ICAO CIRCULAR

CIRCULAR 257-AT/106

1995

ECONOMICS OF SATELLITE-BASED AIR NAVIGATION SERVICES

Guidelines for cost/benefit analysis of communications, navigation and surveillance/air traffic management (CNS/ATM) systems

Approved by the Secretary General and published under his authority

INTERNATIONAL
CIVIL AVIATION
ORGANIZATION
MONTREAL • CANADA

Published in separate English, Arabic, French, Russian and Spanish editions by the International Civil Aviation Organization. All correspondence, except orders and subscriptions, should be addressed to the Secretary General.

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11/94

Foreword

1. The introduction of satellite-based air navigation services to replace many of the existing line-of-sight systems represents a quantum step forward for civil aviation. Following comprehensive studies over several years, the global "communications, navigation and surveillance/air traffic management (CNS/ATM) systems" concept was endorsed by the ICAO Tenth Air Navigation Conference in 1991 and by the 29th Session of the ICAO Assembly in 1992.

2. Apart from the evident technological benefits of the new systems, support for this endorsement had been supplied by a broad economic study which indicated that, at the global level, the benefits from the new systems greatly exceeded the costs of implementing them. The Air Navigation Conference recommended that States perform their own individual cost-effectiveness and/or cost/benefit analyses to determine how they would be affected by the new systems (Recommendation 6/1) and requested that ICAO provide assistance to States in carrying out these analyses (Recommendation 6/2, to which the Assembly subsequently attached high priority). These studies were to give consideration to such factors as the costs of transition to the new systems, including (re)training, which had not been included in the global study.

3. The guidance material presented in this circular is an important element of the envisaged assistance to States. It describes how to identify, measure and aggregate the incremental costs and benefits associated with the replacement of the existing communications, navigation and surveillance systems with the new CNS/ATM systems, and how to use this information to draw conclusions about the expected economic viability of the new systems and their economic impact on service providers (States) and users (air carriers). Guidance is also provided to assist in the choice of the most cost-effective approach to implementation. It will become clear that there is a large element of uncertainty in this process because of the difficulty of quantifying the impact of a number of relevant factors which will affect the actual economic outcome. Planning decisions will therefore require the exercise of judgement as well as economic analysis based on the techniques described in this document.

4. The guidance material presented in this circular is consistent with and complementary to the comprehensive explanatory circular "The ICAO CNS/ATM Systems: Coping with Air Traffic Demand" and to the "Global Co-ordinated Plan for the Transition to the ICAO CNS/ATM Systems", both of which were adopted in 1993 by the committee charged with developing the framework for introducing the new systems (known as the "FANS Phase II Committee"), were subsequently endorsed by the ICAO Council and are being published as ICAO Circular 251 and ICAO Doc 9629, respectively. The purpose of the circular is to present economic evaluation methodologies using illustrative configurations of CNS/ATM

systems and existing technology systems. It does not contain advice on technical specifications of systems. The guidance material draws on reports supplied by States on the subject of cost/benefit methodology and on the application of cost/benefit techniques to CNS/ATM investments. Of particular value was a CNS/ATM cost/benefit analysis guide prepared by the Canadian Government and its consultant (THA-MONENCO) and subsequently adapted for the FANS Phase II Committee (and referred to in this circular as the "FANS Guide").

5. The cost/benefit guidance material in this circular focuses on the methodological approach of Net Present Value, which takes into account transition costs and which is widely recognized and used by financial institutions such as those potentially involved in funding CNS/ATM. The methodology is presented using a step-by-step tabular approach which may be applied manually or through a computer spreadsheet; formatted spreadsheets using Quattro Pro or Lotus software to apply the approach used in this circular are available on diskette from the ICAO Secretariat on request. Some of the tables include calculations based on hypothetical assumptions about various cost and benefit elements. Analysts undertaking cost/benefit studies for particular airspaces must develop assumptions appropriate for those airspaces, using inputs from interested parties such as service providers, aircraft operators and equipment manufacturers.

6. The circular includes a glossary which provides brief explanations of the more common technical terms and acronyms. These explanations should be viewed as an aid to the general understanding of the reader and are not necessarily officially endorsed by ICAO.

7. Unless indicated otherwise, all references in this circular to "cents" mean U.S. cents, and all references to "dollars" mean U.S. dollars.

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Glossary

Please note: The explanations of the acronyms and technical terms provided here should be viewed as an aid to the general understanding of the reader and are not necessarily officially endorsed by ICAO. The reader should also recognize that there are ongoing developments in some of the technology and institutions.

ACARS	**ARINC communications addressing and reporting system.** A system for air-ground data link communication via aeronautical VHF channels allocated for that purpose.
ACAS	**Airborne collision avoidance system.** An aircraft system based on secondary surveillance radar (SSR) transponder signals which operates independently of ground-based equipment to provide advice to the pilot on potential conflicting aircraft that are equipped with SSR transponders.
ACC	**Area control centre.** A unit established to provide air traffic control service to controlled flights in control areas under its jurisdiction.
ADF	**Automatic direction finding system.** An aircraft radio navigation system which senses and indicates the direction to a L/MF non-directional radio beacon (NDB) ground transmitter.
ADS	**Automatic dependent surveillance.** A surveillance technique in which aircraft automatically provide, via a data link, data derived from on-board navigation and position-fixing systems, including aircraft identification, four-dimensional position and additional data as appropriate.
AMSS	**Aeronautical mobile-satellite service.** A system for air-ground communications via satellites using a frequency band allocated for aeronautical purposes.
ASM	**Airspace management.** A component of ATM with the purpose of maximizing, within a given airspace structure, the utilization of available airspace.
ATC	**Air traffic control.** A service whose objective is to prevent aircraft collisions and expedite and maintain an orderly flow of air traffic.

ATFM — **Air traffic flow management.** A service whose objective is to ensure an optimum flow of air traffic to or through areas during times when demand exceeds or is expected to exceed the available capacity of the ATC system.

ATM — **Air traffic management.** A broadly defined function which includes air traffic services, air traffic flow management and airspace management. Its objective is to enable aircraft operators to meet their planned times of arrival and departure and adhere to preferred flight profiles.

ATN — **Aeronautical telecommunication network.** An internetwork architecture that allows ground, air-to-ground and avionic data subnetworks to interoperate by adopting common interface services and protocols based on the International Organization for Standardization (ISO) Open Systems Interconnection (OSI) reference model.

ATS — **Air traffic service.** A generic term meaning, variously, flight information service, alerting service, air traffic advisory service, air traffic control service (area control service, approach control service or aerodrome control service).

CAA — **Civil aviation authority.** A term frequently used for the authority of a State responsible for the control of air navigation in the State's airspace.

CAT I — **Precision approach runway, category I.** An instrument runway served by ILS and/or MLS and visual aids intended for operations with a decision height not lower than 60 m (200 ft) and either a visibility not less than 800 m or a runway visual range not less than 550 m.

CAT II — **Precision approach runway, category II.** An instrument runway served by ILS and/or MLS and visual aids intended for operations with a decision height lower than 60 m (200 ft) but not lower than 30 m (100 ft) and a runway visual range not less than 350 m.

CAT III — **Precision approach runway, category III.** An instrument runway served by ILS and/or MLS to and along the surface of the runway and:

A — intended for operations with a decision height lower than 30 m (100 ft), or no decision height and a runway visual range not less than 200 m.

B — intended for operations with a decision height lower than 15 m (50 ft), or no decision height and a runway visual range less than 200 m but not less than 50 m.

C — intended for operations with no decision height and no runway visual range limitations.

CMU **Communications management unit.** Avionics equipment for managing the communications element of CNS/ATM on board the aircraft, including selection of the means of air-ground communications in a particular environment.

CNS **Communications, navigation and surveillance.** A system which includes the functions of communications, navigation and surveillance, all of which are necessary for the process of getting an aircraft safely and efficiently to its destination.

DGNSS **Differential global navigation satellite system.** An augmentation of GNSS, the purpose of which is to determine position errors at one or more known locations and subsequently to transmit the derived information to other GNSS receivers to enhance the accuracy of the position estimate.

DME **Distance measuring equipment.** Ground and aircraft equipment which provide distance information and primarily serve operational needs of en-route or terminal area navigation.

FANS **Future air navigation systems.** The name originally given to the future potential satellite-based air navigation systems and to the ICAO Committee assigned the task of identifying and assessing the new technology and making recommendations for the future development of air navigation. The FANS (Phase II) Committee was subsequently established for the development of a global plan for the transition to the new system.

FMS **Flight management system.** A pilot-interactive navigational computing and display system which is designed to assist in flying an aircraft, with maximum economy, to a previously planned route fully defined in terms of way-points and changes in altitude. The system is constantly updated with respect to positional accuracy by data received from various navigation aids.

GA **General aviation.** All civil aviation operations other than scheduled air services and non-scheduled air transport operations for remuneration or hire. GA includes instructional flying, business and pleasure flying and aerial work.

GAIT **Ground-based augmentation and integrity technique.** A ground-based component of the GNSS to monitor the integrity of GNSS. It may include a combination of facilities and techniques, for example, wide-area differential GNSS and pseudo-ranging signals.

GES **Ground earth station.** An earth station in the fixed satellite service, or in the aeronautical mobile-satellite service, located at a specified fixed point on land to provide a feeder link for the satellite system.

GLONASS	**Global orbiting navigation satellite system.** A navigation system based on the transmission of signals from satellites provided and maintained by the Russian Federation and available to civil aviation users.
GNSS	**Global navigation satellite system.** The ICAO name for a world-wide system for position and time determination that includes one or more satellite constellations, aircraft receivers and system integrity monitoring, augmented as necessary to support the required navigation performance for the actual phase of operation. GNSS-ranging services will be provided by GPS and/or GLONASS, at least over the medium term.
GPS	**Global positioning system.** A navigation system based on the transmission of signals from satellites provided and maintained by the United States of America and available to civil aviation users.
HF	**High frequency.** The frequency band between 3 MHz and 30 MHz, which is normally used for long-range, over-the-horizon communications.
IFR	**Instrument flight rules.** Rules applicable to flights in instrument meteorological conditions. *Note.— Flights in accordance with IFR may also be conducted in visual meteorological conditions.*
ILS	**Instrument landing system.** A system composed of ground transmitters and an aircraft receiver which together provide guidance for precision approach and landing.
Inmarsat	**International Maritime Satellite Organization.** An organization established by international treaty to supply marine, land and aeronautical mobile communications services using a network of satellites and ground earth stations.
INS	**Inertial navigation system.** Self-contained navigation equipment that determines the aircraft position by sensing aircraft accelerations with a gyrostabilized platform; the system includes a control display unit.
IRS	**Inertial reference system.** Navigation equipment that determines aircraft position by sensing aircraft accelerations with a gyrostabilized platform and provides the information to the RNAV equipment or FMS.
MLS	**Microwave landing system.** A system composed of ground transmitters and an aircraft receiver which together provide guidance for precision approach and landing.

MNPS **Minimum navigation performance specifications.** A set of standards that require aircraft to have a minimum navigation performance capability in order to operate in MNPS designated airspace. In addition, aircraft must be certified by their State of Registry for MNPS operation.

NDB **Non-directional radio beacon.** A navigation aid consisting of a ground transmitter with an omnidirectional antenna pattern operating at low frequency (LF) or medium frequency (MF), and airborne direction-finding equipment.

NPV **Net present value.** The capitalized value of an investment project obtained by discounting to the present the expected flow of future benefits net of all costs.

OMEGA **Omega/very low frequency (VLF).** A long-range global radio navigation system. There are eight Omega transmitter stations located throughout the world; in addition, use is made of nine VLF communications transmitters. Airborne systems may use Omega alone or a combination of the two types of signals for the provision of positional and tracking guidance.

PSR **Primary surveillance radar.** Primary radar is a ground-based system which uses reflected radio signals to determine aircraft position.

RNAV **Area navigation.** A method of navigation which permits aircraft operation on any desired flight path within the coverage of station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these.

RNP **Required navigation performance.** A statement of the navigation performance parameters necessary for operation within a defined airspace. ICAO specifies navigation performance but not any particular types of navigation equipment.

SPS **Standard position service.** Navigation signals offered to civil users and provided by the United States GPS satellite system (as opposed to precision position services (PPS) reserved for military purposes).

SSR Mode A/C **Secondary surveillance radar, Mode A/C.** A radar system wherein a radio signal transmitted from the ground radar station (interrogator) initiates the transmission of a radio signal from the aircraft transponder. In the existing Mode A/C systems, the Mode A reply signal contains information on aircraft identification and the Mode C reply signal contains altitude information which is additional to the basic radar function.

SSR Mode S — **Secondary surveillance radar, Mode S.** An enhanced mode of secondary surveillance radar (SSR) which permits the interrogation of all SSR-equipped aircraft, and the addressed interrogation of suitably equipped aircraft and two-way exchange of digital data between such aircraft and the interrogator (i.e. the selective address and data link capabilities).

UAV — **Uniform annual value.** The average annual cash flow which is equivalent to a single capital (lump sum) value.

VFR — **Visual flight rules.** Rules applicable to flights in visual meteorological conditions.

VHF — **Very high frequency.** The frequency band between 30 MHz and 300 MHz, which is used for line-of-sight aeronautical applications.

VOR — **VHF omnidirectional radio range.** A navigation aid consisting of a ground transmitter and an airborne receiver which provides bearing information.

Chapter 1
Introduction

1. CNS/ATM AND ITS ADVANTAGES

1.1 The process of getting an aircraft safely and efficiently to its destination requires effective air traffic management systems supported by three key functions: communications, navigation and surveillance. **Communications** is the exchange of voice and data information between the aircraft and air traffic controllers or flight information centres. **Navigation** pinpoints the location of the aircraft for the air crew. **Surveillance** pinpoints the location of the aircraft for air traffic controllers. It includes the communication of navigation information from aircraft to traffic control centres which facilitates the continuous mapping of the relative positions of aircraft. ICAO calls the three functions the **CNS** systems and regards them as forming the basic support services of air traffic management (ATM) systems. While the functions are not new in aviation, both aircraft and their avionics have become more sophisticated. Rapidly improving satellite and computer technologies now make even more revolutionary advances possible.

1.2 The efficiency of air traffic control (ATC) services is largely dependent upon the available air-ground communications and surveillance capabilities. Several continental airspaces are covered by reliable air-ground communications and radar surveillance systems. Radar and very high frequency (VHF) radio communications work efficiently on a line-of-sight basis, i.e. where there is no obstruction between the sender and the receiver. Over long distances, however, the propagation limitations of the radio signal present problems. As a result, many flight information regions throughout the world rely on procedural systems for controlling air traffic, some with little or no automation support. This is particularly true in most oceanic areas where radar and VHF communications systems cannot be provided to cover vast areas of oceanic airspace. Instead high frequency (HF) voice communications, which are not restricted to line-of-sight, are used. HF communications, however, are subject to severe fading and interference.

1.3 The application of procedural ATC ensures an adequate level of safety, though at the expense of the most efficient flight profiles and system capacity. In general, flights must be planned via intermediate way-points rather than on the most direct routes and there is limited opportunity to make changes to the cleared flight profiles. This has an adverse effect on aircraft operating costs. Flights operating outside radar and VHF coverage are at present monitored on the basis of ATC clearances and current flight plan information describing the assigned route along which the aircraft is expected to fly. The aircraft position reports, transmitted via HF at relatively infrequent intervals, enable the controller to monitor the aircraft's progress and to ensure that it conforms to its air traffic control clearance.

1.4 The shortcomings of the present systems are due essentially to three factors:

a) the propagation limitations of current line-of-sight systems and/or accuracy and reliability limitations imposed by the variability of propagation characteristics of other systems;

b) the difficulty, for a variety of reasons, of implementing present CNS systems and of operating them in a consistent manner in large parts of the world; and

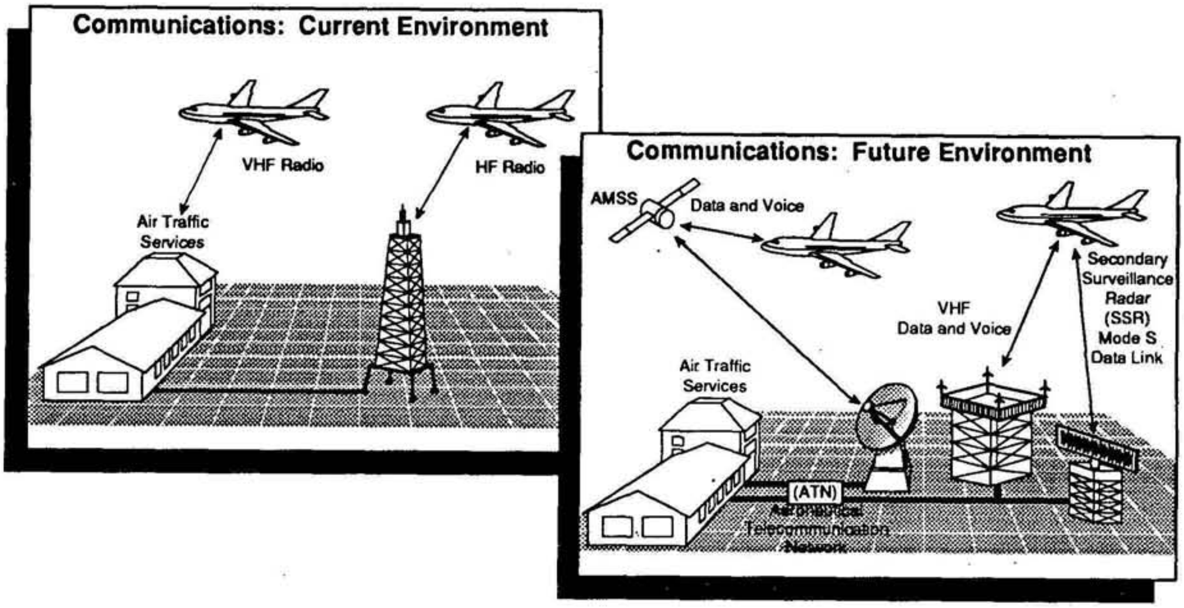
c) the limitations of voice communications and the lack of digital air-ground data interchange systems to support automated systems in the air and on the ground.

1.5 These limitations are intrinsic to the present CNS systems themselves and thus the problems cannot be overcome on a global scale except by new concepts and new CNS systems which will in turn support future ATM systems. The exploitation of satellite technology is the only viable solution that will overcome present limitations and meet future needs on a cost-effective global basis.

1.6 With the new CNS systems, **communications** with aircraft for both voice and data would be by direct satellite-aircraft link operating in the frequency band allocated exclusively to the aeronautical mobile-satellite service (AMSS). In terminal areas and where line-of-sight limitations are not a problem, VHF and SSR (secondary surveillance radar) Mode S would also be used. SSR Mode S will provide, together with independent surveillance, an air-ground data link for transmission of high-rate data for air traffic services (ATS) purposes. The communications system architecture provides for a range of capabilities from basic low-speed data to high-speed data and voice. The various communications sub-networks (AMSS, VHF data link, Mode S data link) will be integrated through an aeronautical telecommunication network (ATN). Simplified representations of both the current and the future communications environments are given in Figure 1-1.

