The Economic Evaluation of CNS/ATM Transition

David L. Allen, Aslaug Haraldsdottir, Robert W. Lawler,
Kathleen Pirotte, Robert W. Schwab

CNS/ATM Projects

Boeing Commercial Airplane Group

0. Introduction

The air transport industry is developing a new operational concept for the Air Traffic Management (ATM) system. This operational concept involves substantial changes to airplanes and ground systems with the introduction of new satellite−based technologies. The current mature ATM systems, based on ground navigational aids, radar, and voice communications, will be unable to cope with expected air traffic growth. A number of states lack such infrastructure and find themselves with a confusing selection of technologies and no clear direction to base decisions on. The industry, lacking a global transition strategy, is in danger of strangling on its own success.

The aviation industry has developed an operational concept known as the Future Air Navigation System (FANS), which relies on satellite−based navigation and communication to provide the improvements needed in communication, navigation, and surveillance (CNS) to efficiently cope with future traffic levels.

The FANS development required industry to consider ATM as a system with interacting ground, space and airborne components. The International Civil Aviation Organization (ICAO) FANS committee also committed to certain technical solutions for improvements to CNS such as the Aeronautical Telecommunications Network (ATN), Global Positioning System (GPS) navigation, and satellite communications. However, since the adoption of the ICAO FANS committee suggestions, progress towards this envisioned end state has been slow. This lack of movement towards full FANS implementation is not due to any particular technical problem; it is due to the lack of consideration given to the business aspects of the problems that FANS was designed to solve. The Air Traffic Management system must be considered as a system; but it must also be considered as a business. The lack of consideration of the economics of transition to the new operational concept has slowed the pace of the implementation process.

The industry effort has focused primarily on development of the technological case for CNS/ATM, with many resulting competing technologies. However, the business case for CNS/ATM has primarily been addressed at a cursory level, resulting in estimates of operational savings without details on the benefit mechanisms. While these financial studies serve to sustain the technological case development they do not meet the requirements of the airline financial analysts and therefore do little or nothing towards investment in the implementation of CNS/ATM applications. Since financial analysts hold the "purse strings" for airplane and ground system upgrades, implementation is slowed until they are confident that the expenditures are justified. To get the envisioned system plan back on track, it is imperative that the industry move from "notional" benefits to "data−driven" benefits with solid business cases.

1.1 Airline Procurement Changes

The intensely competitive nature of the airline industry has driven changes in airline procurement practices. Every factor is carefully analyzed by the airline investment organizations. The era of "technology for technology’s sake" is past. As an example, during the development of the 747−400, a series of aircraft changes were offered to customers as an avionics upgrade package. Over 50 functional enhancements were contained in that package, including GPS integration, ATN, Controller to Pilot Data Link Communication (CPDLC), Automatic Dependent Surveillance (ADS), Company Data Link, and a host of flight crew requested functions. Very few airlines bought the package and thus it was later withdrawn. The airlines felt that the lack of mature benefits coupled with the cost could not justify the purchase of the package. The economic case suffered because of the absence of parallel infrastructure developments to support realization of the operational potential of ATN and other advanced features.

The FAA recently conducted a survey of U.S. domestic airline chief financial officers. The purpose of the survey was to identify criteria that chief financial officers use to measure their companies’ success. The airline responses are summarized as follows:

- Pre−tax profit margin in top 10% of carriers
- Credit rating of BBB or better
- Shareholder return in the top 25% of Standard and Poor

The above goals are not easy to meet in today's competitive environment. As stated earlier, competition is intense and airline investment dollars must be carefully managed. CNS/ATM upgrades must compete for airline investment dollars with cabin system upgrades, training programs, landside upgrades, maintenance upgrades, and every other airline investment. Complicating matters further is the dependence of airline CNS/ATM benefits on ground infrastructure development. This puts a critical link in the development out of the airlines' direct control. The existence of competing technologies adds further uncertainty. Finally, fleet upgrades are expensive and only represent a portion of the cost (which includes training, spares, and aircraft downtime). Airline and airframe manufacturer financial analysts require credible benefits assessment with due consideration of infrastructure risk in evaluating investment return.

After the demise of the 747−400 avionics package, a group of airlines approached Boeing requesting a small subset of the functions, which evolved into the FANS−1 package. The required functions were prioritized and reduced from 50 to 5. A key determinant was the matching of the aircraft functions to those required by the airspace operational concept and the identification of specific benefit mechanisms associated with that function. It was decided to use the existing communication infrastructure rather than wait for ATN with its unknown cost and a substantial development risk.

