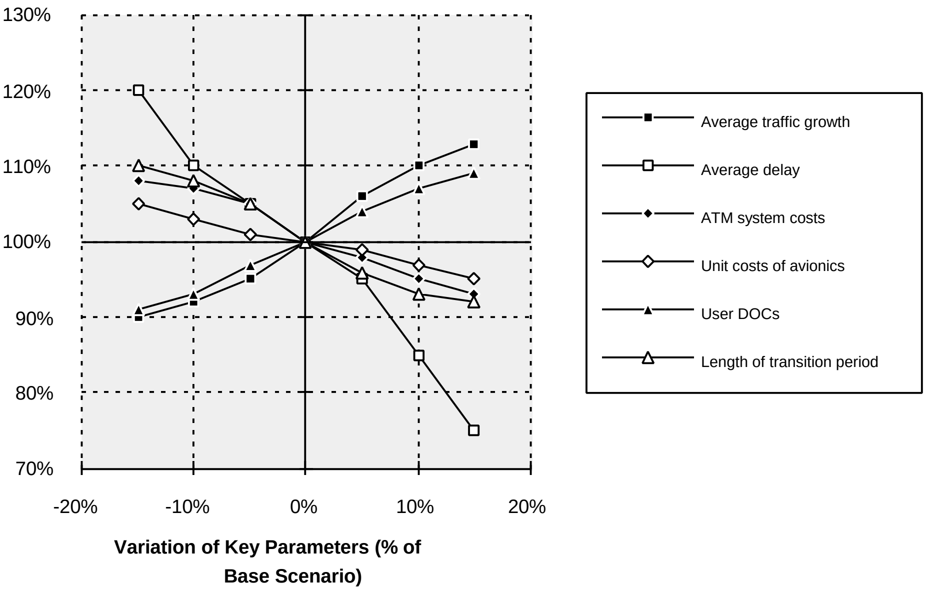
For the purpose of performing the sensitivity analysis the calculation method developed to determine the values of the economic measures of the "baseline" scenario should be applied. Since it is assumed that the analysis will be conducted using a PC-based spreadsheet application, computing the economic viability indicators for varying input or operational performance data should be possible with an acceptable effort. Normally it should not be necessary to repeat complex operational system evaluations - possibly supported by fast-time simulation tools - for the purposes of analysing various sensitivity scenarios. The sensitivity analysis assumes particular levels of uncertainty in the findings of such a system evaluation (e.g. variations in airspace capacities, average delays, lateral and vertical diversions from most "desired" flight path) and analyses those on the basis of the straight-forward economic analysis scheme being applied earlier.

Table K-1 **Analysis of variations of key parameters and their economic impact**

Project Option	*Variation in Key Parameters (% of base scenario)*									
	-10%		-5%		Base (0%)		+5%		+10%	
Key Parameters	NPV	B/C	NPV	B/C	NPV	B/C	NPV	B/C	NPV	B/C
Traffic growth										
Unaccommodated demand										
Efficiency increase avg. delay avg. lateral div. avg. vertical div.										
ATM system costs investment costs staff costs										
Avionics costs										
User DOCs										
Interest/discount rates										
Project time scale transition time implement. date										

Having computed the economic performance measures for various parameter variations, the results should be generated in a sensitivity analysis diagram. On the basis of such a illustration of the sensitivity analysis results, the most critical factors and the degree of their impact can be easily identified. Figure K-1 provides an exemplary sensitivity analysis plot. In this case the economic performance of the project option - measured in NPV - is highly sensitive to variations in the achieved average delay. The most optimistic case (average delay 15% lower than assumed in baseline scenario) would see a NPV increase of 20%, whereas the opposite scenario (15% higher average delay) would reduce the NPV of the option by around a quarter. On the other hand the project seems to be relatively insensitive to the assumed unit costs of avionics.

Figure K-1 Sensitivity analysis diagram



K.2 SCENARIO MODELLING

In addition to the variation of individual key parameters, the sensitivity analysis should also define and analyse "pessimistic" and "optimistic" scenarios where parameter variations are assessed on an aggregated level, meaning that changes in their values are assessed jointly. Though it should be considered that such "pessimistic" and "optimistic" scenarios can rarely be precisely defined, the previously performed analysis of individual parameters on the basis of defined ranges of factor variation can serve as an orientation. In addition to the "baseline" scenario, a "low" and "high" cost scenario, as well as a "low" and "high" benefit scenario need to be defined. While the cost scenarios should contain the extreme values for ATM system costs or unit costs of avionics (e.g. ±15% of cost figures assumed in the "base" scenario), the benefit scenarios need to cover the ranges of variation for traffic growth, capacity increase, efficiency improvement and/or transition time.