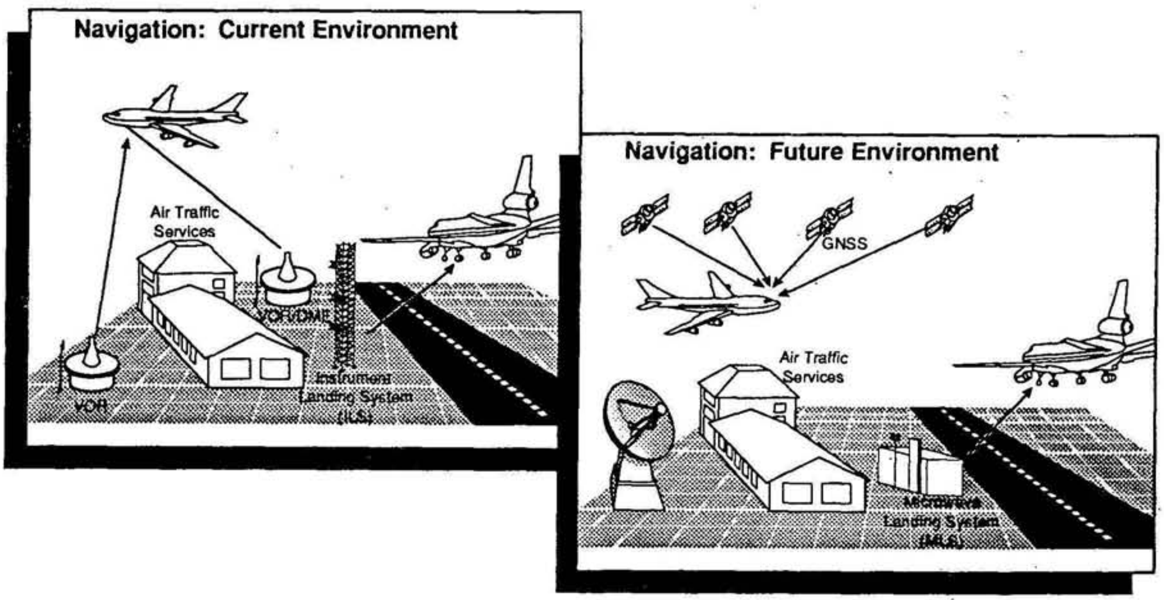
1.7 With regard to **navigation**, ICAO is developing the concept of required navigation performance (RNP) which will define the performance required in a particular airspace or phase of flight and enable that required performance to be achieved with any of a variety of navigation equipment. The ICAO system concept is, however, quite definite in its preference of the global navigation satellite system (GNSS) for navigation. This system includes satellite constellations, aircraft receivers and integrity monitoring facilities. ICAO sees GNSS as providing independent on-board position determination and as being the key feature of the future concept. It is expected to evolve into the sole means of navigation and eventually replace the current long-range and short-range navigation systems such as Omega, non-directional radio beacon (NDB) and VHF omnidirectional radio range (VOR). Additionally, GNSS will provide global coverage and will be accurate enough to support en-route navigation and meet non-precision type approach needs, and perhaps also limited or even full precision approaches in the future. Simplified representations of the current and future navigation environments are given in Figure 1-2.

1.8 For **surveillance**, secondary surveillance radar, augmented by Mode S where traffic conditions warrant, will remain in wide use, especially in high-density areas. In other areas, particularly in oceanic airspace and in remote land areas, surveillance will be carried out by



Source: The ICAO CNS/ATM Systems: Coping with Air Traffic Demand.

Figure 1-1. Communication



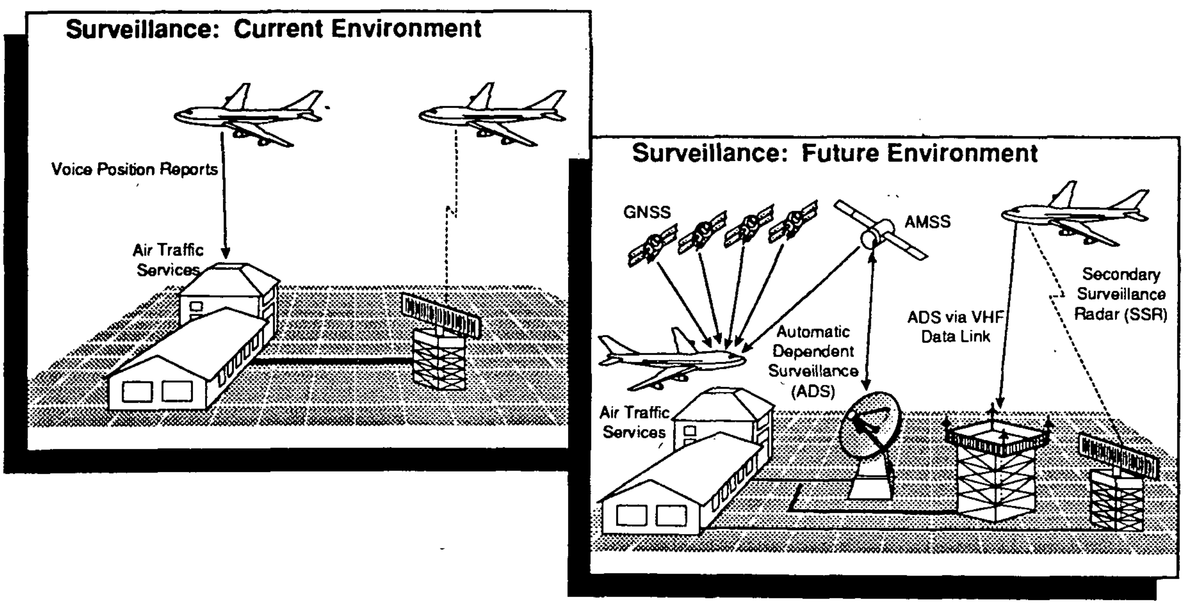
Source: The ICAO CNS/ATM Systems: Coping with Air Traffic Demand. Note that it is possible that Differential GNSS may be used instead of MLS to support precision approach and landing in the future (see Chapter 5, Section 3).

Figure 1-2. Navigation

automatic dependent surveillance (ADS). With ADS, the aircraft automatically transmits its position (derived from on-board navigation systems) to air traffic service centres via satellite or other communications link. This will provide comprehensive surveillance information in areas where few or no surveillance services are available today. Simplified representations of the current and future methods of surveillance are given in Figure 1-3.

1.9 As regards ATM, the new CNS systems will provide for a closer interaction between the ground systems and the aircraft systems before and during flight. Thus they will permit a more flexible and efficient use of airspace, both en route and in terminal areas. Implementation of the CNS/ATM systems will also support increased traffic in terminal areas.

1.10 The flexibility afforded by the CNS systems will facilitate the automation of ATM systems, from the simplest to the most advanced, in a globally consistent fashion. Together, the new systems are expected to result in improved data handling and transfer of information between operators, aircraft and units providing various air traffic services; extended surveillance by ADS; and advanced ground-based data processing systems. ATM can then evolve by taking advantage of improved navigation accuracy; improved accommodation of a flight's preferred profile in all phases of flight, based on the operator's objectives; improved conflict detection and resolution; automated generation and transmission of conflict-free clearances; and adaptation to changing traffic conditions. These developments, together with improved flight planning, will lead to more dynamic airspace and ATM, particularly in high-density airspace, and are essential for coping with growth and reducing congestion.



Source: The ICAO CNS/ATM Systems: Coping with Air Traffic Demand.

Figure 1-3. Surveillance

1.11 The great advantage of the CNS/ATM systems for individual States is that they will be able to provide CNS services in a far easier manner than at present. Many States have difficulty installing and maintaining ground-based navigation equipment in harsh terrain such as jungles, mountains, seas and deserts. With the CNS/ATM systems in place, access to a satellite ground station will give a State a complete range of satellite services for aviation. It will thus be able to provide ATS over its entire area of responsibility. In addition, the GNSS will provide complete en-route navigation coverage over the whole world without the need for ground facilities. The users of the air navigation system will enjoy particular economies. At present, aircraft follow fixed routes based on navigation aids installed on the ground. This creates congestion in some areas since all aircraft fly on the same routes. The CNS/ATM systems will allow departure from these fixed structures. This will reduce delays which airlines incur when they try to sequence themselves on the same air routes and will also enable them to fly more direct routes, with consequential savings in fuel, time and equipment.

1.12 The transition to CNS/ATM systems will be one of the largest undertakings ever carried out by the aviation community, not only because of the immense scale of the change but also because the transition will fundamentally affect how aviation administrations provide air traffic services. A broad indication of how the transition might proceed is as follows:

Present-1997	Continuing developments, trials and pre-operational demonstrations.
Present-2000	Gradual implementation and use of various elements of the system. Some aircraft and administrations will use the CNS/ATM systems with backup from the terrestrial systems.
2000-2005	Full CNS/ATM services available in parallel with existing systems so that appropriately equipped aircraft can have maximum operating benefits from the CNS/ATM systems.
2005-2010	The international terrestrial system not required for the CNS/ATM systems progressively dismantled.
2010	The CNS/ATM systems are the sole systems for international use.

In any such transition timetable, there will be a period when the CNS/ATM systems and the existing terrestrial systems are operating in parallel. While this period allows for aircraft operators to change their equipment, and for service providers to phase out those ground facilities which will no longer be required, maintaining two systems is very costly. The costs associated with transition are therefore an important component of the economic assessment of implementation of the CNS/ATM systems.

2. REASONS FOR COST/BENEFIT ANALYSIS

2.1 The providers of air traffic control services, the users of these services, and financing organizations all need to be advised of the financial implications, and convinced of the economic viability, of the new CNS/ATM systems. In addition to the assessment of over-all viability, it is important to determine the separate impacts on State administrations responsible for providing the services, and on airlines and other aircraft operators who use the services. For example, some State administrations may find that the capital and operational costs of the new system are greater than at present. On the other hand, any extra equipment and operational costs borne by the airlines are likely to be more than offset by the benefits they receive from more efficient flight paths made possible by the new system. In these circumstances, en-route charges may need to be adjusted to ensure that the costs to the service providers are fully recovered; the cost/benefit analyses can give guidance on the scope and scale of these adjustments.

2.2 There is a range of technical and institutional options for implementing the CNS/ATM concept. As examples of technical options, in some airspaces the communication element can be VHF (for voice and data), or satellite (voice and data), or SSR Mode S (data), or any combination of these. As regards institutional options, a State might independently supply services within its airspace or join forces with other States under various possible arrangements, including the use of delegated intermediaries. Since the costs and benefits associated with the CNS/ATM concept relate to the implementation plan, cost/benefit analysis can help a State or region choose the implementation option most appropriate to its circumstances.

2.3 Cost/benefit analysis can also provide guidance on the appropriate timing for implementation of various elements of the new system. The relative values of benefits and costs associated with implementation are likely to vary with volume of traffic. For example, it is possible that benefits from CNS/ATM will be more responsive than costs to traffic growth so that the new system will become more economically attractive as traffic increases over time. It is equally important to recognize that delays in implementation will mean loss of benefits in the near term. Cost/benefit analysis can take into account these facts and help identify the scheduling of investments which will yield the greatest reward over-all.

3. MEASURES OF ECONOMIC VIABILITY

3.1 The existing line-of-sight systems of communications, navigation and surveillance and associated air traffic management facilities provide air traffic control services necessary for the conduct of today's air transport task. The **performance** of the systems can, in principle, be measured by their impact on the capacity of the airspace to cope with the traffic volume; on the cost, safety, reliability and speed with which the air traffic task is undertaken; and on the environmental effects of air traffic.

3.2 The new CNS/ATM systems will change some of the performance measures identified above. Their purpose is to increase the capacity of the airspace and reduce the operating cost of the air transport industry and, at the same time, improve on or at least maintain the level of safety currently achieved by the industry.

3.3 A comprehensive economic evaluation, or cost/benefit analysis, of the new systems requires the prediction of their over-all performance during the planning period, which is then compared with the predicted performance of the existing systems. Since there are various dimensions of performance, a difficult challenge for such an evaluation is to combine these dimensions into a single performance measure by expressing each dimension in terms of a common unit of account (e.g. dollars).

3.4 The guidance material in this circular focuses primarily on the costs of operating the two (existing and new) ATC systems and on the impact of these two systems on the cost of operating the aircraft which perform the air traffic task. The major benefits from implementing CNS/ATM will be the cost savings from withdrawal of the ground-based facilities of the existing present-technology systems and the reduction in aircraft operating costs brought about because of increased airspace capacity and/or more direct flight paths. Passenger time savings resulting from CNS/ATM are identified as a separate benefit. It is assumed that the level of safety is unchanged as a result of implementation of CNS/ATM. Although it is expected that environmental costs will be reduced by CNS/ATM through increased efficiency of aircraft operations, this issue is not explicitly addressed.

3.5 The prospective economic viability of an investment project depends on the extent to which the total benefit from the investment exceeds its total cost. CNS/ATM is more complex than most projects and consists of a package of investments. Measures of the viability of the *new* investment package (the project case) are based on a comparison with the *existing* systems (the base case). The existing systems are defined to include their normal and expected maintenance and possible development over the planning horizon. The new facilities will replace the existing facilities; as the latter are phased out, so their costs can be regarded as benefits from installing the new systems. The most important benefits of CNS/ATM are the cost reductions from more efficient flight operations and reduced flight times which are expected to emerge as CNS/ATM is implemented.

3.6 A rigorous approach for developing a measure of the expected economic performance of an investment project is the Net Present Value (NPV) or life-cycle approach, which focuses on the annual flows of costs and benefits (cash flows) related to the project. The costs and benefits in cash flow terms will not be distributed evenly over time. Typically, there will be large capital expenditures in the early years of a new project followed by many years of benefits as well as of operating and maintenance costs. The present values (i.e. current year capitalized values) of each stream of cash flows associated with each cost or benefit item can be determined by a process of discounting the future cash flows. This process takes into account the effect of the rate of interest on the present value of each future cash flow. The present values of all the costs can then be aggregated; likewise, the benefits. Using these aggregated values, the following two alternative measures of the over-all viability of the project can be calculated:

a) $\text{Benefit/cost ratio} = \dfrac{\text{benefit}}{\text{cost}}$

b) Net Present Value = benefit minus cost

If measure a) is greater than one, or if measure b) is greater than zero, the project is economically viable (given the assumptions embodied in determining the benefits and costs).

3.7 Other more simplified approaches are available for determining the measure of economic viability. One such approach, here called the "snapshot" method, is based on accrual accounting concepts. Instead of capitalizing (as present values) the projected cash flows, the typical annual costs and benefits in a designated future year following the establishment of the new project can be estimated. Under this approach, the capital costs of the project are represented by the annual depreciation and interest associated with the new investment. The depreciation and interest saved by withdrawing the equipment of the existing system can be recorded as benefits, along with estimates of other annual benefits associated with the project. The annualized benefits and costs can be aggregated and the benefit/cost ratio calculated.

3.8 It is expected that the estimation of the monetary value of the future benefits from the implementation of CNS/ATM will be more difficult than the estimation of costs, at least as regards those benefits related to improved efficiency of aircraft operations. In some situations it may be acceptable to avoid attempting to evaluate these benefits and to restrict the analysis to determining the costs of achieving the goals associated with CNS/ATM. This approach is particularly relevant where the key issue is the choice of implementation option from among several competing technical or institutional solutions. The analysis will suggest the "least cost" option for providing the required quality and range of services.

4. GLOBAL ECONOMIC EVALUATION OF CNS/ATM

4.1 In 1988, the ICAO Special Committee on Future Air Navigation Systems (FANS) reported on the results of a global cost/benefit analysis for the new CNS/ATM systems. Many simplifying assumptions were necessary in order to reduce the analysis to manageable proportions. Thus, there were limits on the range of costs and benefits that could be considered and important questions of transition economics were not addressed.

4.2 The snapshot approach was adopted by FANS. The capital costs of the global CNS/ATM systems, which were assumed to be fully in place by the year 2010, were represented by estimates of the annual depreciation of the ground facilities, satellites and avionics equipment. Estimates of the annual maintenance and operating costs associated with the systems were added to the depreciation costs to derive a total annual cost of $1 011 million in constant 1987 prices.

4.3 The annual depreciation and maintenance and operating costs associated with the existing systems were estimated to total $1 068 million (in 1987 prices). This cost is avoided by the replacement of the existing systems with the new CNS/ATM systems and therefore appears as a benefit. The major source of benefit identified in the FANS analysis was the efficiency improvements for air carrier and general aviation (GA) aircraft resulting from the use of advanced CNS/ATM systems as compared with the present systems. It was estimated that more direct aircraft routings and improved tracking and scheduling of aircraft by airlines would produce annual gross benefits of between $4 146 million and $5 571 million.

4.4 These estimates of annual costs and benefits imply annual net benefits ranging from $4 203 million to $5 628 million and benefit/cost ratios ranging from 5.2 to 6.6.

4.5 Because of its adoption of the snapshot approach, the FANS analysis did not take into account the costs of transition from the existing system to the new system. Transition costs may include having to bring forward capital investment programmes (i.e. replace existing equipment before it is fully depreciated), or having to operate some of the existing facilities after the new facilities have been put in place, or incurring retraining costs during the transition. The FANS analysis also did not include the financing cost of capital (i.e. interest). Another important FANS assumption was that basic GNSS navigation services (not including integrity monitoring) would be available free of charge from systems already at least partly in place.

4.6 At the same time, some potential benefits from CNS/ATM were not evaluated by FANS. In particular, the new systems would reduce some of the costs related to traffic congestion and delays incurred as traffic demand expanded. ICAO has forecast that the total aircraft-kilometres flown by scheduled airlines will grow by 35 per cent during the 1990s provided the airport and airspace facilities can accommodate this growth. Further growth in demand is expected in the following decade. Although developments in the existing system could provide some expansion in capacity, it would probably be insufficient to cope with expected traffic demand. There is, therefore, a prospect of serious delays, and perhaps suppression of demand, without implementation of the CNS/ATM systems. The new systems can also accommodate aeronautical passenger communications, such as telephone and fax services for the travelling public. Although having a lower priority than safety-related communications, these passenger communications services nevertheless represent an additional benefit of CNS/ATM.

5. EVALUATION OF CNS/ATM AT STATE AND REGIONAL LEVELS

5.1 The first task in a cost/benefit study of CNS/ATM implementation in a State or region is the technological specification of the system options appropriate in the airspace of that State or region. This is addressed in Chapter 2. Chapter 3 considers some basic managerial and institutional assumptions which affect the magnitude and distribution of the costs and benefits of CNS/ATM implemented at the State and regional level. Chapter 4, the heart of the document, presents in detail the NPV methodology, including the measurement and aggregation of the costs and benefits and the derivation of the net present value and cost/benefit ratio. It includes 12 tables to illustrate step by step the recording of data and assumptions and the calculation of the cost and benefit items. The tables, done in spreadsheet format using Quattro Pro or Lotus, are also available on diskette. Several specific applications of the methodology are considered in Chapter 5, which also discusses the assessment of the impact on the results of changing the assumptions and parameter values (sensitivity analysis). In the final chapter, several alternative methods to NPV for economic evaluation are summarized, including the snapshot approach used by FANS.

5.2 In addition to the main text, there are two appendices. Appendix 1 provides some parameter estimates for possible use in the calculation of aircraft efficiency benefits. A list of references and other documents of direct relevance to a cost/benefit analysis of CNS/ATM systems is given in Appendix 2.

Chapter 2
Configurations of Alternative Systems

1. INTRODUCTION

1.1 In order to proceed with a cost/benefit analysis in a State or region, it is necessary to project the evolution over the planning horizon from the existing systems to the new CNS/ATM systems (Section 2) and to establish in detail the equipment configurations for the CNS/ATM systems (Section 3). The incremental costs and benefits of this development as compared with the projection of the existing systems over the same planning horizon can then be determined. The evolution of the systems and equipment configurations may be available in national or regional planning documents. The following framework may also be of assistance in this process.

1.2 The implementation of new systems involves change from the status quo, which raises the issue of incremental costs. This concept is explained in Section 4 of this chapter.

2. AIRSPACE TYPES AND SYSTEM EVOLUTION

2.1 The projection of the equipment configuration will vary with the type of airspace for which the study is being undertaken. Airspace types are defined by geographic factors and traffic density. Examples are:

a) continental airspace with low-density traffic;

b) continental airspace with high-density traffic;

c) oceanic airspace with low-density traffic;

d) oceanic airspace with high-density traffic;

e) terminal airspace with low-density traffic; and

f) terminal airspace with high-density traffic.

Table 2-1, produced by the FANS(II) Committee, illustrates for each of the navigation, communications and surveillance functions the evolution from the existing systems to the new systems in a number of different types of airspaces.