Boeing offered the FANS−1 package, but the process paused once more. Even though FANS−1 was initiated by enthusiasts within some airlines, the airline financial people needed to concur before they would authorize release of funds to purchase the FANS−1 package. The airlines and Boeing developed business cases based on route structures that had committed programs to implement the infrastructure to support specific operational enhancements. This was the key to success. Boeing was able to use the business case to authorize the initiation of the FANS−1 system development. The airlines were able to use that business case to present a credible basis for investment to their financial departments and obtain authorization to purchase FANS−1.

1.2 Lessons Learned

The lessons learned from the FANS−1 program development included:

- Develop an operational concept for the airspace which can be supported by the avionics and the infrastructure.
- Develop a phased introduction of that operational concept where the operational benefit associated with each step outweighs the cost.
- Develop a credible business case tied to specific benefits mechanisms.
- Select technology only if it supports the business case.
- Do not allow "gold−plating" of technology.
- Assure maximum integration with the ground environment.
- Establish implementation dates and ensure that they are adhered to.

Certainly, the ICAO plans contain the ultimate CNS/ATM operational concept. However, investment dollars are not available to allow a "grand switch" to be pulled and have the end−state concept realized in one step, world−wide. This requires development of operational enhancement phases, which needs to be done carefully, because if a single phase does not meet the cost/benefit criteria the whole process stops.

The CNS/ATM industry committees are primarily populated with engineering and flight operations personnel, which leads to a focus on technical maturity. The industry is getting to the point, however, where the achievement of business case maturity may be more important than technical maturity. Certainly, engineers and flight operations people would rather continue to improve the technical implementation, but it is time to prove the business case and implement the technology in a coordinated manner across all ATM regions. There needs to be a concerted effort to bring business and financial people into consensus on CNS/ATM implementation. It is clear that we can always make the technical solution a little better. By bringing in the business people, we can apply sound business evaluation practices to the process and assure that we are not over−engineering the technology.

Finally, airborne and ground implementation must be kept in step, both on functionality and schedule. CNS/ATM functions are implemented at the Air Traffic Management system level, not the airplane or ground level. Without simultaneous and well integrated development and implementation efforts, major benefits will be lost.

1.3 What Is Needed?

For the purposes of this paper, the term CNS/ATM stakeholders refers to all of those entities which have a stake in the implementation of CNS/ATM. It is important to recognize that not all stakeholders have the same roles, motivations, and benefits. The CNS/ATM stakeholders are airspace users (airlines, military and general aviation), states, ATC service providers, airframe manufacturers, airframe equipment suppliers, communications network service providers, and ATM equipment suppliers.

The stakeholders with the major influence, however, are the states and the airspace users. The users and the ATC service providers are at the "top of the food chain", but the users are at the very top because the ATC service providers get paid to deliver services to them. The rest of the stakeholders provide equipment or services to the two main stakeholders. While the supporting stakeholders might pace the implementation of CNS/ATM through performance or non−performance, the investment decisions are made by the airlines and ATC service provider. So, if the airlines are the prime drivers in the implementation of the CNS/ATM concept, and their participation in industry development indicates substantial interest, why isn't more progress made? In most cases the missing element is an adequate business case to support procurement decisions that are made in the airline finance departments.

1.3.1 Airline Business Case

Figure 1.2 illustrates the factors that influence an airline's decision to deploy technology. The industry, if committee meeting agendas are any indication, seems to assume that the major factor or dependency is "technical maturity". This is no longer the case for FANS technologies. Technical maturity is a factor, but only as a component in a sound business case. The primary influences on investment decisions are financial in nature and a solid business case is the prime determinant.