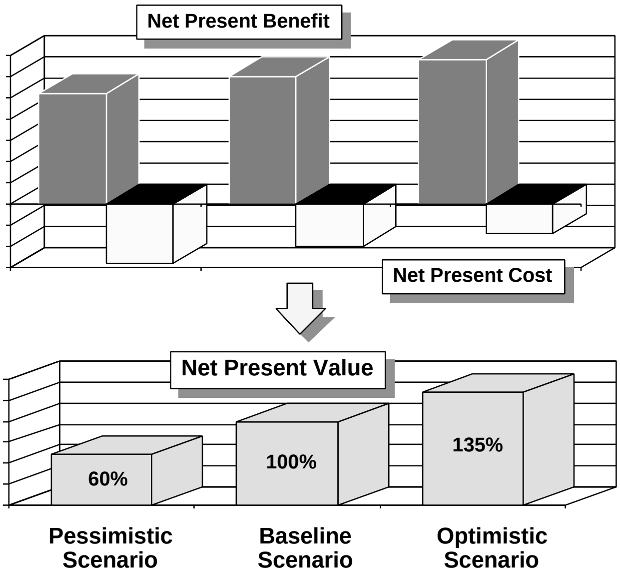
As Figure K-2 illustrates, this will lead to eight scenarios additional to the "base-line" scenario, with two extreme cases; the most "pessimistic" scenario ("high" costs and "low" benefits) and the most "optimistic" scenario ("high" benefits and "low" costs). The values provided in Figure K-2 and in supporting Figure K-3 illustrating the impact on net present benefits, costs and incomes, are exemplary.

Again the calculation method developed to determine the economic performance for the "base" scenario should be applied. Under the premise of using a PC-based spreadsheet tool the complexity level of this scenario analysis should be relatively low.

Figure K-2 Scenario modelling

Benefit Scenarios		Cost Scenarios: Low	Cost Scenarios: Base	Cost Scenarios: High
		ATM System Costs -10% Avionics Costs -5%	ATM System Costs Base Avionics Costs Base	ATM System Costs +10% Avionics Costs +5%
Low	Traffic Growth -10% Unacc. Demand +5% Avg. Delay +15% Opt. Profiles -10%	NPV: 95% of Base Scenario	NPV: 80% of Base Scenario	**Pessimistic Scenario** NPV: 60% of Base Scenario
Base	Traffic Growth Base Unacc. Demand Base Avg. Delay Base Opt. Profiles Base	NPV: 110% of Base Scenario	**Baseline Scenario** NPV: 100% of Base Scenario	NPV: 85% of Base Scenario
High	Traffic Growth +10% Unacc. Demand -5% Avg. Delay -15% Opt. Profiles +10%	**Optimistic Scenario** NPV: 135% of Base Scenario	NPV: 125% of Base Scenario	NPV: 105% of Base Scenario

Figure K-3 Presentation of different scenarios



The findings of the analysis of the most critical individual parameters and their impact on the economic viability of the project, as well as of the analysis of the economic consequences for various cost and benefit scenarios ("pessimistic" and "optimistic" scenario analysis) need to be integrated into the final comparative appraisal of the competing project alternatives. A CBA exclusively relying on a NPV analysis for a "base" scenario is usually not sufficient, due to the large amount of uncertainty involved in any system appraisal of future time intervals.

In many CBA studies such a "classical" sensitivity analysis is seen as sufficient, although it may be necessary to consider more advanced techniques such as decision support analysis.

K.3 DECISION SUPPORT TOOLS AND PROBABILISTIC ANALYSIS

Decision support analysis aims to consider all of the important information available about a project and its operating environment, specifically the fact that the future performance of a system may be highly uncertain. This is different from the usual types of analysis which focus on the typical or most likely outcomes of a process. Decision support analysis uses probabilistic methods to determine the outcome of a choice and an example of this approach is shown in probabilistic sensitivity analysis.

Probabilistic sensitivity analysis allows input parameters to be varied independently according to a probability distribution. Example distributions are normal, Poisson, triangular, etc. This approach is much more flexible than simply using stepped changes to a baseline scenario. The result of the analysis will be a distribution of an output variable (e.g. NPV). Such a distribution can give a mean output, confidence intervals (e.g. 95% of outputs are greater than 100 MECU) and also an indication of the option with least risk (i.e. that with least spread in the output distribution). Inexpensive PC tools are available to conduct such analyses.