Table 2-1. CNS Systems evolution

Airspace	Function	Current system	Future system
Oceanic continental en-route airspace with low-density traffic[1]	Navigation	OMEGA/LORAN-C NDB VOR/DME Barometric altimetry INS/IRS	RNAV/RNP GNSS Barometric altimetry GNSS altitude INS/IRS
	Communications[2]	VHF voice HF voice	VHF voice/data AMSS data/voice HF voice; North and South poles only[3]
	Surveillance	Primary radar/SSR Voice position reports	ADS
Continental airspace with high-density traffic	Navigation	OMEGA/LORAN-C NDB VOR/DME Barometric altimetry INS/IRS	RNAV/RNP GNSS Barometric altimetry GNSS altitude[4] INS/IRS
	Communications[2]	VHF voice	VHF voice/data AMSS data/voice SSR Mode S data link
	Surveillance	Primary radar SSR Mode A/C	SSR (Mode A/C or Mode S) ADS
Oceanic airspace with high-density traffic	Navigation	MNPS OMEGA/LORAN-C Barometric altimetry INS/IRS	RNAV/RNP GNSS Barometric altimetry GNSS altitude[4] INS/IRS
	Communications[2]	HF voice	AMSS data/voice
	Surveillance	Voice position reports	ADS
Terminal areas with high-density traffic	Navigation	NDB VOR/DME ILS Barometric altimetry INS/IRS	RNAV/RNP GNSS MLS NDB[5] VOR/DME[6] Barometric altimetry INS/IRS
	Communications[2]	VHF voice	VHF voice/data SSR Mode S data link AMSS data/voice[7]
	Surveillance	Primary radar SSR Mode A/C	SSR (Mode A/C or Mode S) ADS[8]

1. Includes low-altitude, off-shore and remote areas.
2. The aeronautical telecommunication network (ATN) based on the International Organization for Standardization (ISO) open system interconnection (OSI) reference model provides for internetworking of aeronautical air-ground and ground-ground data links and is applicable to all airspace in future systems.
3. Until such time as satellite communications are available.
4. To be used where barometric altimetry is not functional, especially at high altitudes.
5. NDB will be progressively withdrawn.
6. VOR/DME will be progressively withdrawn.
7. Depends on outcome of feasibility studies.
8. The need for primary radar is reduced.

Source: Global Co-ordinated Plan for the Transition to the ICAO CNS/ATM Systems.

2.2 In some remote areas, the services provided by the current system are limited because the facilities are scarce or absent, a situation that might continue (at least in some areas) if CNS/ATM is not implemented. The new satellite systems will be especially beneficial to the quality of service in these areas.

2.3 A State would normally have ATC responsibility for more than one type of airspace, each with different CNS/ATM requirements. Cost/benefit analyses might be undertaken for each type of airspace, but it may be more appropriate to merge the airspaces and carry out one analysis for the combined airspace.

3. EXAMPLES OF CNS/ATM EQUIPMENT CONFIGURATIONS

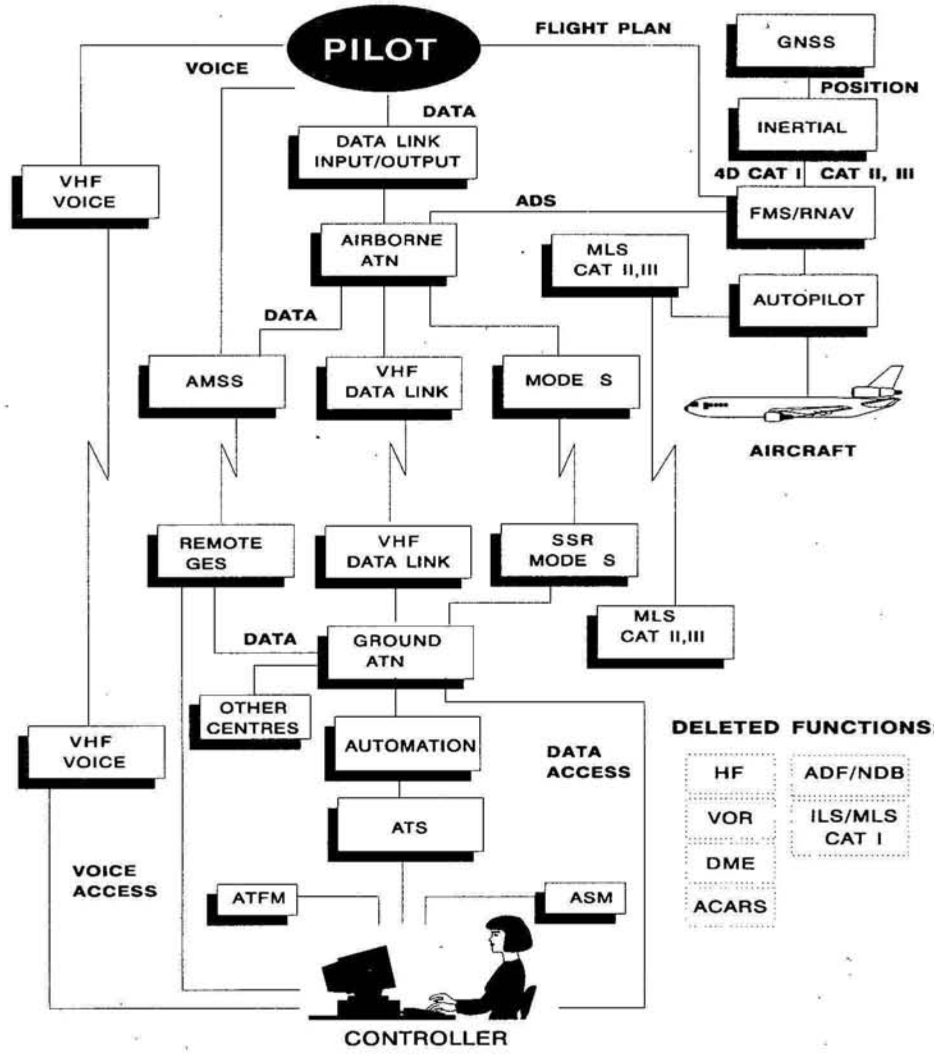
3.1 More detailed specifications of the systems and equipment configurations on board aircraft and on the ground must be developed by operational and technical experts. The required quantities of equipment for each airspace can then be estimated and costs derived.

3.2 Figure 2-1, taken from the FANS Guide, illustrates the configurations of the full CNS/ATM system components in the aircraft and on the ground, which would apply in high-density airspaces. The AMSS and GNSS systems each have space (satellite) components which are not shown separately in the figure. In addition to the CNS components, the figure shows the ATM elements (which were not given in Table 2-1), the Category II and III Microwave Landing Systems (MLS) and the Aircraft Flight Management System (FMS). The FMS receives input from the GNSS and inertial navigation systems, provides ADS messages and interacts with ATM automation functions on the ground. Existing systems, which will no longer be required when the new CNS/ATM systems are fully in place, are indicated in the figure (deleted functions).

3.3 Differential GNSS systems (DGNSS) are potential augmentations of GNSS for precision approach and landing and hence potential alternatives to MLS. DGNSS systems are the subject of intensive research and development, and their adoption by the civil aviation community is currently under consideration. This issue is examined further in Chapter 5.

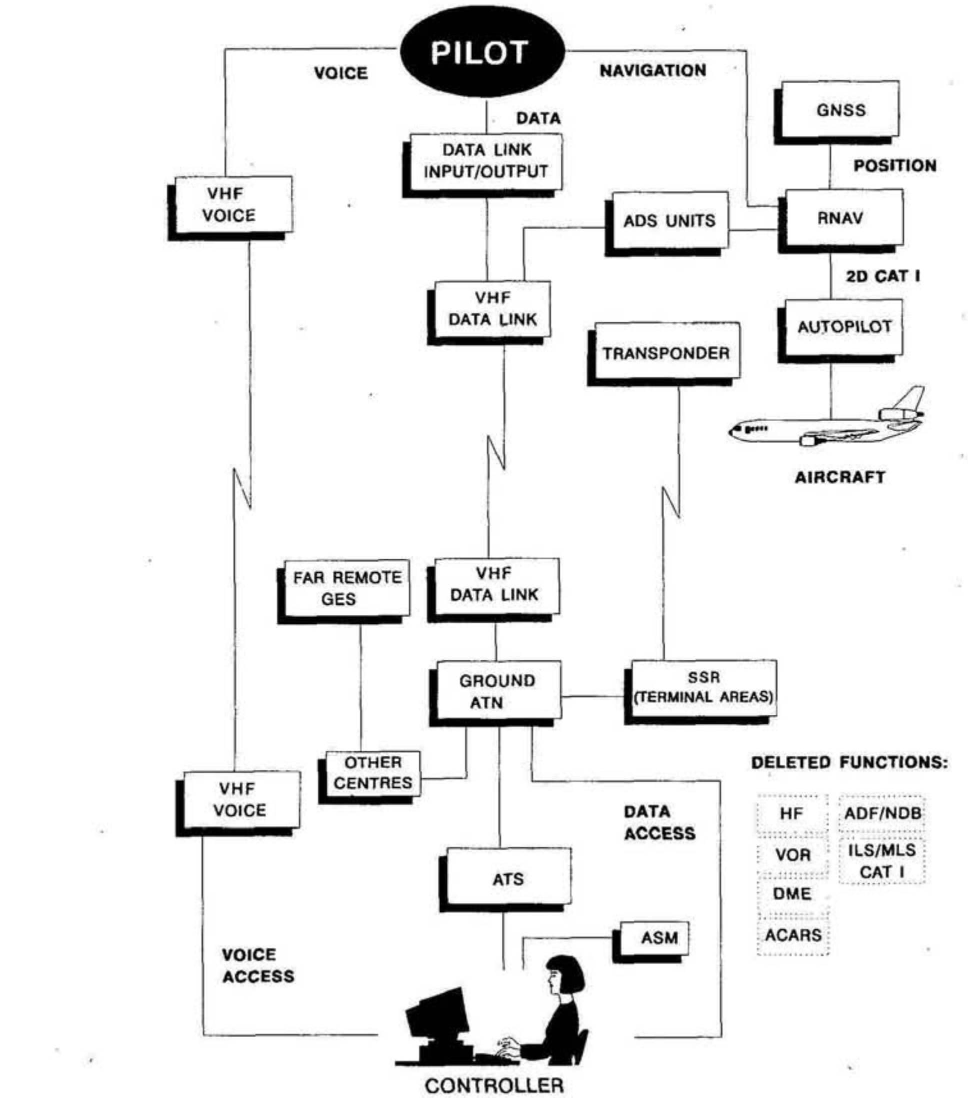
3.4 Implementation of CNS/ATM may require expenditure on ground components of the Aeronautical Telecommunications Network (ATN). The ATN provides for the transfer of data between communications subnetworks, accommodating differences in the technologies and protocols which apply in these subnetworks. ATN routers, which must observe common inter-networking conventions and standards, select ground and aeronautical subnetworks based on user-specified communication requirements and subnetwork availability.

3.5 Development of ATM systems and automation in air traffic control centres is another aspect of CNS/ATM implementation. Automation in air traffic control centres involves data processing and communications and requires computer hardware and software. It is used to support Air Traffic Services (ATS), Air Traffic Flow Management (ATFM) and Airspace Management (ASM), which together make up the function of Air Traffic Management (ATM). Expenditure in these areas may be linked closely with the evolution of the CNS systems and may be necessary to achieve the benefits expected from the total system. However, some of this expenditure would also have occurred under the existing



Source: The FANS Guide.

Figure 2-1. Full CNS/ATM Systems Aircraft and Ground Components



Source: The FANS Guide.

Figure 2-2. Partial CNS/ATM Systems Aircraft and Ground Components

systems and therefore might not be included in the cost/benefit analysis as an incremental cost associated only with CNS/ATM. Where this is the case, it is important also to exclude any benefits attributable directly to this expenditure.

3.6 Figure 2-2, also from the FANS Guide, illustrates the components of partial CNS/ATM systems both in the aircraft and on the ground. This lower cost configuration might apply in a State or region with a low-density ATM environment. The CNS systems in this example essentially consist of a VHF data link, an ADS unit and GNSS for navigation. If VHF coverage is incomplete, then AMSS can be made available through a ground earth station (GES). The aircraft should have an SSR Mode A/C transponder to support radar surveillance (Mode A/C) in terminal areas. Landing aids beyond GNSS Category I are not available.

4. CONCEPT OF INCREMENTAL COSTS

4.1 Implementation of the CNS/ATM systems (the project case of a cost/benefit analysis) will require expenditures, spread over a period of time, on the items of new equipment identified above. These incremental expenditures (A in Figure 2-3) are unique to CNS/ATM and would not be incurred if CNS/ATM were not implemented. However, in this latter event (the base case of a cost/benefit analysis), incremental expenditures on present technology equipment would be required in order to continue operating the existing system (B in Figure 2-3). These latter costs are unique to the existing system; they would be avoided if CNS/ATM were to be implemented and are, in effect, a benefit of CNS/ATM.

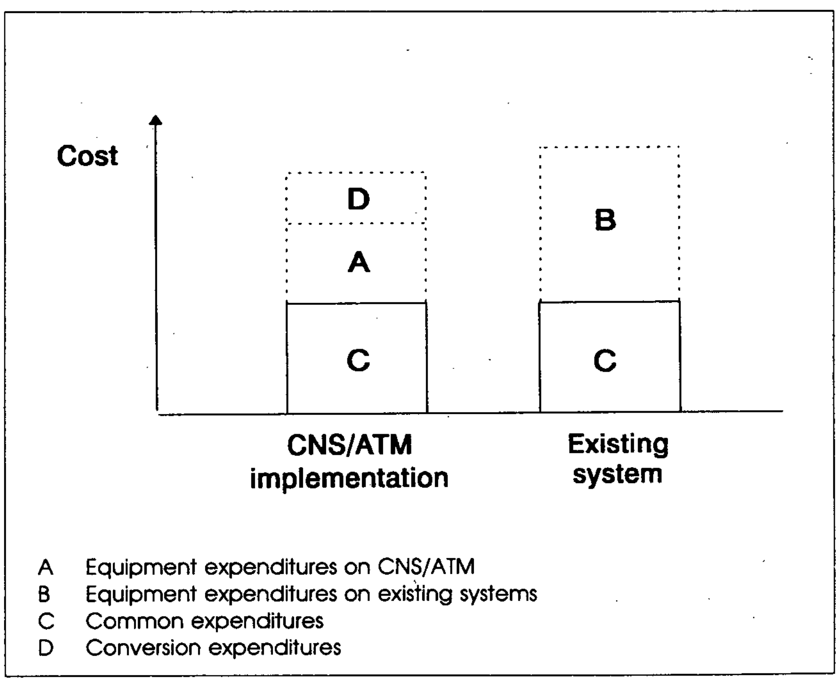


Figure 2-3. Classification of expenditures

4.2 There are substantial annual expenditures which are common to both the new and existing systems (C in Figure 2-3). These expenditures would be incurred irrespective of whether CNS/ATM was implemented or the existing system was retained. Expenditures on VHF voice facilities and inertial navigation equipment might fall into this category. As regards its treatment in a cost/benefit study, each expenditure item of this type must be either included in the costs of both systems or excluded from the costs of both systems. They do not affect the net cost of implementing CNS/ATM.

4.3 Included among the expenditures common to both the project and base cases are those which, in the project case, are required to maintain the existing systems during CNS/ATM implementation in order to allow similar types of services to be offered under both the existing and new systems for a limited period. These expenditures are part of the costs of transition to the new system. In the cost/benefit analysis, it is convenient to include this element of common expenditures among the costs of both the project case (CNS/ATM) and the base case (existing system).

4.4 There is a further category of CNS/ATM costs (i.e. conversion costs) incurred only in the project case and only during implementation. These costs (D in Figure 2-3) are also part of the costs of transition and include, for example, retraining and staff redeployment.

4.5 This discussion leads to another interpretation of incremental cost, being the extra cost or net cost, associated with the implementation of CNS/ATM compared with the cost of continuing with the existing system (A + D – B in Figure 2-3).

Chapter 3
Policy and Institutional Assumptions

1. INTRODUCTION

1.1 The economic viability of CNS/ATM in a State and the economic impact of the new systems on groups of stakeholders (for example, ATC service providers and aircraft operators) will be influenced by the policy and institutional environment. The costs and benefits of CNS/ATM implementation in a State will be affected by a range of national and regional policies covering the aviation industry and the economy generally (Section 2) and by the rate of transition to CNS/ATM in neighbouring regions and in the aircraft fleet (Section 3). Also, the institutional arrangements among providers and users of ATC services will impact on how the costs and benefits are shared among them (Section 4).

2. NATIONAL AND REGIONAL POLICIES

2.1 Access to the full potential operational benefits of CNS/ATM is conditional on a broad range of aviation, economic and social policies, primarily national but also, in some cases, regional (for example, in the European Union).

2.2 The interaction between CNS/ATM and airport capacity, and the airway/airport interface, may impact on the operational benefits achieved by aircraft. For example, airport congestion may act as a constraint on the benefits from CNS/ATM. It is important to link correctly the benefits of congestion relief to the relevant investment in airport and/or en-route capacity and avoid double counting of benefits.

2.3 The increase in automation of air traffic management, the withdrawal of some ground-based navigation aids, and the possible relocation of some ATC service providers to fewer centralized locations should result in labour productivity improvements and hence reductions in unit labour costs, over the long term. Some of these benefits may not be realized without effective redeployment of staff to other economic activities. The redeployment task may itself involve an economic or social cost which should be acknowledged in a cost/benefit study. The feasibility and cost of redeployment will depend on government policy as well as the economic environment in the region concerned.

3. ASSUMPTIONS ABOUT THE RATE OF TRANSITION

3.1 From the perspective of a State or region, the economics of CNS/ATM will be greatly influenced by the proportion of the fleet equipped with CNS/ATM and the proportion maintaining avionics for both the new and the existing systems at particular points in time. These assumptions will affect the magnitude of both the benefits from more efficient flight paths and the costs of maintaining dual systems. The assumptions will need to be made year by year throughout the planning period and incorporated into the cost/benefit analysis.

3.2 The extent to which aircraft flying on international routes to and from the State are encouraged to switch to CNS/ATM will be affected by the rate at which CNS/ATM is implemented in other (particularly neighbouring) States and regions. Furthermore, the scope for CNS/ATM-equipped aircraft to achieve benefits from more efficient flight paths in a State's airspace may be greater if neighbouring airspaces are also operating under CNS/ATM rather than under the existing system. This is illustrated (in a stylized fashion) in Figure 3-1. Changes in separation standards and in the structure of route networks may be required, in addition to the installation of technology, in order to achieve the maximum benefits.

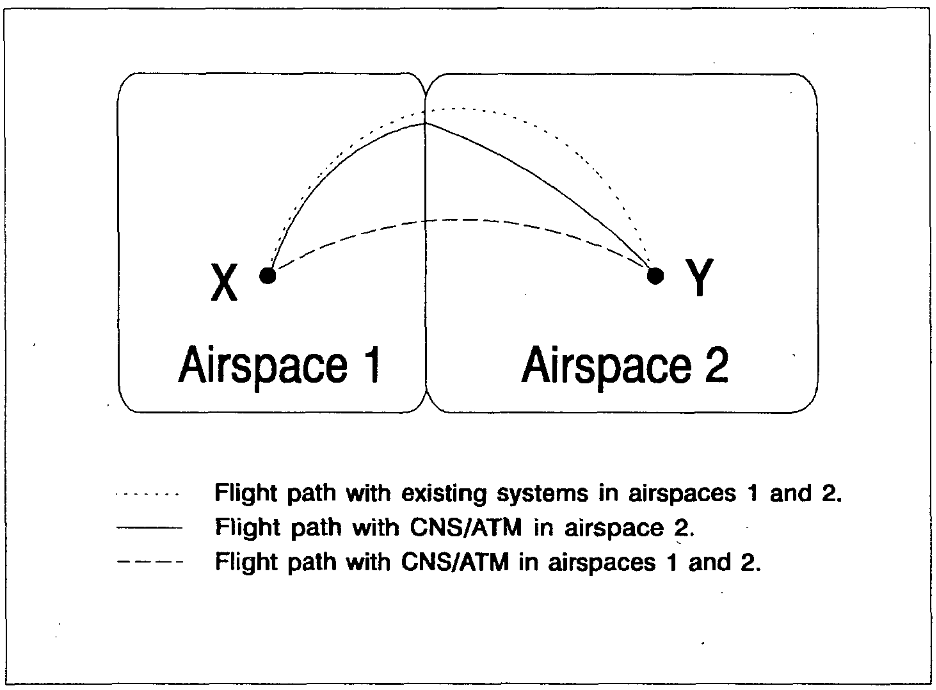
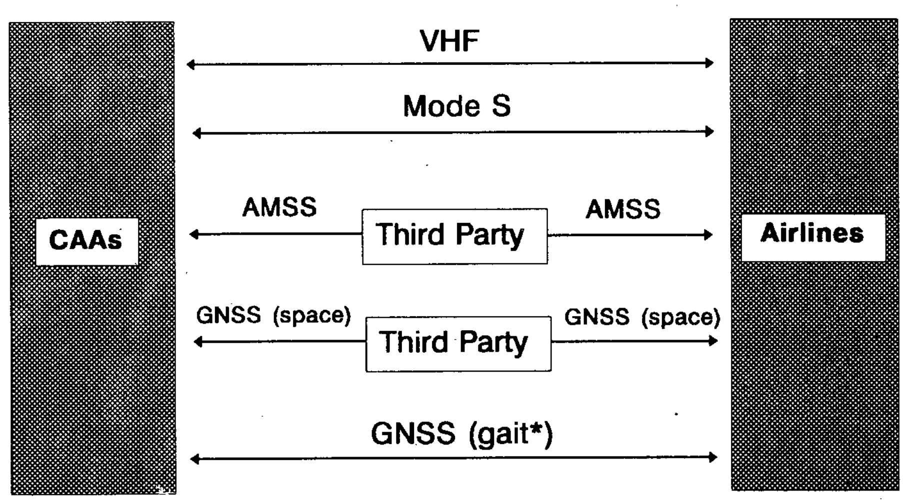


Figure 3-1. Benefits from reductions in flight paths

4. ECONOMIC LINKS BETWEEN STATES, SERVICE PROVIDERS AND AIRLINES

4.1 The process of economic evaluation will involve allocation of the costs and benefits among ATC service providers and aircraft operators so that separate cost/benefit measures can be derived for each sector. However, the implementation of CNS/ATM will increase the complexity of the relationships among those involved in the industry. In today's line-of-sight technology, the Civil Aviation Authorities (CAAs) of the States normally provide services directly to the airlines. Under the new system, other providers of some of the services will become much more prominent. For example, multinational service providers, such as Inmarsat, may act as intermediaries between the CAAs and the airlines in the supply of satellite communications. In addition, other organizations may supply other elements of the ATN and provide GNSS services as well as GNSS integrity monitoring services. Some of the links between States (CAAs), airlines and third-party providers for major CNS/ATM functions are indicated in Figure 3-2.