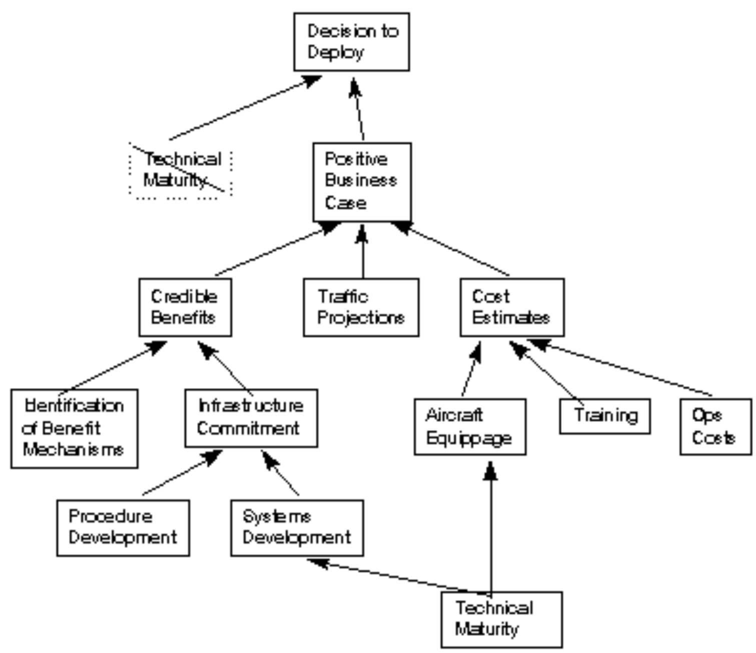

Figure 1.2: Decision Dependency Diagram

The credibility of the business case must be emphasized. As illustrated in Figure 1.2, the benefit mechanisms are influenced by numerous factors, many of which introduce uncertainty, or investment risk, into the analysis. A solid business case must provide an analysis which measures the influence of each factor to provide guidance as to which uncertainties should be minimized. Clearly, if the major influence in a business case has the greatest uncertainty, and that uncertainty cannot be controlled, the business case will be weak. Unfortunately, this is the position in which many CNS/ATM enhancements find themselves. For example, the benefit mechanism of reduced longitudinal separation using CNS/ATM enhancements requires the implementation of changes on the aircraft and in the ground infrastructure. While the aircraft equipage is under the control of the airline, the development of the ground infrastructure and procedures is clearly not under their control.

1.3.2 Disciplined Process for Business Analysis

The CNS/ATM industry is proud of the disciplined engineering process which is used to develop technical upgrades. There must also be a disciplined process for the development of business cases, which is available to all of the stakeholders. It must be adapted to a particular airspace with specific traffic flows. While the operational concept needs to be consistent with growth to the full ICAO plan in order to support interoperability, the concept in all cases needs to be applied to particular airspace regions. The constraints of a region's operation dictate the infrastructure upgrade commitments necessary to provide a benefit for financial analyst review. Once the operational concept is developed, the requirements for airplane and infrastructure upgrades can be developed and implementation commitments made. This becomes the basis for the business case. Once the business case is complete and accepted by the appropriate financial decision makers, an integrated development plan can be established.

The preceding paragraph may seem a little simplistic, but the industry often gets these tasks out of sequence. The initial CNS/ATM package for the 747−400 established airplane requirements, but was supported only by vague requirements for the infrastructure. There was no operational concept, no airspace or infrastructure commitment at the traffic management level, and finally no business case. The FANS−1 development didn't get all the necessary work done in quite the right order, but for the most part the above sequence was followed.

1.3.3 Industry Pressure

As stated earlier, there are intense pressures on the airlines and governments to improve the Air Traffic Management systems around the world. There are several sources for this pressure:

- Some ATM systems are becoming antiquated and difficult to maintain.
- Airlines need increased efficiency and capacity in the system.
- Multiple parties actively advocating particular technology "solutions."

While in some respects this pressure is good, the divergence of potential solutions complicates the decision making process. Clearly, neither the airlines nor the service providers can afford to implement every proposed new technology. These potential solutions often compete for the same benefits and drive different investments. As stated earlier, successful implementation requires simultaneous implementation by multiple service providers and airlines. The end result is a pretty confusing picture for both the airline and ATC service provider decision makers.

2.0 CNS/ATM Focused Team

The CNS/ATM Focused Team (C/AFT) was formed to deal with the issues discussed in Section 1. The team is currently comprised of airframe manufacturers (Airbus, Boeing, and Douglas), airlines (American Airlines, British Airways, QANTAS, and United Airlines), International Air Transport Association (IATA) and the FAA. The team's membership will grow substantially at the meeting in July 1997, with the addition of new airline and service provider members. The C/AFT team developed the following statement to describe its purpose and objectives:

> The C/AFT is an informal forum which will gather economic, technical, and risk data and develop methodologies for use by airlines, ATC service providers, government agencies, and industry in determining the economic−driven strategy for CNS/ATM deployment. It will also provide the vehicle to monitor that deployment.

The initial task of the team was to develop a methodology for the economic analysis of CNS/ATM enhancements and regional plans. A survey of the existing literature did not uncover an existing methodology which met the requirements of the team. Figure 2.1 illustrates the analysis process developed by the team.