4.2 For most of the sub-systems of CNS/ATM, the capital costs of equipment and the associated operational costs will be allocated directly to ATC service providers and airlines according to ownership. The same will apply to the sub-systems of the existing systems.



* ground-based augmentation and integrity technique (for detection and correction of errors in the satellite signals).

Figure 3-2. Links between States, Airlines and Third Parties

4.3 The allocation of the costs of the services of third-party providers is not as straightforward. Consider the satellite communications services linking aircraft and the ATC service provider. One option is for the ATC authority to be regarded as purchasing the service and to be sent the bill from the AMSS provider (see Figure 3-3). The ATC authority is therefore allocated the cost, and the cost/benefit result from the perspective of the State will appear much less favourable than if the airlines pay the AMSS provider directly for the service. The cost/benefit result from the airline perspective will be correspondingly more favourable. Although the perceptions of States and airlines might be affected in this way, the over-all cost/benefit result will not be greatly affected. Furthermore, the States should ultimately recover from aircraft operators the full costs they incur, including the costs of the services purchased from the AMSS provider.

4.4 The space segment, and possibly other elements, of the GNSS service will also be supplied by third-party providers. For the time being the standard position service of the United States' global positioning system (GPS) and the Russian Federation's global orbiting navigation satellite system (GLONASS) will be available free of charge. However, in due course, the kinds of institutional issues raised above in connection with AMSS may also need to be addressed for GNSS. The options of direct charging of users by the GNSS supplier and indirect charging via the ATC providers are possibilities.

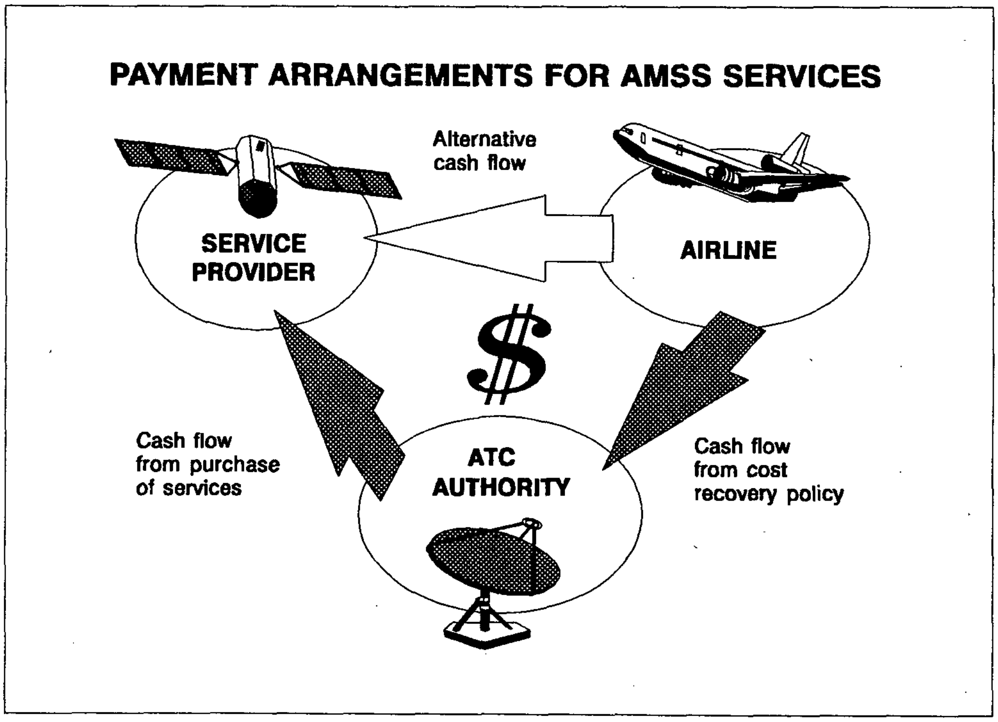


Figure 3-3. Payment arrangements for AMSS services

Chapter 4
Net Present Value Analysis

1. OUTLINE OF THE APPROACH

1.1 The Net Present Value (NPV) approach requires predictions of the future profiles of the annual costs and benefits associated with the implementation of CNS/ATM systems. Once all the year-by-year expenditures and benefits are established, the net benefit (benefit minus cost) for each year can be calculated and discounted back to the base year in accordance with standard accounting practices. The net present value of all the costs and benefits associated with the new system can then be established. Figure 4-1 provides an overview of the NPV approach.

1.2 Since future costs and benefits of CNS/ATM will depend on the volume of traffic, a forecast of traffic demand for each future year over the planning horizon (e.g. 20 years) is a prerequisite of the estimation of annual costs and benefits (Section 2).

1.3 Implementation of CNS/ATM systems will involve the ATC service providers and aircraft operators in the purchase and operation of many items of CNS/ATM equipment, which will be different from the equipment of the existing technology systems (Section 3). Apart from these equipment-related costs, CNS/ATM may involve the ATC service providers and/or the aircraft operators in the purchase of services from third parties (Section 4). An example is the purchase of signal transmission via the satellites of the AMSS.

1.4 The benefits of CNS/ATM include all the future equipment purchases and associated expenditures required to maintain the existing present-technology system in the long term (Section 5). These expenditures, by the ATC service providers and air carriers, would be necessary in the absence of CNS/ATM but will be avoided once CNS/ATM is in place.

1.5 By specifying the cost flows year by year as they occur, it is possible to take into account the extra costs associated with CNS/ATM implementation which are incurred only during the period of transition to the new system. For example, some equipment belonging to the existing-technology system may be near the end of its life and in need of replacement during the transition period, even though it will not be required in the long term. Retraining costs before and during transition can also be included.

1.6 The CNS/ATM systems will provide more efficient flight paths for aircraft than is possible under the existing technology, thereby resulting in cost savings for airlines (Section 6). This is a very important type of benefit from CNS/ATM. Reduced flight times will also mean time savings for passengers (Section 7).

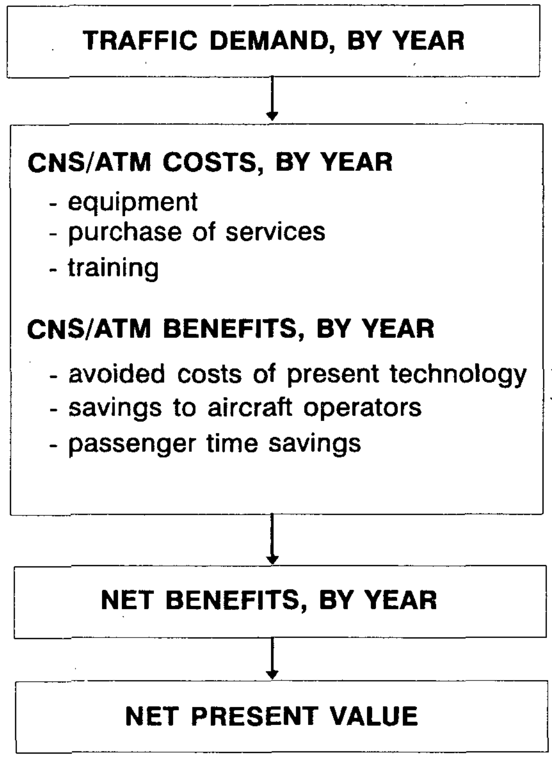


Figure 4-1. Overview of Net Present Value approach

1.7 Section 8 discusses other costs and benefits not included in the previous sections. Section 9 brings together all the cost and benefit items into a single summary table.

1.8 The time profile of expected annual costs (expenditures) and benefits must extend over a long period such as 20 years (a period which will be used as a model in the present guidelines). Although the future costs and benefits are distributed over a long time span and are often transacted in different currencies, they can all be valued in a single currency at constant base-year exchange rates and product prices. By adopting this approach, it is assumed that future trends in exchange rates and general inflation would affect costs and benefits equally, with no net impact on the economic viability of CNS/ATM. Many States may, however, wish to distinguish between the "hard" and "soft" currency components of costs and benefits and to identify the impact on their balance of payments.

1.9 In order to take into account the fact that one dollar now is more valuable than one dollar in the future even if prices are stable (as evidenced by the existence of real interest rates), it is necessary to express the net benefit for each future year in terms of its equivalent in the base year (i.e. usually the most recent past year). As discussed in Section 10, this is achieved by a discounting process and puts all the net benefits generated in each year on a comparable basis, allowing them to be aggregated into a single net present value.

1.10 The present value of a given future cost or benefit decreases the further into the future the cost or benefit occurs. Costs and benefits in the far distant future can be ignored. If a 20-year period of analysis is used, residual asset values are estimated and included as a negative capital cost at the end of the analysis period.

1.11 Throughout the analysis, it is important to keep the cost and benefit impacts on the ATC service providers separate from those on the aircraft operators. The NPV can then be calculated for the service providers and for the aircraft operators. The key measure of the economic viability of CNS/ATM is, however, the over-all aggregated NPV result.

2. TRAFFIC DEMAND AND AIRCRAFT NUMBERS

2.1 Most of the benefits and some of the costs associated with CNS/ATM depend on the quantity of traffic served by the system. The number of hours flown by aircraft in the relevant airspace is the measure of traffic demand which directly affects the calculations of most of the costs and benefits of the new system. A forecast of annual values of this variable over the 20-year period of analysis is therefore required.

2.2 Information on flight-hours in the base year (i.e. the most recent past year) is not expected to be available directly but could be derived from data on the numbers of aircraft movements, average distance flown per movement and average aircraft speed in the airspace, using the following relationship:

$$\text{Flight-hours} = \frac{\text{aircraft movements} \times \text{average distance flown}}{\text{average speed}}$$

2.3 Data on movements, average distance and average speed should be compiled for the most recent year. Separate measurements of these variables could be made for the arrivals/departures and through-flights of the air carriers, for instrument flight rules (IFR) general aviation and for visual flight rules (VFR) general aviation.

2.4 Having estimated the number of flight-hours in the base year for the various types of movements, forecasts for flight-hours can then be developed. Assuming the average distance and speed per movement in the airspace remain unchanged over the forecast period, the growth in flight-hours will be the same as the growth in aircraft movements.

2.5 For the air carrier sector of the market, aircraft movements depend on passenger numbers, and on the average size and load factor of aircraft. Flight-hours in year "t" (flight-hours t) can therefore be derived from flight-hours in the base year (flight-hours b) as follows:

$$\text{Flight-hours t} = (\text{flight-hours b}) \times (1 + p)^t \times (1 - f)^t \times (1 - s)^t$$

where p = average annual growth in passenger numbers (measured as a fraction)
f = average annual growth in average load factor (fraction)
s = average annual growth in average aircraft size (fraction)

For example, if it was expected that the load factor would increase from 50 per cent to 55 per cent over 5 years, then f would equal 2 per cent per annum ($5/50 \times 1/5 \times 100$), or 0.02 per annum (as a fraction), and not 1 percentage point per annum.

Suppose flight-hours b = 200 000, p = 5 per cent per annum, f = 0, and s = 2 per cent per annum. Then the number of flight-hours in year 5 is derived by:

$$\text{Flight-hours } 5 = (200\,000)\,(1 + 0.05)^5\,(1 - 0)^5\,(1 - 0.02)^5$$
$$= (200\,000)\,(1.28)\,(0.90)$$
$$= 230\,400$$

2.6 Forecast growth in the number of passengers is usually based primarily on an assumption about general economic growth. Forecasts of trends in average load factor and aircraft size may be based on past trends and expectations about fleet development.

2.7 As freighter aircraft usually represent a small proportion of movements in an airspace, they can be included with the passenger aircraft in the analysis of air carrier movements.

2.8 For general aviation traffic, flight-hours in year "t" might be expressed as:

$$\text{Flight-hours t} = (\text{flight-hours b}) \times (1 + g)^t$$

where g = forecast average annual growth rate in flight-hours.

2.9 Forecasts of avionics investment will depend on forecasts of the number of aircraft using the relevant airspace which are, in turn, related to forecasts of aircraft flight-hours. Since commercial aircraft usually operate in the airspaces of various States and regions, an approach must be found to determine the number of aircraft to be allocated to the specific airspace which is the subject of the analysis. ICAO's global statistics on aircraft numbers and hours flown indicate that each aircraft of commercial airlines flies about 2 700 hours per annum (7.4 hours per day), on average. If the total hours flown by air carrier aircraft in the subject airspace was A, then A/2 700 aircraft could be allocated to the airspace for costing purposes. Adjustments to these figures could of course be made to reflect national and regional utilization of aircraft (hours flown per annum per aircraft) rather than the global average. If it is assumed that aircraft utilization remains constant over the period of the analysis, the number of aircraft will grow at the same rate as the total aircraft flight-hours.

2.10 The number of domestic aircraft, whose operations are all within the airspace being analysed, could be determined directly (from the fleets of the domestic airlines). If the total number of flight-hours can be disaggregated into domestic and international operations, then the number of international aircraft to be allocated to the airspace can be derived from the international flight-hours using the method described in the previous paragraph.

2.11 For general aviation aircraft, it may be appropriate to base avionics investment on the number of these aircraft registered in the State or region whose airspace is the subject of the analysis.

2.12 Forecasts of both flight-hours and aircraft numbers for each year in the forecast period can be recorded in tabular form. Table 4-1 contains a hypothetical example of such forecasts; note that 1993 has been chosen as the base year for the analysis and 2013 as the last year of the analysis. Separate estimates for domestic and international operations could be recorded in additional tables of a similar structure.

3. EXPENDITURES ON CNS/ATM EQUIPMENT

3.1 CNS/ATM systems implementation is the project case of the analysis. The equipment items or types required to implement CNS/ATM need to be identified, based on the system configuration appropriate for the State or region (Chapter 2). The distribution of investment spending (in constant base-year prices) must be specified throughout the implementation period. Spending on staff training during the period of installation of the new equipment must also be specified. Figure 4-2 presents a possible time profile of expenditures associated with CNS/ATM implementation.

3.2 Under the present value approach, it is necessary to forecast not only the total quantity of equipment ultimately required but also the particular years in which the equipment will be installed. Investment in ground equipment will vary from year to year, with larger investments being made early in the planning period. A large amount of investment in avionics equipment will be required in the earlier part of the implementation period in order to equip the existing fleet. In later years, further investment in avionics will be related to the *increase* in the number of aircraft operating in the airspace.

Table 4-1. Forecast of flight-hours and aircraft numbers, by type of aircraft operator

	Base year	Forecast years						
	1993	1994	1995	1996	1997	1998	....	2013
AIR CARRIER								
Flight-hours (thousands) (A)	200	206	212	219	225	232		
Aircraft utilization (hours per aircraft per year) (B)	2 700	2 700	2 700	2 700	2 700	2 700		
Aircraft numbers (C = 1 000 x A/B)	74	76	79	81	83	86		
GENERAL AVIATION								
IFR flight-hours								
IFR aircraft numbers								
VFR flight-hours								
VFR aircraft numbers								

Note.— In this and subsequent tables, aircraft numbers are always rounded to the nearest whole number.

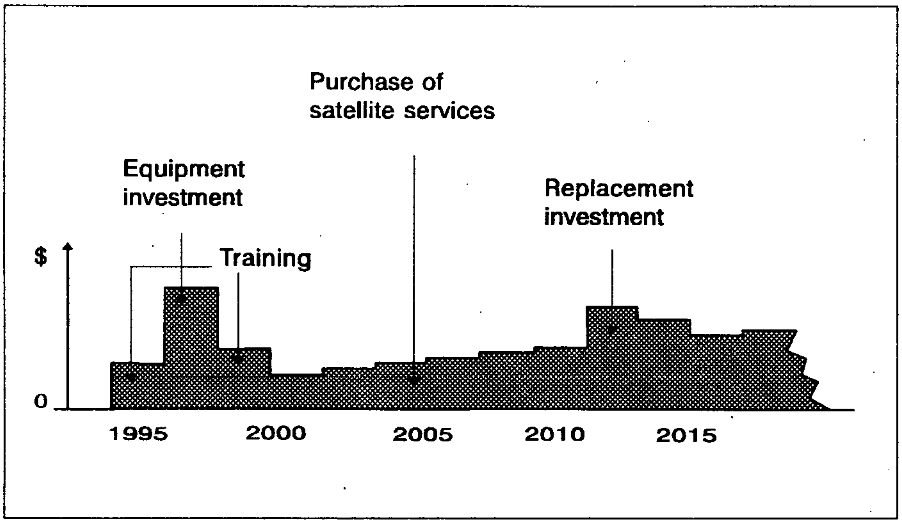


Figure 4-2. Simplified profile of typical CNS/ATM costs

3.3 Table 4-2 has a representative list of ground and aircraft equipment which might be required for a CNS/ATM system. The investment expenditure for each item, for each year during the 20-year period 1994 to 2013, can be recorded in such a table. Investment expenditure is equal to the real (inflation-adjusted) price of each unit of equipment multiplied by the number of units purchased. (Section 4.3 of Chapter 5 has further discussion of the concept of real prices.) While investment expenditures will be quite lumpy, coming in discrete blocks, the associated operational and maintenance expenditures will be distributed over the life of the equipment. Valuations of the depreciated assets in place at the end of the analysis period are recorded as negative expenditures in the final column ("Residual") of Table 4-2. Valuations can be calculated as follows:

$$\text{Residual asset value} = \text{value at purchase} \times \frac{\text{remaining life}}{\text{total asset life}}$$

Table 4-2 and the subsequent tables used to illustrate the methodology include a column for 1993, the base year of the analysis. Although investments commence after 1993, some of the tables require 1993 data in order to derive the investment in the following year.

3.4 *Ground equipment items*

3.4.1 For some of the ground equipment items, only one unit or very few units are required. Furthermore, the cost may not be the same for each unit of an item, in which case the expenditure estimates must be made on a unit-by-unit basis. For example, the cost of a ground earth station (GES), which receives and transmits satellite communications signals and is therefore part of the Aeronautical Mobile-Satellite Service (AMSS), will depend on its location and the extent of site preparation involved.

Table 4-2. Forecast of CNS/ATM equipment investment, by year (Project Case; millions of dollars)

Equipment suite	Base year 1993	Forecast years 1994	1995	1996	1997	1998	....	2013	Residual
GROUND AND SPACE									
AMSS voice/data	–								
VHF voice/data	–								
SSR Mode A/C	–								
SSR Mode S surveillance	–								
SSR Mode S data	–								
ATN	–								
GNSS integrity monitoring	–								
ATM Automation	–								
Other	–								
Total	–								
AIRCRAFT									
AMSS voice/data	–								
VHF voice/data	–								
SSR Mode S	–								
CMU	–								
GNSS	–								
FMS	–								
ADS	–								
Total	–								

– means not applicable.

Note.— Total expenditures for each year should be rounded appropriately.

3.4.2 There are various options for implementing AMSS. States may purchase the service on a usage basis from a third party and hence avoid most of the upfront capital expenditure (including the GES). This option is considered further in Section 5. Alternatively, a State could lease satellite capacity and provide its own GES, perhaps in co-operation with neighbouring States since a single GES can cover a wide area. It should be noted that, from a technical perspective, very few GESs will be required (perhaps only one or two for a whole continent).

3.4.3 Although a VHF voice system may already be installed, investment expenditure will be required for implementation of data link capability. Since character-oriented systems are being used in some areas in the short and medium terms, further investment may be required at a later date in order to convert all networks to a bit-oriented format in line with ATN specifications. Costs will depend on the existing infrastructure.

3.4.4 SSR Mode S surveillance and data link systems may be installed in high-density traffic areas. The costs of implementing this technology will depend on the existing infrastructure and the complexity of the proposed system.

3.4.5 States will need to assess the expenditure necessary to implement the ground subnetworks of the ATN, which will depend on the complexity of the communications systems and on the existing infrastructure. This expenditure may take the form of capital investment and/or annual lease payments for links provided by telecommunications companies. The expenditure might include the construction of new or expanded communications links (e.g. to remote earth stations) which are required for CNS/ATM. The expenditures might be considerable in countries where the telecommunications network is not yet well developed. There are various other options or scenarios for implementing the ATN including the contracting of a third party, such as an international aeronautical communications service provider, for the provision of subnetworks or comprehensive services.

3.4.6 While the basic GNSS signals are being offered free of charge by the United States and the Russian Federation, any augmentation of these services, including integrity monitoring of the signals, must be provided and financed by ATC service providers or users. A ground-based GNSS integrity monitoring system may involve the installation of a number of stations around the globe, with costs allocated among user States. Satellite capacity may also be required for broadcasting integrity information to aircraft. States are likely to share the costs of these services, according to agreed criteria. Monitoring might also be performed in the GNSS receiver on board the aircraft, the cost being incorporated into the cost of the receiver. Differential GNSS (DGNSS), which enhances the performance of GNSS to support the approach, and landing and departure phases of flight, is discussed in Chapter 5.

3.4.7 It will be necessary to estimate the expenditure required on ATM systems and automation which is considered to be part of the implementation of CNS/ATM. The amount of automation necessary and the associated investment requirements will be influenced by the type and volume of traffic.

3.5 *Aircraft equipment items*

3.5.1 Investment in CNS/ATM avionics in each year of the analysis will depend on the rate at which equipment is expected to be installed in aircraft using the airspace and on the price of the equipment. One approach to the calculation of avionics investment would be to aggregate all the avionics elements and follow the procedure illustrated in Table 4-3. It is stressed that the calculations shown here are for illustrative purposes only and are based on hypothetical assumptions.

3.5.2 The most expensive element of the new aircraft equipment is expected to be the high-gain antennas and avionics necessary for AMSS. However, this equipment may only be required for aircraft operating out of line of sight of VHF systems. This would suggest that the population of aircraft using the airspace be divided into two groups: those operating out of line of sight of VHF (e.g. long-haul aircraft) and those operating within the areas provided with VHF services (e.g. short haul). Tables similar to Table 4-3 would be completed for both groups, and the sum of the avionics investments for the two groups transferred to the bottom row of Table 4-2 (without the need for completing the other rows in the bottom panel of Table 4-2 corresponding to the individual avionics sub-systems such as AMSS, VHF, Mode S, communications management unit (CMU), etc.).

3.5.3 Referring to Table 4-3, the method of forecasting the number of aircraft allocated to the airspace was discussed in Section 2 of this chapter. It will be necessary to assess the proportion of these aircraft operating outside VHF and therefore requiring AMSS as part of their CNS/ATM equipment. This proportion is included in the hypothetical example in Table 4-3 (row B). One minus this proportion (i.e. the proportion not requiring AMSS) would appear in the corresponding table (not shown) for the group of aircraft not requiring AMSS. The number of aircraft ultimately requiring AMSS (and not requiring AMSS) is then calculated in row C in the two tables (row C = row A x row B). Since the process of equipping the fleet will occur progressively over the transition period, it is necessary to make assumptions

Table 4-3. Forecast of CNS/ATM avionics investment (for the group of aircraft requiring AMSS) (Project Case)

	Base year	Forecast years						
	1993	1994	1995	1996	1997	1998	....	2013
Number of aircraft allocated to airspace (A = C in Table 4-1)	74	76	79	81	83	86		
Proportion of aircraft ultimately requiring AMSS (B)	0.8	0.8	0.8	0.8	0.8	0.8		
Number of aircraft ultimately requiring AMSS (C = A x B)	59	61	63	65	66	69		
Proportion of these aircraft which will have become CNS/ATM equipped (D)	0	0	0.02	0.05	0.20	0.40		
Number of equipped aircraft (E = C x D)	0	0	1	3	13	28		
Increase in number of equipped aircraft ($F = E_t - E_{t-1}$)	–	0	1	2	10	15		
Price of equipping each aircraft (thousands of dollars) (G)	–	600	600	600	600	600		
Investment in equipment (thousands of dollars) (H = F x G)	–	0	600	1 200	6 000	9 000		
Other expenditure associated with installation of CNS/ATM avionics (I)	–							
Total investment in CNS/ATM avionics (J = H + I)	–							

– means not applicable.

about the trend in the proportion of these aircraft which will have become equipped with CNS/ATM (with or without AMSS) (row D). This proportion will rise from zero to one over the transition period. The number of equipped aircraft and the increase in the number of equipped aircraft can then be calculated for each year (rows E and F). Given the average price of equipping each aircraft (row G), the annual investment in equipment can be calculated (row H). Note that, in this example, investment is assumed to begin after 1993; the amount of the investment in 1994 (if any) is assumed to depend on the increase in the number of equipped aircraft between 1993 and 1994. Towards the end of the period, replacement investment for some items of equipment may be necessary. The table has room for inclusion of any other expenditure (row I) that may be associated with the installation of CNS/ATM avionics.

3.5.4 The cost of equipping aircraft with CNS/ATM avionics is an important parameter which should be established in consultation with aircraft operators and equipment manufacturers. In addition to the costs of equipment procurement and installation labour and hardware, the total cost may include a share of the certification costs for the new systems, and there may also be costs associated with aircraft down time or out-of-service time required for installation. If the aircraft are operated in different regions for which there are different avionics requirements, this would further increase avionics costs. The issue of interoperability and the cost penalties of a lack of commonality in the requirements of different regions are important considerations in the implementation of CNS/ATM.

3.5.5 Although the avionics cost per aircraft (row G) is expected to be greater for the group of aircraft which will be AMSS equipped, it should be recognized that the AMSS avionics infrastructure will most likely be used for passenger (i.e. public) communications (e.g. telephone and fax) as well as aviation safety communications (ATS and airline operational communications). A significant part of the investment costs of the set of antennas required for AMSS may be assumed to be met from passenger communications revenues. The costs of the electronic equipment required for voice and data safety communications should be included in the evaluation of CNS/ATM.

3.5.6 Other items of CNS/ATM avionics expenditure may include new VHF voice/data facilities, a CMU for selecting the appropriate communications subnetwork in a given circumstance, a GNSS receiver, an ADS unit, and upgrading of the FMS and SSR systems. Since the items and their specifications will vary to some degree among aircraft, an average cost of fully equipping each aircraft should be estimated.

3.5.7 In the approach outlined above, the CNS/ATM avionics requirement is treated in aggregate. Alternatively, it would be possible to treat different elements of CNS/ATM avionics separately, as indicated in Table 4-2. An individual version of Table 4-3 could be developed for each of the items GNSS, ADS, AMSS, and so on, if the rates of transition for these items differ. The output from such tables could then be transcribed to the appropriate rows of Table 4-2.

3.5.8 The method (described in Section 2 of this chapter) for allocating air carrier aircraft costs to an airspace on the basis of aircraft-hours flown in the State's airspace rather than the number of aircraft registered in the State is consistent with the measurement of air carrier efficiency benefits based on the reduction in aircraft-hours flown in the airspace (to be discussed later in this chapter). In the case of general aviation, the number of locally registered aircraft may be a suitable basis for cost allocation because most general aviation movements are restricted to the local airspace. Separate calculations for the IFR and VFR categories of general aviation are necessary because of differences in equipment requirements and costs.

4. PURCHASE OF SERVICES FROM THIRD-PARTY SUPPLIERS

4.1 Some of the services required for the operation of the CNS/ATM systems may be sold to ATC service providers and/or aircraft operators by third-party suppliers. The annual purchases from third parties can be recorded in a table similar to Table 4-4.

4.2 The basic GNSS navigation signals from the United States' GPS and the Russian Federation's GLONASS systems are expected to be available free of charge for some years, and States should take this into account in their calculations. As part of the CNS/ATM systems, the service providers may lease communications circuits from a telecommunications corporation or may purchase services on a per message basis.

4.3 From a costing perspective, the purchase of aeronautical mobile-satellite services is an important option for States. Such a service would be provided on a usage basis at a price quoted in terms of cents per kilobit plus a relatively small annual connection charge. Communication service providers could supply satellite communications and the associated ground communications and would cover all their capital and operating costs from sales of services to civil aviation authorities and other customers. Charges would need to cover the degree of functionality (e.g. availability, continuity, integrity) necessary to meet aeronautical safety communications requirements, which are more demanding than the requirements of, for example, public communications.

Table 4-4. Forecasts of purchases from third-party providers, by year (Project Case; millions of dollars)

	Base year	Forecast years						
Service	1993	1994	1995	1996	1997	1998	....	2013
AIRLINE OR CAA								
GNSS signals	–							
Satellite communications	–							
CAA								
Ground communications links	–							
TOTAL	–							

– means not applicable.

Note.— Total purchases for each year should be rounded appropriately.

4.4 The annual number of kilobits purchased depends on the number of each of the various types of messages and the average message length. The number of messages depends on the number of flight-hours for which AMSS is the chosen method of communication and on the message frequency. Therefore:

Quantity of messages in kilobits = total flight-hours
× proportion of aircraft which are AMSS equipped
× proportion of hours for which each equipped aircraft uses AMSS
× message frequency × message length in kilobits

4.5 A forecast of the number of flight-hours in the airspace by all aircraft is required for each year of the analysis period. Guidance on forecasting flight-hours was given in Section 2 of this chapter. An assumption about the increase over the period in the proportion of aircraft that will be equipped with AMSS is also required. This should be consistent with the assumptions in 3.5 above.

4.6 The proportion of flight-hours for which AMSS-equipped aircraft will actually use AMSS depends on the availability of the alternative VHF or Mode S data links. The latter communications options will tend to be favoured when they are available, for example, in terminal and continental airspace with high-density traffic. Aircraft that use AMSS in oceanic and remote areas will probably switch to VHF (or Mode S) as soon as they are in range of these facilities. The proportion of flight-hours when AMSS is used might eventually decline if VHF or SSR Mode S data link is installed or expanded at some future date.

4.7 Assumptions about message frequency and message length applicable to the airspace should be developed by operational and technical experts. The message length, in kilobits, must be sufficient to include both the message content and an overhead imposed by the communication system (i.e. addressing information). The FANS Guide identified two groups of messages — automatic dependence surveillance (ADS) messages and other air traffic services (ATS) and flight service messages. ADS messages provide surveillance data derived from on-board navigation systems. The FANS Guide assumed, for illustrative purposes, that 12 ADS messages would be sent per hour, each message being 1.5 kilobits in length. The quantity of messages was therefore 18 kilobits per hour. In practice, the average message frequency in an airspace will depend on traffic density and separation criteria. Other ATS and flight service messages could include various reports concerning clearances, transfer of communication (e.g. between ATC centres), weather conditions, warning and advisory messages and general traffic information. Some of these messages could be initiated on aircraft and some on the ground. Careful judgement will be required in the assessment of the quantities of these messages expected in the specific airspace.

4.8 The method of calculating the forecast annual costs of satellite utilization in the transmission of messages is illustrated in Table 4-5 using a hypothetical example . As described above, the total cost is derived from forecasts of flight-hours in the airspace and the proportion of hours of satellite usage, along with assumptions for the quantity of message information per hour and the transmission price. It must be re-emphasized that States need

Table 4-5. Forecasts of purchases of AMSS services (Project Case)

	Base year	Forecast years						
	1993	1994	1995	1996	1997	1998	....	2013
Total flight hours (thousands) (A = A in Table 4-1)	–	206	212	219	225	232		
Proportion of aircraft which are AMSS equipped (B = B x D both in Table 4-3)	–	0	0.016	0.04	0.16	0.32		
Hours flown by AMSS-equipped aircraft (C = A x B)	–	0	3	9	36	74		
Proportion of hours when AMSS is used (D)	–	–	0.50	0.50	0.50	0.50		
Quantity of messages per hour (Kbits) (E)	–	–	25	25	25	25		
Quantity of messages per year (thousands of Kbits) (F = C x D x E)	–	0	38	113	450	925		
Transmission price* (dollars per Kbit) (G)	–	–	0.5	0.5	0.5	0.5		
Total transmission cost (thousands of dollars) (H = F x G)	–	0	19	56	225	463		

– means not applicable.
* Satellite utilization only; no message processing assumed.

Note.— Hours flown by AMSS-equipped aircraft are rounded to the nearest hour.

to make their own assumptions for the various parameter values. Having completed Table 4-5, the bottom row can then be transcribed to the appropriate row (satellite communications) in Table 4-4.

5. EXPENDITURES ON PRESENT-TECHNOLOGY EQUIPMENT

5.1 *Present-technology system maintained in the long term (base case)*

5.1.1 This is the base case for the analysis, representing the situation if CNS/ATM were not to be implemented. Since many elements of the present-technology systems will eventually be made redundant by the CNS/ATM systems, the projected expenditures required to maintain these elements of the present system in the long term can be regarded as benefits of CNS/ATM. Both ATC service providers and aircraft operators benefit from savings of this kind.

5.1.2 Figure 4-3 illustrates the pattern of projected investment expenditures which might be required to fully maintain the present-technology system over the planning period. The base case scenario for expenditures will vary among the regions and will probably emphasize maintenance rather than expansion of the existing infrastructure. In remote regions where the present technology systems are not well developed, the base case expenditures might be quite low. In those regions where most elements of the existing system are already in place, substantial replacement investment will nevertheless be necessary at some point in the future, and further units of equipment may need to be purchased to accommodate expanding traffic volumes. If the trend in most parts of the world is to implement CNS/ATM, then the costs of maintaining the present-technology system in the region which is the subject of the analysis will be adversely affected. There will be extra costs associated with interfacing with the new systems as they become the prevailing standard. The availability of present-technology equipment items would be likely to decline, and their prices to increase.

5.1.3 Table 4-6 contains a representative list of ground and aircraft equipment based on present technology and illustrates a suitable format for recording the investment expenditures and related costs for each future year. If the project case (CNS/ATM) includes DGNSS for precision approaches, then the base case expenditures in Table 4-6 would need to include ILS/MLS expenditure for precision approaches (see Chapter 5).

5.1.4 Required investment in ground equipment will need to be assessed on an item-by-item basis and will occur earlier in the planning period in situations where existing equipment is nearing the end of its economic life.

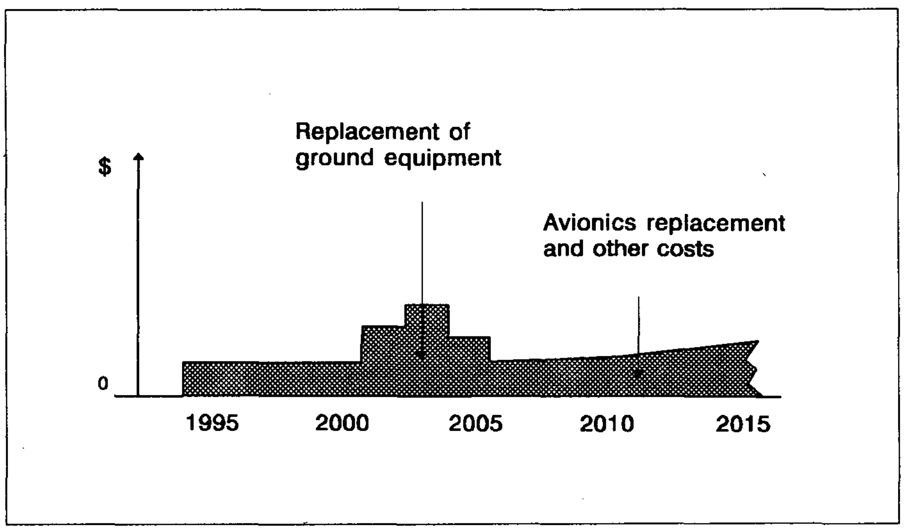


Figure 4-3. Simplified profile of present-technology costs

Table 4-6. Forecast of equipment investment required for maintenance of present-technology system in the long run (Base Case; millions of dollars)

	Base year	Forecast years							
Equipment suite	1993	1994	1995	1996	1997	1998	....	2013	Residual
GROUND									
HF voice	–								
VHF voice	–								
Omega	–								
NDB	–								
VOR	–								
DME	–								
Primary radar	–								
SSR Mode A/C	–								
Total	–								
AIRCRAFT									
HF voice	–								
VHF voice	–								
Omega	–								
ADF	–								
VOR	–								
DME	–								
SSR Mode A/C	–								
Total	–								

– means not applicable.

Note.— Totals should be rounded appropriately.

5.1.5 Projected investment in avionics equipment will consist of two components, namely replacement investment and investment associated with expansion of the aircraft fleet. Table 4-7 uses a hypothetical example to illustrate the method of calculating both the annual numbers of suites of avionics equipment purchased and the equivalent monetary investment. The number of replacement suites in each year depends on the number of aircraft in the fleet and the depreciation rate, or economic life, of the avionics equipment. If the average economic life of the equipment is assumed to be 20 years, then about 5 per cent of the existing complement of equipment suites (which is equal to the number of aircraft in the existing

Table 4-7. Forecast of avionics investment required for maintenance of present-technology system in the long run (Base Case)

	Base year	Forecast years						
	1993	1994	1995	1996	1997	1998	....	2013
Number of aircraft allocated to airspace (A = C in Table 4-1)	74	76	79	81	83	86		
Proportion of existing avionics suites to be replaced (B)	0.05	0.05	0.05	0.05	0.05	0.05		
Number of avionics suites replaced (C = A × B)	4	4	4	4	4	4		
Number of extra avionics suites associated with fleet expansion (D = $A_t - A_{t-1}$)	–	2	3	2	2	3		
Total number of avionics suites purchased (E = C + D)	–	6	7	6	6	7		
Price per suite (thousands of dollars) (F)	–	400	400	400	400	400		
Investment in avionics (thousands of dollars) (G = E × F)	–	2 400	2 800	2 400	2 400	2 800		

– means not applicable.

Note.— The result of the calculation of the number of avionics suites is rounded to the nearest whole number.

fleet) will need to be replaced each year, on average (see row B in Table 4-7). The other important assumption (row F) is the average cost of fully equipping each aircraft with present-technology avionics (which would be replaced by new technology avionics under CNS/ATM).

5.1.6 If present-technology avionics is treated in aggregate as in Table 4-7, the bottom row of Table 4-7 can be transcribed directly to the bottom row of Table 4-6. However, separate treatment of different avionics items (e.g. Omega, HF voice) may be warranted, as suggested in Table 4-6. Versions of Table 4-7 could be developed for each item of equipment, rather than for the entire suite of equipment, and the output from such tables transcribed to the appropriate rows of Table 4-6.

5.2 *Expenditures incurred during CNS/ATM transition (part of project case)*

5.2.1 The investment expenditures necessary to maintain, or partially maintain, the present-technology system during the transition to CNS/ATM need to be added to the CNS/ATM equipment expenditures established in Section 3 of this chapter. Again, the costs of interfacing between the systems will increase and the availability and prices of present-technology equipment will be adversely affected as the new systems become the prevailing standard.

5.2.2 Table 4-8, which has the same structure as Table 4-6, can be used to record expected investment expenditures. Again the ground equipment will need to be assessed on an item-by-item basis.

5.2.3 Investment in present-technology avionics during the CNS/ATM transition will depend on the number and price of present-technology suites that will need to be purchased during the transition period. The number of new present-technology avionics suites necessary for all aircraft to retain present-technology capabilities was calculated in Table 4-7; the proportion that will be required during a period of transition to CNS/ATM will vary from one

Table 4-8. Forecast of investment in present-technology system during transition to CNS/ATM (Project Case; millions of dollars)

	Base year	Forecast years							
Equipment suite	1993	1994	1995	1996	1997	1998	....	2013	Residual
GROUND									
HF voice	–								
VHF voice	–								
Omega	–								
NDB	–								
VOR	–								
DME	–								
Primary radar	–								
SSR Mode A/C	–								
Total	–								
AIRCRAFT									
HF voice	–								
VHF voice	–								
Omega	–								
NDB	–								
VOR	–								
DME	–								
SSR Mode A/C	–								
Total	–								

– means not applicable.

Note 1. Some of these systems may become unavailable as the transition proceeds.
Note 2. Totals should be rounded appropriately.

(early in the period) to zero (by the end). The pattern of change in this proportion, which may be quite abrupt, will be influenced by the expected rate of transition to CNS/ATM in other regions. The methodology is illustrated in Table 4-9, using a hypothetical example.

5.2.4 Separate versions of Table 4-9 may be necessary for different avionics items. For example, the removal of HF (and its replacement by AMSS) may be much quicker than the removal of NDB/VOR (and its replacement by GNSS). The outputs of these tables can be transcribed to Table 4-8.

6. EFFICIENCY BENEFITS FOR AIRCRAFT OPERATORS

6.1 The improved navigation, communications and surveillance brought about by implementation of CNS/ATM will allow more direct routing of aircraft, which will generate savings in fuel cost and other aircraft operating costs. The amount of these savings will depend on the reduction in the number of aircraft-hours flown in the airspace as a result of CNS/ATM and on aircraft operating costs per hour. Because different aircraft can have greatly different operating costs per hour, it is advisable to categorize aircraft according to aircraft operating costs and to calculate savings for each aircraft category. These savings can be calculated as follows:

Table 4-9. Forecast of investment in present-technology avionics during transition to CNS/ATM (Project Case)

	Base year	Forecast years						
	1993	1994	1995	1996	1997	1998	....	2013
Number of new avionics suites necessary for all aircraft to retain present-technology (A = E in Table 4-7)	–	6	7	6	6	7		
Proportion of the above present-technology avionics suites to be purchased during the transition to CNS/ATM (B)	–	1.00	1.00	1.00	1.00	0.80		
Number of present-technology avionics suites to be purchased during CNS/ATM transition (C = A x B)	–	6	7	6	6	6		
Price per suite (thousands of dollars) (D = F in Table 4-7)	–	400	400	400	400	400		
Investment (thousands of dollars) (E = C x D)	–	2 400	2 800	2 400	2 400	2 400		

– means not applicable.

Note.— Calculation of the number of avionics suites rounded to the nearest whole number.

Savings in aircraft operating costs = total flight-hours
× proportion of hours flown by particular aircraft category
× proportion of same aircraft type equipped with CNS/ATM
× percentage reduction in flight-hours attributable to CNS/ATM ÷ 100
× variable aircraft operating cost per hour

6.2 The pattern of these benefits to aircraft operators that might be expected to emerge after CNS/ATM is installed is illustrated in Figure 4-4. During the transition period, the benefits could increase quite rapidly as more and more aircraft become equipped with CNS/ATM. However, whether the benefits will be directly proportional to the number of equipped aircraft will depend on how the airspace is managed by the authorities during the transition. After the transition period, the benefits will increase slowly as the population of aircraft in the airspace increases in response to traffic demand.

6.3 The calculation of aircraft efficiency benefits for each year for a particular aircraft category is illustrated in Table 4-10, using a hypothetical example. A similar table must be completed for each aircraft category operating in the airspace. Total savings in aircraft operating costs can then be calculated by aggregating the savings across the various aircraft categories.

6.4 The categories of aircraft could be quite broadly defined and related to aircraft size. The proportions of flight-hours for each category will depend on the nature of the routes in the airspace (e.g. short-haul or long-haul); the proportions must add up to one and may be constant over the period of analysis. The proportion of aircraft that are CNS/ATM equipped should be consistent with related information in Table 4-3. The aircraft must be sufficiently equipped to take advantage of the benefits of the new system.

6.5 Variable aircraft operating costs per hour are those which are directly related to the number of flight-hours. They include fuel and some maintenance costs, and possibly also aircraft capital costs and crew costs, depending on the scope for utilizing these latter resources in the time periods that have been saved.

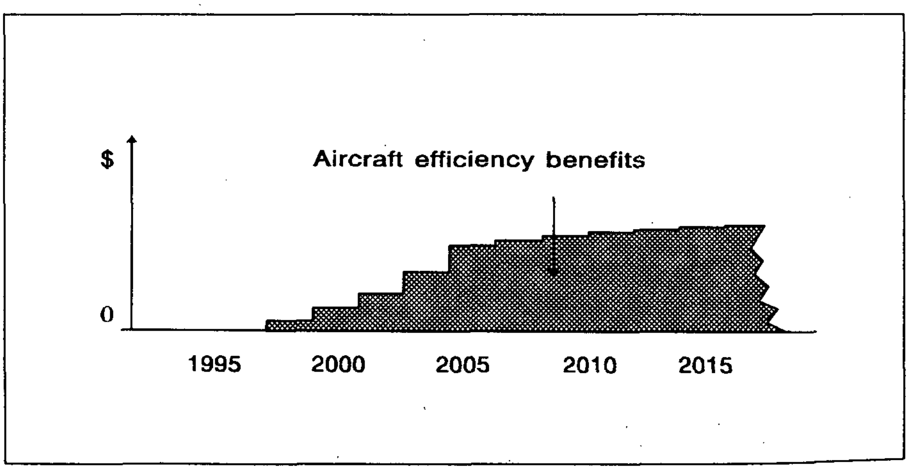


Figure 4-4. Simplified profile of aircraft efficiency benefits from CNS/ATM

Table 4-10. Forecast of aircraft efficiency benefits from CNS/ATM (for a particular aircraft category)

	Base year	Forecast years						
	1993	1994	1995	1996	1997	1998	....	2013
Total flight-hours (thousands) (A = A in Table 4-1)	–	206	212	219	225	232		
Proportion of total hours flown by particular aircraft category (B)	–	0.5	0.5	0.5	0.5	0.5		
Proportion of same aircraft category equipped with CNS/ATM (C)	–	0	0.02	0.05	0.20	0.40		
Per cent reduction in flight-hours attributable to CNS/ATM (D)	–	0	1	2	3	3		
Reduction in number of flight-hours attributable to CNS/ATM (thousands) (E = A × B × C × D/100)	–	0	0.02	0.11	0.68	1.39		
Variable aircraft operating costs per hour for particular aircraft type (F)	–	2 800	2 800	2 800	2 800	2 800		
Operating cost savings (thousands of dollars) (G = E × F)	–	0	100	300	1 900	3 900		

– means not applicable.

Note.— Operating cost savings (row G) are rounded to the nearest $100 000.

6.6 A key parameter is the percentage reduction in flight-hours achieved by CNS/ATM. The parameter for the study region should be based on assessments by technical experts of the current flight patterns and the potential for more direct flight patterns brought about by CNS/ATM (i.e. by a comparison of the service levels provided in the base case and project case). The FANS Committee identified two types of air carrier efficiency improvements, namely communications improvements related to company operations and efficiencies associated with air traffic services. The range of percentage improvements reported by FANS is given in Appendix 1. The percentage efficiency improvements quoted are less for Europe and North America than for other, generally less developed, areas of the world. These estimates take into account the increased flexibility of airlines to choose the optimum flight paths and schedules, but they do not fully account for possible benefits related to the alleviation of congestion in the airspace.

6.7 When traffic volumes approach the capacity of the airspace (determined by the existing ATC system), the resultant congestion may cause extended or circuitous flight paths, delays in flights and disruptions to timetables. Unless the airspace capacity is increased, growth in demand would cause congestion and delays to escalate, with very serious consequences for aircraft operating costs (and passenger travel times). The reduced separation standards and improved airspace management made possible by the implementation of CNS/ATM can increase airspace capacity and hence eliminate most of the costs of congestion that might otherwise be incurred. In order to estimate the benefits from reduced congestion, it is necessary to forecast the extent of the extra flight times and delays that would have been expected if the existing air traffic control system had been retained and had attempted to handle growing traffic demands. These delays would represent a cost for the traffic that experienced them. This cost is quantifiable in principle, although in practice the estimation of the delays and the related costs is a difficult task.

6.8 The potential for reductions in flight-hours because of reduced congestion attributable to CNS/ATM may be developed from information about current congestion delays in the airspace being analysed and in other busier airspaces. It might be assumed that congestion delays without CNS/ATM would escalate over time as demand grew. It would be necessary to assess the extent to which benefits from congestion relief would be available during the transition period when only a proportion of the aircraft are equipped with CNS/ATM. Note that if congestion is expected to be alleviated by other measures apart from, or together with, implementation of CNS/ATM, it may not be appropriate to attribute all of the associated benefit to CNS/ATM.

6.9 If general aviation activity is significant in the airspace, calculations of benefits should be carried out separately for air carrier flights and general aviation flights in order to take account of differences in operating costs per hour.

7. TIME SAVINGS FOR PASSENGERS

7.1 Communications and navigation improvements, which produce more direct flight paths and less delay from airspace congestion, will reduce the passenger travel time for a given journey. If passengers value these time savings, they represent an additional benefit. However, this benefit differs from the cost savings for service providers and air carriers identified above. Its validity is sometimes questioned and ultimately depends on consumers' willingness to pay for it.

7.2 The total annual passenger time savings for each aircraft category can, in principle, be expressed in monetary terms as follows:

Value of passenger time savings = flight-hours saved
× average passenger load per flight × value of passenger time per hour

The time profile of these benefits may be similar to the profile of aircraft efficiency benefits. Estimates of flight-hours saved have been discussed previously. The average passenger load depends on the average aircraft size and load factor. Because the number of general aviation passengers is relatively small, general aviation can be ignored in these calculations. The value of passenger time is, in practice, extremely difficult to quantify and will depend on passenger perceptions and trip purpose (in particular, whether the travel is for leisure or for business purposes). Assuming an attempt is made to estimate the value of passenger time, the structure for calculating and recording these savings suggested in Table 4-11 can be used. A similar table should be completed for each aircraft category and total savings obtained by aggregating across the aircraft categories (as for the calculation of aircraft efficiency benefits).

8. OTHER COSTS AND BENEFITS

8.1 There are various other costs and benefits associated with CNS/ATM implementation that have not been explicitly identified above.

8.2 **Maintenance and operational costs** associated with the CNS/ATM system (project case) and the present-technology system (base case) should be included separately in the analysis. Labour might be the most important of these costs. For the present-technology system, these costs might also include the purchase of HF services from third parties. As discussed previously, the costs associated with the base case are benefits of CNS/ATM. During the period of CNS/ATM implementation, there is likely to be a net maintenance and operational cost (i.e. project case costs greater than base case costs) for ATC service providers because of the presence of the two systems during the transition. In later years, there may be a net benefit to service providers because of efficiencies in operating the new system compared with the existing system. For example, centralization of some of the services and ATM automation may result in labour savings.

8.3 CNS/ATM implementation may also include the costs of **decommissioning** equipment of the existing system and the costs of **redeployment** of labour referred to in Chapter 3. These costs will occur towards the end of the implementation period, and the present values of these costs will be reduced by the discounting process. On the other hand,

Table 4-11. Forecast of the value of passenger time savings from CNS/ATM (for a particular aircraft category)

	Base year	Forecast years						
	1993	1994	1995	1996	1997	1998	....	2013
Flight-hours saved (thousands) (A = E in Table 4-10)	–							
Average passenger load per flight (B)	–							
Passenger hours saved (thousands) (C = A × B)	–							
Value per hour of passenger time saved (dollars) (D)	–							
Value of passenger time saved (thousands of dollars) (E = C × D)	–							

– means not applicable.

the costs of **retraining** staff to use the new CNS/ATM systems will be incurred in the early years of implementation and may be significant for both the service providers and the aircraft operators.

8.4 An important benefit from AMSS is represented by the net revenues from passenger communications available to help meet the infrastructure costs of AMSS, especially the cost of aircraft antennas. However, most of this benefit could be incorporated into the analysis by an appropriate adjustment to the cost of AMSS avionics, as discussed in 3.5.3, in which case it cannot be included again as a separate benefit.

9. SUMMARY OF COSTS AND BENEFITS FOR THE PRESENT VALUE APPROACH

9.1 All the costs and benefits of CNS/ATM for each year of the analysis are summarized in Table 4-12. The net impacts on the ATC service provider (W), the aircraft operators (X) and passengers (Y) are identified separately, and the over-all net benefits (Z) reported. The estimate of the net impact on the ATC service provider could be used in the development of cost recovery policies for their services.

9.2 The totals for each year's expenditures on CNS/ATM equipment and services and on present-technology equipment, recorded in Tables 4-2, 4-4, 4-6 and 4-8, are transferred to the appropriate rows in Table 4-12. The aircraft efficiency benefits (i.e. reductions in operating costs) from Table 4-10 and the passenger time savings (valued in monetary terms) from Table 4-11 are also transferred to Table 4-12, following aggregation across aircraft types as described in Sections 6 and 7. The other net costs (retraining, maintenance and operational, decommissioning and staff redeployment) and net benefits discussed in Section 8 should be recorded in Table 4-12, as indicated.

9.3 The passenger time savings are the only benefits in Table 4-12 allocated directly to passengers. However, passengers and freight shippers will, in principle, be the ultimate recipients of all the other benefits net of costs arising from CNS/ATM, assuming these other net benefits are passed on to passengers and shippers in the fares and rates that they pay.

9.4 An illustrative profile of the over-all net benefits from the implementation of CNS/ATM is shown in Figure 4-5. The figure also shows how the profiles of CNS/ATM costs and benefits have contributed to the net result. The large upfront costs yield net benefits later on.

9.5 Figure 4-6 gives a bird's-eye view of the relationships and information flows among Tables 4-1 to 4-12. Tables 4-2, 4-4, 4-6, 4-8, 4-10 and 4-11 have been grouped together under the heading "cost and benefit tables". Of these, Tables 4-2, 4-4, 4-6 and 4-8 receive inputs from corresponding Tables 4-3, 4-5, 4-7 and 4-9, which are called "subsidiary tables" and contain detailed calculations. In practice, there may be several versions of the subsidiary tables as explained earlier in the chapter. Tables 4-1 to 4-12 have all been produced by the ICAO Secretariat in spreadsheet format (Quattro Pro or Lotus) which analysts may find useful.

Table 4-12. Forecasts of all CNS/ATM costs and benefits (millions of dollars)

	Base year	Forecast years							
	1993	1994	1995	1996	1997	1998	.....	2013	Residual
ATC SERVICE PROVIDERS									
Costs									
Equipment investment									
– CNS/ATM	–								
– Present technology (project case)	–								
Maintenance and operational	–								
Purchases of intermediate services	–								
Retraining	–								
Decommissioning of existing system	–								
Staff redeployment	–								
Benefits									
Equipment investment									
– Present technology (base case)	–								
Maintenance and operational	–								
Other	–								
Net benefits (W)	–								
AIRCRAFT OPERATORS									
Costs									
Equipment investment									
– CNS/ATM	–								
– Present technology (project case)	–								
Maintenance	–								
Purchases of intermediate services	–								
Retraining	–								
Benefits									
Equipment investment									
– Present technology (base case)	–								
Maintenance	–								
Aircraft operator efficiency improvements	–								
Other	–								
Net benefits (X)	–								
PASSENGERS									
Benefits									
Travel time savings (Y)	–								
TOTAL NET BENEFITS (Z = W + X + Y)	–	Z_1	Z_2	Z_3	Z_4	Z_5	.....	Z_{20}	R_z

– means not applicable.

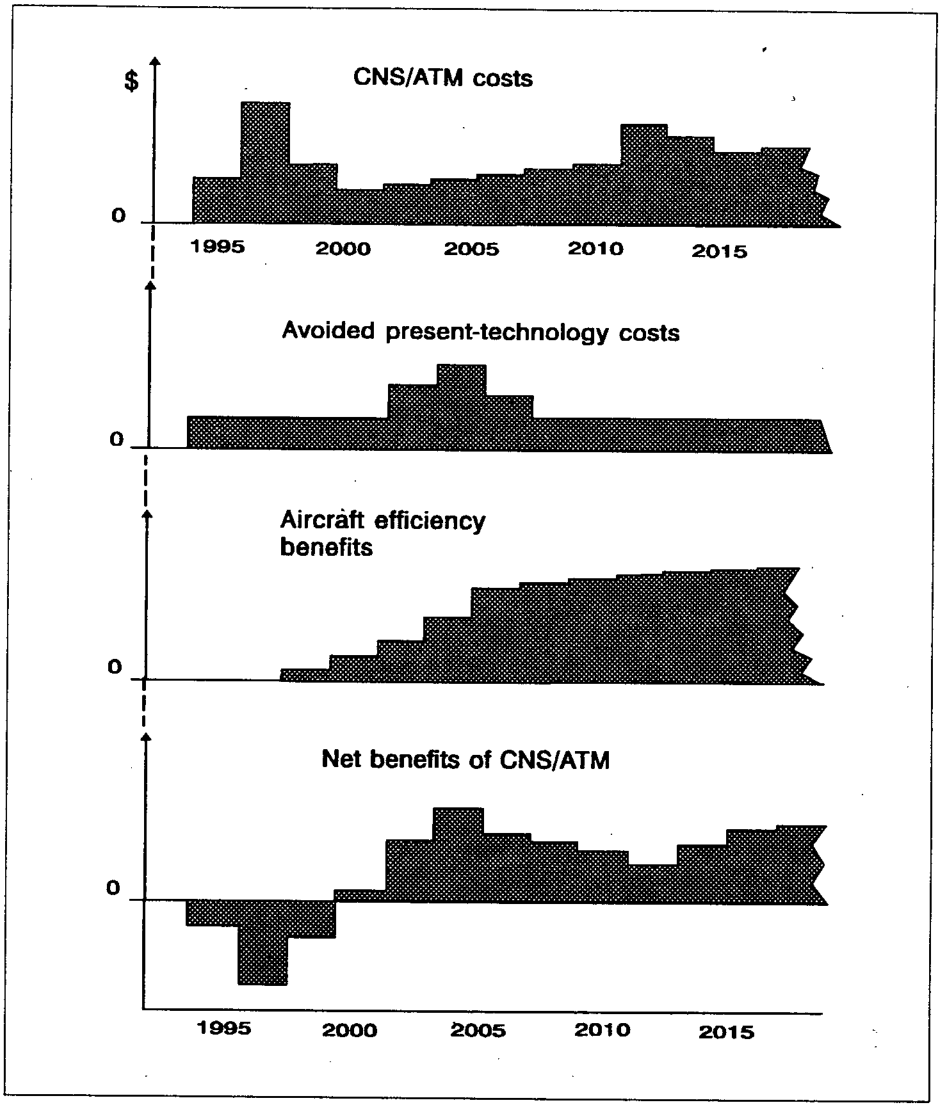


Figure 4-5. Costs and benefits of CNS/ATM

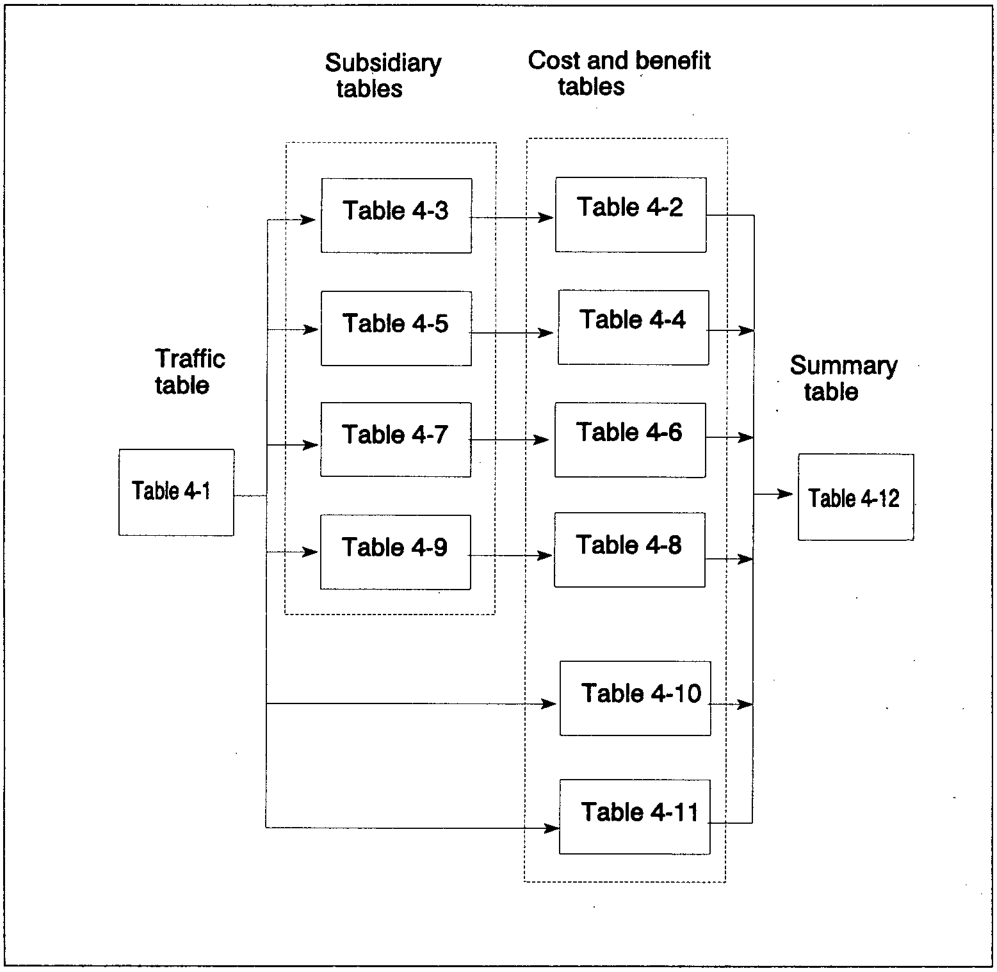


Figure 4-6. Organization of tables

10. NET PRESENT VALUES

10.1 Before any conclusions can be drawn about the economic viability of CNS/ATM in the State or region, the future monetary values must be discounted back to equivalent present values. An explanation of the concepts of "present value" and "discounting" can be found in any standard accountancy textbook. The present value (V) of an amount (F) accruing "t" years in the future can be calculated by:

$$V = \frac{F}{\left(1 + \frac{d}{100}\right)^t}$$

where d = the discount rate in per cent per annum.

For example, if a benefit of $10 million is expected in five years' time and the discount rate is 7 per cent per annum, then the present value of this future benefit is:

$$\frac{10}{(1 + 0.07)^5} = \$7.1 \text{ million}$$

(If $7.1 million is invested at the beginning of the period and earns a rate of return of 7 per cent per annum, its value after five years will be $10 million.)

10.2 The discount rate to be used in the evaluation is the minimum rate of return required from investment in the project. It is related to the cost of the funds needed to support the project, which in turn is related to the long-term interest rate. Because the future cash flows have all been expressed in real terms (i.e. in constant base-year prices), the discount rate should be a real rate. The real discount rate is equal to the nominal rate minus the expected annual rate of inflation.

10.3 If a commercial approach to the analysis is adopted, the real discount rate selected for the analysis would probably be based on the real long-term government bond rate in the country plus a premium representing the degree of risk associated with the project. The government authorities may have an agreed discount rate normally used in evaluations of public sector projects or major transportation or civil aviation projects.

10.4 The simplest procedure for assessing the over-all viability of CNS/ATM is to calculate the present values of the net benefits in each of the future years (given in the bottom row Z of Table 4-12). The net present value for the project is then given by the algebraic sum of these present values (some of which will be negative, i.e. net costs):

$$NPV = \frac{Z_1}{(1 + r)} + \frac{Z_2}{(1 + r)^2} + \frac{Z_3}{(1 + r)^3} \cdots \frac{Z_{20}}{(1 + r)^{20}} + \frac{R_z}{(1 + r)^{21}}$$

where $r = d/100$.

If the net present value is positive, then the project earns a rate of return greater than the discount rate used in the analysis and is regarded as viable at that rate. The NPVs for the service providers and the aircraft operators can be found by carrying out the same exercise for rows W and X, respectively, in Table 4-12.

10.5 The analyst must decide on the period of analysis. For a 20-25 year period, the impact of the residual values may be quite small after being discounted back to the base year of the analysis. However, a shorter period may be more appropriate in some circumstances.

10.6 There are various other options for expressing the results of the analysis. For example, the present value of the costs and the present value of the benefits can be calculated separately, and then the benefit/cost ratio determined. This can be done for the project as a whole as well as for the service providers and the aircraft operators.

Chapter 5
Issues and Applications

1. INTRODUCTION

1.1 The most important application of the cost/benefit studies is to provide a measure of the over-all financial return from the total package of investments in the new CNS/ATM systems. However, the tables in Chapter 4 were organized so as to identify the separate NPVs for the aircraft operators and service providers. This would enable service providers to use the analysis to adjust the charges for their services. Some comments on this application are given in Section 2.

1.2 An issue which affects the economic evaluation of CNS/ATM systems is the relationship of CNS/ATM to the various options for precision approach and landing systems, including the microwave landing system (MLS) and differential GNSS. The treatment of this issue, which includes appropriate specifications of the base case and project case, will be considered in Section 3 of this chapter.

1.3 Confidence in the results of cost/benefit analyses will be affected by uncertainties associated with the long-term forecasts of costs and benefits. Section 4 describes how sensitivity analysis can be used to investigate the impact of the various assumptions underlying the estimates of costs and benefits.

1.4 It is expected that the source and extent of the net economic benefits of CNS/ATM will differ between regions. There is a brief discussion of this issue in Section 5 in order to promote a broad understanding of regional differences in the impact of CNS/ATM implementation.

1.5 It was stated in Chapter 1 that cost/benefit analysis can assist in the choice of implementation option. A State or region may be faced with a variety of technical and institutional options, the most promising of which could be subjected to detailed economic analysis. Section 6 of this chapter considers this question. Finally, in Section 7, economic analyses to assist with decisions regarding the choice of data link and surveillance facilities (within the CNS/ATM concept) in high-density continental airspace are discussed.

2. COST RECOVERY

2.1 The NPV for the ATC service provider for an airspace is the total lump sum or capitalized amount, in the base year, of the expected flow of net financial impacts on the service provider as a result of the transition from present-technology systems to CNS/ATM. This estimate can provide guidance on how cost recovery or user charges should be **adjusted** as a result of CNS/ATM implementation. The NPV analysis does not throw light on the economics of the existing pricing structure. However, if the current charges adequately cover the capital and operating costs of the present technology system, then adjustment of the charges in accordance with the NPV will preserve the balance between expenses and revenues.

2.2 If the cost/benefit analysis of CNS/ATM implementation yielded a positive NPV for the service provider, then a reduction in the user charge may be indicated. A negative NPV for the service provider would suggest an increase in the charge. Taking as an example the latter situation, the required increase in charge can be gauged after calculating the average annual flow of cash, sometimes called the uniform annual value (UAV), which is equivalent to the NPV. The UAV is derived by multiplying the NPV by the same real interest rate used for discounting purposes in Chapter 4. Other factors such as the pressure of demand for services on system capacity and the effect of general inflation on costs may also be considered when deciding on changes in service charges.

3. CNS/ATM AND MLS

3.1 As mentioned in Chapter 2, differential GNSS (DGNSS), which would enhance the performance of GNSS, is an evolving component of CNS/ATM. It would involve a network of ground stations and/or satellites which would be used in the measurement of errors in the GNSS satellite signals, the calculation of corrections to these signals, and the broadcasting of these corrections to aircraft. In this way, DGNSS could support some (if not all) types of approach, landing and departure operations and provide other benefits. It is therefore regarded as a potential alternative to MLS systems which are to replace instrument landing systems (ILS) under the current ICAO ILS/MLS transition plan in Annex 10 to the Convention on International Civil Aviation. The appropriateness of the ILS/MLS transition plan will be reviewed at a Special Communications/Operations (COM/OPS) Divisional Meeting scheduled for March 1995.

3.2 Figure 5-1 illustrates the costs and benefits of a transition from ILS to MLS, and an alternative transition from ILS to DGNSS. These representations are hypothetical, with no intention to prejudge the results of studies on this issue, but rather to highlight the possibility that DGNSS might be a more cost-effective replacement of ILS than MLS, assuming that DGNSS can achieve the necessary precision. It is tentatively assumed here that potential benefits to air carriers from curved approaches and increases in runway capacity might be similar with MLS or DGNSS. Since DGNSS is an enhancement of CNS/ATM, its adoption might increase the benefits attributable to the CNS/ATM systems as a whole and contribute to their over-all viability.

3.3 There are two types of DGNSS which might be regarded as part of the CNS/ATM systems concept. The first is **wide-area DGNSS**, which would use dispersed reference stations with the possibility of providing Category I precision approaches at airports across

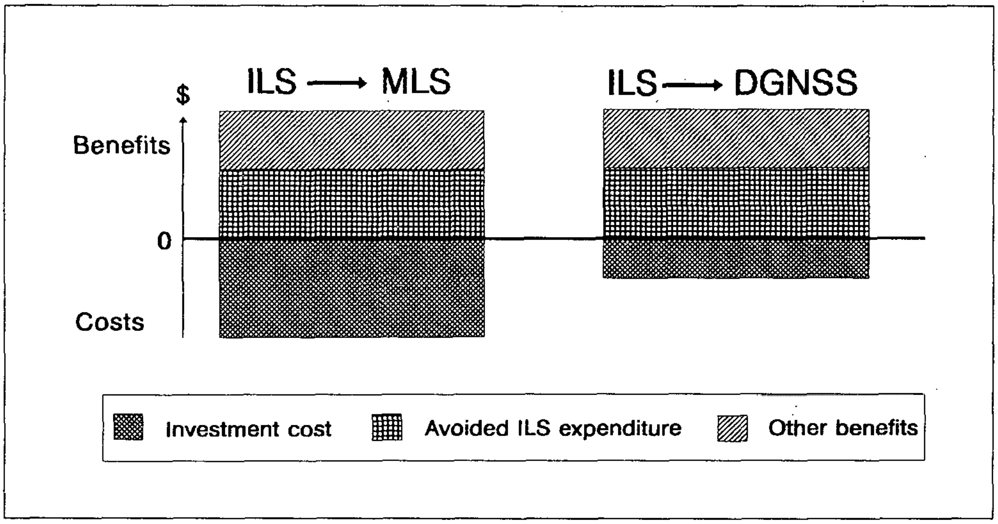


Figure 5-1. ILS/MLS and CNS/ATM

a large region. In a cost/benefit analysis of CNS/ATM which included wide-area DGNSS, the *project case* would include the necessary additional avionics investment, as well as any further costs associated with ground stations, satellites and communications services incurred by the ATC service providers. It may be appropriate for States to join with neighbours in the provision of wide-area DGNSS services, sharing the costs. Also the wide-area DGNSS function is likely to be collocated with (and share facilities with) the ground-based GNSS integrity monitoring function discussed in 3.4.6 of Chapter 4. In regard to avionics, the development of a multi-mode receiver, capable of operating with ILS, MLS or DGNSS and costing perhaps 20 per cent more than an ILS receiver, is being considered. Assumptions about these matters may impact on the costs to be included in the analysis.

3.4 It would be possible to define the *base case* of the cost/benefit analysis referred to above to include Category I (MLS) systems on the basis of the currently agreed ICAO ILS/MLS transition plan. The base case expenditures would then contain the considerable investment flows related to Category I (MLS) implementation. However, since the existing systems of most runways with Cat I capability are ILS, the preferred approach might be to include Cat I (ILS) in the base case (along with the other present-technology systems such as NDB, VOR, etc.) since this is the system that will be replaced by DGNSS. This approach would ideally involve the estimation of the benefits to air carriers from curved approaches and increased system capacity. In this regard, it is significant that DGNSS would not only replace ILS but also provide service at small airports without existing ILS systems.

3.5 The second type of DGNSS which might also become part of the CNS/ATM concept is **local-area DGNSS**. This system would rely on a single reference site near an airport and provide support for precision approaches and landings (possibly Cat I/II/III) and operations at that airport. The technical feasibility and performance of local-area DGNSS are the subject of current research and development efforts. In a cost/benefit analysis of CNS/ATM which also included local-area DGNSS, the further expenditures required for implementing and operating such a system in the State would be included in the project case. The base case could be defined to include the existing Category I/II/III (ILS) systems.

4. SENSITIVITY ANALYSIS

4.1 The NPV methodology described in this circular gives a forecast of the over-all economic performance of the CNS/ATM project. This forecast is dependent on many assumptions and judgments about future traffic levels, equipment costs and pricing policies, and about the speed and success of the transition process. More specifically, assumptions are required for the following variables over the analysis period:

- Forecasts of total flight-hours
- Capital costs of ground equipment
- Avionics prices
- Proportion of the fleet equipped with CNS/ATM
- Quantity of AMSS messages per hour
- Price of AMSS satellite usage
- Price for access to GNSS signals
- Efficiency improvements for aircraft flights (reduction in flight-hours attributable to CNS/ATM)
- Value per hour of passenger time saved.

4.2 The main purpose of the cost/benefit analysis is to derive the NPV estimate based on the "most likely" set of assumptions. However, uncertainty about these assumptions translates into uncertainty about the estimates of the project's NPV. One method of addressing this issue is sensitivity testing, which can be used to determine the impact of alternative assumptions on the NPV estimate. This is discussed further for three of the assumptions listed above, i.e. avionics prices, price for GNSS signals and efficiency improvements for aircraft flights. The feasibility of sensitivity testing is greatly increased by the use of computer spreadsheets that can rapidly perform the calculations.

4.3 *Avionics prices*

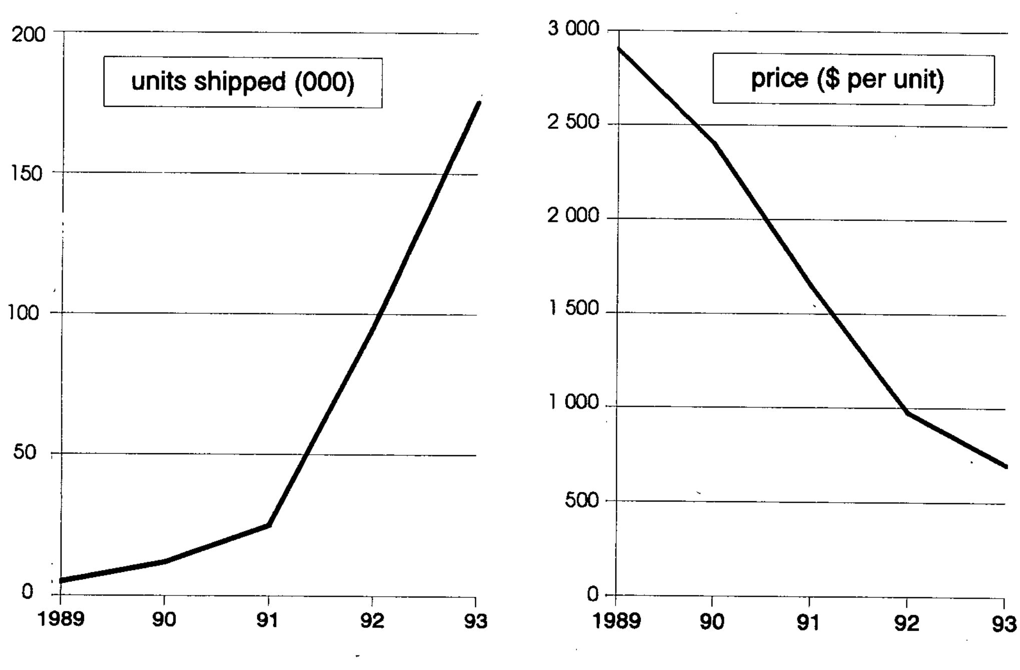
4.3.1 Prices of newly developed electronics equipment such as avionics often drop as the number of units manufactured and sold increases, because of economies of scale. This is clearly illustrated in Figure 5-2 — showing trends in the quantity produced and price of GPS Receivers — taken from the *Economist*, 6 November 1993. (Note that there are various applications of GPS, such as navigation, surveying, map-making and fleet management, requiring different specifications for receivers. Figure 5-2 does not refer to GPS receivers used by commercial aircraft; its purpose is to highlight the relationship that can exist between quantity and price when new products of this type are introduced and absorbed into the market.)

4.3.2 The assumption for the price of CNS/ATM avionics equipment is specified in Table 4-3, which feeds into Table 4-2 and, eventually, Table 4-12. The price must be specified in real terms, i.e. in terms of the general level of prices in the base year. Any information on the actual prices of a piece of equipment in a year other than the base year must be adjusted for general inflation between the base year and the year in question. That is,

$$\text{Real price of equipment in year } N = \text{nominal price in year } N \times \frac{\text{general price index in base year}}{\text{general price index in year } N}$$

4.3.3 An assumption that the price remains constant in real terms over the planning period means that the actual (nominal) price will increase in line with general inflation. A constant nominal price implies a real price that falls at the same rate at which the general price index is rising. Note that avionics prices will be in hard currency terms, and the general price index in the economy of that currency should be used for adjustment purposes.

4.3.4 The most likely trend in prices of various items of avionics may be based on a survey of industry views. Sensitivity of the NPV to these prices could be tested by assuming prices diverge from the most likely assumption by up to, for example, 30 per cent. The risk of divergence might be greater in more distant years than in the immediate future.



Source: Colwell-Kirtland International and Economist, March 1993.

Figure 5-2. Quantity and price of GPS receivers

4.4 *Price for GNSS space signals*

4.4.1 Free access to the standard position services (SPS) of GPS and GLONASS, which were established as military systems, is a reasonable "most likely" assumption on the basis of statements from the United States and the Russian Federation. The United States has offered GPS SPS free of charge for the foreseeable future; the offer of free access applies for at least 10 years, with a minimum of 6 years' advance notice of a change in policy. The Russian Federation has confirmed free access to GLONASS SPS without charge for 15 years starting from 1995.

4.4.2 The international civil aviation community appreciates the value of these offers in facilitating the transition process but may, in due course, decide to establish a civil GNSS which would satisfy the desire of the ATC authorities of individual States for an acceptable level of control over the system. Although the issue of cost recovery is a complex one, States or regions may wish to attempt an assessment of the possible impact of the costs of such an investment on the cost/benefit analysis of the total CNS/ATM systems.

4.4.3 The annual cost of maintaining a global civil system requiring 24 navigation satellites could be derived from assumptions about the capital costs of the satellites (including their launch), depreciation rates and interest rates. A cost per flight-hour could then be derived after making an assumption about the quantity of aircraft traffic using the system. However, non-aviation users might make a very significant contribution to the cost (GPS has already attracted an extensive range of users). Also, pricing may be on a "per user" rather than a "per unit of usage" basis, given the difficulty of monitoring usage. Finally, when specifying the pricing assumption, it is important to recognize that the option of purchasing the service from a civil system (or from GPS or GLONASS) will not be relevant for quite a few years. The impact on the NPV of CNS/ATM will therefore be reduced because of the discounting of future cash flows.

4.4.4 The assumption adopted for the purchase of access to GNSS signals is recorded in Table 4-4 which then feeds into Table 4-12.

4.5 *Efficiency improvements for aircraft flights*

4.5.1 There are two reasons for conducting sensitivity tests for efficiency improvements for aircraft flights. The first is that these benefits are likely to be the largest financial item in the cost/benefit analysis. The second is the scarcity of research and published information on the size of the percentage reductions in flight times attributable to CNS/ATM, which is a key parameter in the calculation of the benefits.

4.5.2 Technical experts may be able to assess the prospects for these benefits in the airspace and advise on the most likely outcome. Sensitivity tests could then be used to evaluate the impact of increasing or decreasing the benefits by, for example, 20 per cent. The assumptions for this item are recorded in Table 4-10 which feeds into Table 4-12.

5. REGIONAL DIFFERENCES IN ECONOMIC IMPACT

5.1 The economic impact of CNS/ATM will depend on the circumstances of the region in which it is being implemented. This can be discussed after first summarizing the benefits from implementation of CNS/ATM (Figure 5-3). The cost savings from withdrawal of ground-based navigation aids and radars will accrue to the providers of ATC and traffic management services. Air carriers will receive financial benefits from increased airspace capacity and/or more direct flight paths.

5.2 In continental airspaces with highly developed present-technology systems, avoidance of the need to maintain and replace existing systems will result in substantial cost savings. There are few benefits from this source in airspaces without present-technology systems (e.g. oceans, remote areas). On the other hand, instalment of CNS/ATM systems will have a greater positive impact on the quality of navigation and surveillance services, and hence on the opportunities for more direct flights, in the latter airspaces than in those with extensive existing systems where flight paths may already be relatively direct.

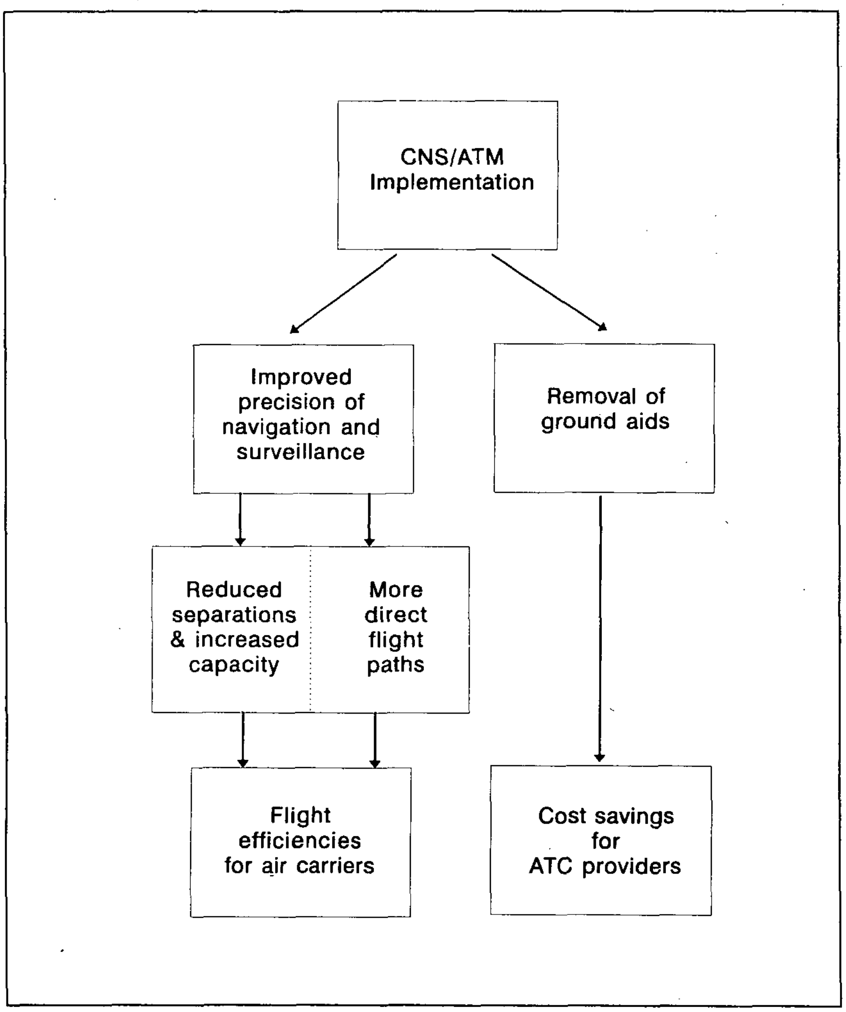


Figure 5-3. A simplified view of the impact of CNS/ATM

5.3 In regions with heavy traffic, airspace congestion may be, or may become, a problem unless improved systems are established. Navigation and surveillance improvements resulting from CNS/ATM will bring additional benefits in these regions by allowing reductions in separation standards (while maintaining safety) and hence increasing airspace capacity and removing bottlenecks.

6. CHOICE OF IMPLEMENTATION OPTION

6.1 It may be appropriate to compare the economics of a partial CNS/ATM system (such as that illustrated in Figure 2-2) with a more complete CNS/ATM system, the latter having more communications options and more automation in the traffic control centre (as indicated in Figure 2-1). Cost/benefit analyses for each of these options can be carried out. The more expensive option would be expected to provide more benefits and, in particular, greater efficiency improvements for aircraft flights. The option with the larger (more positive) NPV is the more attractive one, from an economic perspective.

6.2 In this analysis, the biggest challenge is to estimate the impact of each option on the efficiency of aircraft flights (especially flight times). A comparison of the two options is essentially a comparison of the extra cost of the more complete CNS/ATM system with the extra benefits from reduced flight times expected from this option.

6.3 In certain circumstances, alternative technologies can be employed to produce a similar specific objective, and a comparison of the effectiveness of the alternatives is based solely on their costs. For example, either MLS or DGNSS might be used to achieve similar benefits for approach and landing; also Mode S, or VHF, or AMSS might be used to provide similar data communications services. The relative costs of each of these technologies may depend on the traffic and infrastructure environment. The last section of this chapter illustrates how the cost/benefit methodology can be adapted to determine the lower cost option.

7. THE CHOICE BETWEEN VHF AND MODE S

7.1 In oceanic and remote areas, the communications element of CNS/ATM will clearly be AMSS. In some of the higher-density continental airspaces, however, AMSS may be much less cost-effective for data communications than VHF data or Mode S (which are both line-of-sight systems) because the operating costs of the latter two are low and their capital costs can be shared among many users. For this type of airspace, civil aviation administrations may wish to compare the relative costs of VHF and Mode S for data communication before proceeding with their implementation of CNS/ATM. This comparison should, however, take into account the fact that an SSR Mode S facility may provide both surveillance and data link services. Since an SSR Mode S data link system can also provide surveillance, it is difficult to allocate the common costs of the system between the two functions. It may therefore be more appropriate to examine the options for providing both surveillance and data link services.

7.2 There are various possible equipment options within the CNS/ATM concept for providing surveillance and data link in high-density continental airspaces. The cost-effectiveness of the options will depend on the existing facilities. It is suggested that States undertake a comparative analysis of the two options which are the most promising in the circumstances. For the purposes of describing the methodology, the combination of SSR Mode A/C and VHF data is here arbitrarily designated as the project case and SSR Mode S (surveillance and data) as the base case. If it is assumed that the quality of service offered by VHF data/SSR Mode A/C is similar to that provided by SSR Mode S, a cost/benefit analysis becomes a least cost analysis. The methodology for this type of analysis is illustrated in Table 5-1, which is a framework for recording the annual costs (cash-flow expenditures)

Table 5-1. Forecasts of VHF data/Mode A/C and Mode S costs (thousands of dollars)

	Base year	Forecast years							
	1993	1994	1995	1996	1997	1998	...	2013	Residual
ATC SERVICE PROVIDERS									
Costs of VHF Data/Mode A/C (Project Case)									
Equipment investment	–								
Maintenance and operational	–								
Purchase of third-party services (if any)	–								
Costs of Mode S (Base Case)									
Equipment investment	–								
Maintenance and operational	–								
Purchases of third-party services (if any)	–								
Net benefit of VHF Data/Mode A/C	–								
AIRCRAFT OPERATORS									
Costs of VHF Data/Mode A/C (Project Case)									
Equipment investment	–								
Maintenance	–								
Costs of Mode S (Base Case)									
Equipment investment	–								
Maintenance	–								
Net benefit of VHF Data/Mode A/C	–								
TOTAL NET BENEFIT OF VHF DATA/MODE A/C (Z)	–	Z_1	Z_2	Z_3	Z_4		...	Z_{20}	R_z

– means not applicable.

associated with the implementation of the two options. For each of the two options, it is necessary to identify the **additional** expenditures associated with servicing the specific airspace segment being investigated. For example, VHF data may be collocated with VHF voice, sharing some of the costs of facilities; furthermore, SSR Mode A/C facilities may already be in place. The net benefits of VHF data/Mode A/C are equal to the expenditures on Mode S less the expenditures on VHF data/Mode A/C, for each year. The total net benefit of VHF data/Mode A/C in each year (Z_1, Z_2, Z_3, ...) is the sum of the net benefit of VHF data/Mode A/C for ATC service providers and for aircraft operators. The present value of all the total net benefits of VHF data/Mode A/C (i.e. the costs of Mode S net of the costs of VHF data/Mode A/C) is calculated by the process of discounting and aggregation as described in Chapter 4. This is the net present value for the project case against the base case. A positive value would indicate that VHF data/Mode A/C was the lower cost option.

7.3 Another potentially attractive option for data link and surveillance in some airspaces is VHF data plus ADS. States may decide to compare this option with VHF data/SSR Mode A/C, using the methodology described above.

Chapter 6
Alternative Methods of Economic Evaluation

1. INTRODUCTION

1.1 The primary objective of this circular has been to describe the Net Present Value approach to cost/benefit analysis and to explain how this approach can be applied to the economic evaluation of the implementation of CNS/ATM systems. In this last chapter, other methods of economic analysis of CNS/ATM are outlined.

1.2 In Section 2, *cost-effectiveness analysis* is defined and its application to the evaluation of CNS/ATM systems is assessed. *Least-cost analysis*, which is related to cost-effectiveness analysis, is considered in Section 3. The *snapshot approach* is described in Section 4 in sufficient depth to assist those States wishing to follow the example of the FANS Committee and apply this method of analysis to CNS/ATM implementation. Finally, the *pay-off period* and *utility value analysis* methods are outlined in Sections 5 and 6, respectively.

2. COST-EFFECTIVENESS ANALYSIS

2.1 Cost-effectiveness analysis is sometimes used to evaluate projects when it is not practical to translate the benefits of the project into monetary terms. Since costs cannot be directly compared with benefits on the basis of a common unit of account, the approach cannot indicate in clear quantitative terms whether the main objective of a project warrants the cost involved. Rather, it can be used to assist the decision-maker to choose among several alternative ways of achieving a broadly defined objective in a way which has the potential to minimize the costs and maximize the benefits. The costs of prospective investment projects are quantified in present value terms and the benefits are described as fully as possible. The projects are then assessed and compared in a judgemental fashion. An attempt should be made to estimate the principal impacts or benefits in physical units even if it is not possible to put monetary values on such measures. Cost-effectiveness ratios for each project can then be computed by dividing the present value of the costs of the investment by the measure of its principal impact.

2.2 The principal benefit of the CNS/ATM systems which is difficult to measure is the efficiency benefit for aircraft operators. As discussed in Section 6 of Chapter 4, the main problem in determining this benefit is that of forecasting the reduction in the number of flight-hours attributable to the CNS/ATM project. The additional step of expressing this benefit in financial terms requires reasonably straightforward assumptions about variable aircraft operating costs per hour.

2.3 Cost-effectiveness analysis might be helpful in the evaluation of the options discussed in Section 6 of Chapter 5. Alternative specifications of CNS/ATM implementation could be compared in terms of their equipment and operational costs and in terms of judgements about their expected impact on flight efficiencies.

3. LEAST-COST ANALYSIS

3.1 This method of analysis is a simplification of cost-effectiveness analysis. The purpose is to compare the costs associated with several alternative ways of achieving a specific objective. There is no attempt to quantify the benefits associated with the alternatives; the latter are assessed only on the basis of their costs (in present value terms), the lowest cost option being the preferred one.

3.2 This approach is relevant whenever it can be reasonably assumed that the benefits of the options will be similar. This may be the case for comparisons between Mode S and VHF, as discussed in Section 7 of Chapter 5.

4. SNAPSHOT APPROACH

4.1 This approach involves choosing a future date by which the CNS/ATM systems would be established and operational, and then comparing the economics of operating this system with the economics of operating the existing systems, had they been retained and developed. Forecasts of the annualized costs and benefits at this date are required. The year 2010 is regarded as a suitable date by which the transition to CNS/ATM should be completed.

4.2 By looking beyond the implementation phase, this approach does not take into account the transition costs of bringing forward capital investment programmes (i.e. replacing existing equipment before it is fully depreciated), having to operate some of the existing facilities after the new facilities have been put in place, or retraining staff during the transition, nor does it include the consequences of possible delays in obtaining the benefits of more direct flights.

4.3 As with the NPV approach, CNS/ATM is the project case. The derivation of the depreciation and interest expenses in 2010 associated with the equipment of the CNS/ATM systems is illustrated in Table 6-1. The initial capital investment cost for each equipment item is calculated from the base year price per unit and the number of units required in the year 2010. The annual depreciation cost for each item is derived from the initial investment cost. One method is to divide the initial investment cost by the expected life of the equipment, which might vary with the type of equipment. The FANS Guide has assumed a life of 15 years for communications equipment. The annual interest cost for each item is calculated by multiplying the initial investment cost by a specified rate of interest. The same rate is used for all investments and should be related to the cost of funds.

Table 6-1. CNS/ATM equipment costs, 2010

Equipment suite	Unit cost	Number of units	Total capital cost	Annual costs: Depreciation	Annual costs: Interest	Annual costs: Total
GROUND						
AMSS voice/data						
VHF voice/data						
SSR Mode S						
ATN						
GNSS integrity monitoring						
ATM automation						
Total						
AIRCRAFT						
AMSS voice/data						
VHF voice/data						
SSR Mode S						
CMU						
GNSS						
FMS						
ADS						
Total						

4.4 Apart from these equipment-related costs, CNS/ATM will involve the purchase of services from third parties (intermediate service providers) by either the ATC service providers or the aircraft operators or both. One example is the purchase of signal transmission via the satellites of the AMSS. Table 6-2 shows how the quantity and cost of these services can be recorded and aggregated. The total annual cost of a service is calculated by multiplying the price per unit of service by the quantity of units purchased.

4.5 The existing present-technology system is the base case. The depreciation and interest expenses associated with the equipment items of the present-technology system are avoided if the CNS/ATM systems are in place and hence are interpreted as benefits of CNS/ATM. The derivation of these expenses is illustrated in Table 6-3. The approach is similar to that used for determining CNS/ATM equipment costs.

4.6 The totals of Tables 6-1, 6-2 and 6-3 can be transcribed to Table 6-4, which summarizes the annualized costs and benefits which would flow from CNS/ATM systems in 2010 as compared with systems based on today's technology.

Table 6-2. Purchases from intermediate service providers, 2010

Service	Unit cost	Number of units	Total cost
AIRLINE OR CAA			
GNSS signals			
Satellite communications			
CAA			
Ground communications links			
TOTAL			

Table 6-3. Present-technology equipment costs, 2010

Equipment suite	Unit cost	Number of units	Total capital cost	Annual costs		
				Depreciation	Interest	Total
GROUND						
HF voice						
VHF voice						
Omega						
NDB						
VOR						
DME						
Primary radar						
SSR Mode A/C						
Total						
AIRCRAFT						
HF voice						
VHF voice						
Omega						
ADF						
VOR						
DME						
SSR Mode A/C						
Total						

Table 6-4. Annualized costs and benefits of CNS/ATM in 2010

Cost or benefit item	ATC service providers	Aircraft operators	Passengers	Totals
COSTS OF CNS/ATM SYSTEM IN 2010				
CNS/ATM equipment costs				
– Depreciation			–	
– Interest			–	
Net maintenance and operational			–	
Purchases from intermediate service providers			–	
Total	C_1	C_2		C
BENEFITS OF CNS/ATM SYSTEMS IN 2010				
Avoided equipment costs of present-technology				
– Depreciation			–	
– Interest			–	
Efficiency improvements for aircraft operators	–		–	
Passenger time savings	–	–		
Total	B_1	B_2		B

– means not applicable.

4.7 The difference in the maintenance and operational costs associated with the two systems is recorded in Table 6-4 (net maintenance and operational). Costs common to both systems can be omitted from the analysis.

4.8 The savings to aircraft operators from more efficient flight paths (calculated from the forecast of flight-hours, percentage reduction in flight-hours attributable to CNS/ATM and aircraft operating costs per hour) are included in Table 6-4. Passenger time savings are also included.

4.9 The calculations of costs and benefits in the snapshot approach are simpler than in the NPV approach. All ATC services are provided only by CNS/ATM (the project case) or only by the present-technology system (the base case). Although it does not take into account the costs of transition, the snapshot approach is a useful tool for assessing the economics of CNS/ATM in the long term. The snapshot approach was adopted by the FANS Guide and has been applied by a number of States.

5. PAY-OFF PERIOD

5.1 The pay-off period for an investment project is the number of years necessary to recoup the capital outlay from the stream of benefits generated by the project. CNS/ATM is a complex project with capital expenditures and benefits spread over a relatively long period, as indicated in Figure 4-5. The figure also shows the characteristic pattern of negative net benefits (benefits net of outlays) in the early years of implementation, followed by many years of positive net benefits.

5.2 Application of the pay-off criterion involves tracking the cumulative net benefit, which, for a given year, is the algebraic sum of the net benefits in the current year and all of the preceding years back to the project's commencement. The project meets the criterion in the year that cumulative net benefits become zero, which is year 13 in Figure 6-1.

5.3 The pay-off criterion, as described here, ignores the financial cost of capital (interest costs). Also, it does not require forecasts of expenditures and benefits beyond the pay-off period. In these respects, it represents a simplified approach to the economic evaluation of CNS/ATM.

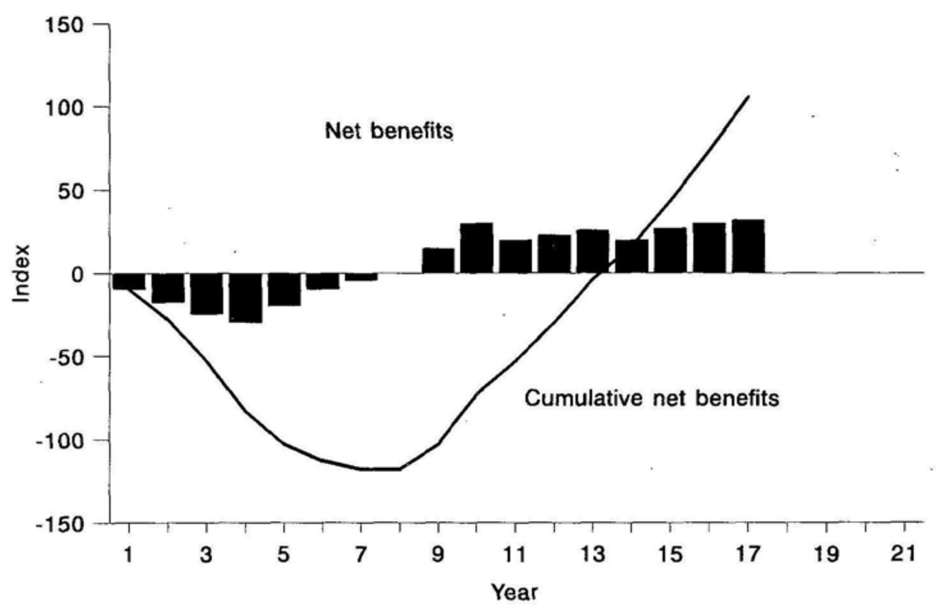


Figure 6-1. Net benefits and cumulative net benefits of CNS/ATM

6. UTILITY VALUE ANALYSIS

6.1 The cost/benefit methods of project evaluation described in this circular focus on the financial consequences of CNS/ATM. However, as mentioned in Chapter 1, the ATC system has other consequences apart from those which are measurable in dollar terms (e.g. safety, environmental, co-ordination with the military). Utility value analysis is an approach for evaluating CNS/ATM implementation on the basis of a wide range of performance dimensions.

6.2 Utility value analysis involves identifying the objectives or goals to be served by the ATC system, rating the relative importance of these goals, and assessing the performance of the various system options (e.g. CNS/ATM systems, present-technology system), first with respect to each goal separately, and then with respect to over-all goal attainment. The weight given to individual goals in the measure of over-all goal attainment depends on their relative importance according to the subjective views and preferences of various interest groups. System performance in regard to the individual goals is estimated as objectively as possible but will often be based on expert judgement.

Appendix 1
Efficiency Improvements due to CNS/ATM

(percentage improvements)

Traffic Area	Category	Minimum	Maximum
Oceanic	ATS	0.50	1.50
	OPS	1.00	1.00
	Total	1.50	2.50
Europe	ATS	1.00	1.50
	OPS	0.25	0.25
	Total	1.25	1.75
North America	Total	0.35	0.55
Balance of World	ATS	2.00	3.00
	OPS	1.00	1.00
	Total	3.00	4.00

Source: International Civil Aviation Organization, Special Committee on Future Air Navigation Systems, Fourth Meeting (FANS(II)/4), 1988.

Note.— The figures in the table above are estimates that were based on broad judgements rather than detailed analysis. States should exercise care in their interpretation and use.

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— END —

ICAO PUBLICATIONS
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The following summary gives the status and also describes in general terms the contents of the various series of publications in the air transport field issued by the International Civil Aviation Organization:

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Also of interest to Contracting States are reports of meetings in the air transport field, such as sessions of the Facilitation Division and the Statistics Division and conferences on the economics of airports and air navigation facilities. Supplements to these reports are issued, indicating the action taken by the Council on the meeting recommendations, many of which are addressed to Contracting States.

7/95, E/P1/2500

Order No. CIR257
Printed in ICAO