As illustrated in Figure 2.1, existing traffic demand forecasts, along with available data on system performance, are used to develop the regional priorities for CNS/ATM implementation. The regional priorities are then input into a constraints analysis which identifies associated performance factors. The team then uses the existing regional CNS/ATM implementation plans as a baseline for development of transition plans which use the performance factors identified in the constraints analysis, and provide outputs for economic modeling. The final output of the process is in the form of recommended changes to regional plans. Sections 3−6 describe each step of the C/AFT methodology in more detail.

3.0 Identification of Regional Priorities

The C/AFT analysis process illustrated in Figure 2.1 starts with a look at the current and predicted regional constraints and operational costs in the air traffic management system. The objective of this analysis is to identify the primary areas of constraint and inefficiency in the system, for the various regions around the world. This provides a list of regional priorities, which will allow the more detailed analysis in the following steps to focus on the problems whose solutions yield the most benefits.

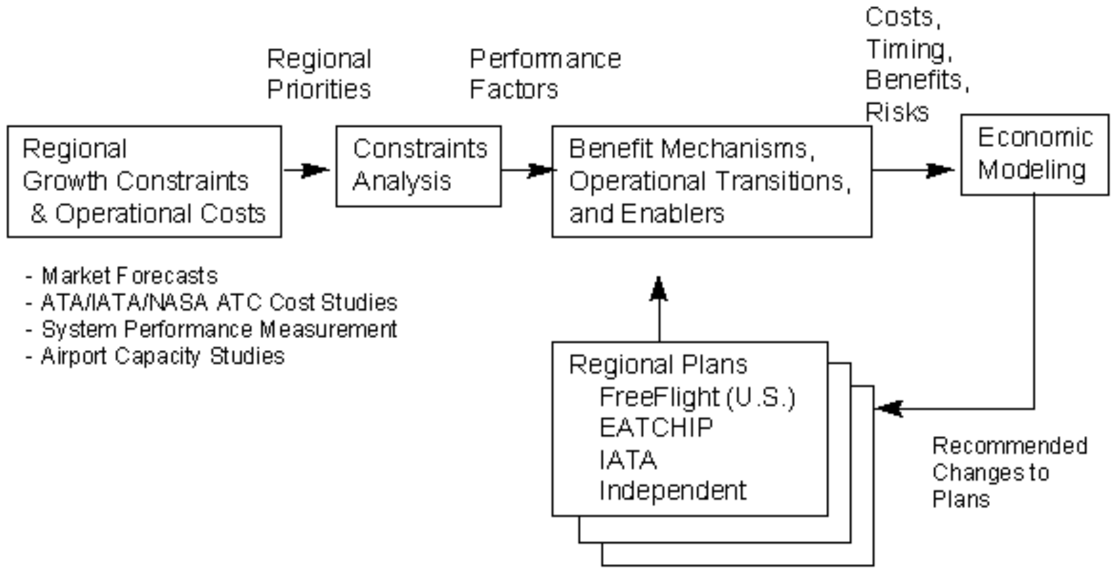

Figure 2.1: CNS/ATM Focused Team Analysis Process

One of the fundamental assumptions behind all air traffic growth forecasts is that air traffic control systems and airport capacities respond to demand. The 1997 Boeing Current Market Outlook predicts an average annual passenger traffic growth of 4.9% per year through the year 2016. The predicted growth rate varies regionally, and other forecasts predict slightly different rates, but it is clear that the aviation community needs to work to ensure that the air traffic management system accommodates growth.

3.1 Definition of Terms

Table 3.1 lists the key terms related to capacity, efficiency and user benefits used in this paper. The distinction between capacity and efficiency as defined in Table 3.1 is often blurred. For example, orderly traffic flows are often more circuitous than the shortest distance path would be, but may be easier to manage. Altitude restrictions (i.e. constraining an airplane to fly at a flight level other than the optimum altitude for the current gross weight) are inefficient, but are often caused by a lack of capacity in the airway system. Section 3.2 discusses why it is important to distinguish operating cost caused by lack of capacity from cost due to procedural constraints.

3.2 Capacity, Demand and Delay

Figure 3.1 shows the basic relationship between capacity, demand and delay for a transportation system element such as an airport. As demand approaches capacity, system delay increases exponentially, thus causing operating costs to escalate. The net effect is that traffic demand for the area is not accommodated, and growth is constrained.

Figure 3.1 illustrates the possible trade between traffic demand and delay for different levels of capacity.

The figure could be thought of as the capacity of an airport with two parallel runways with 3500 feet between centerlines. If the airport capacity were increased from airport operating point 1 to airport operating point 2, perhaps with the addition of arrival sequencing automation or a Precision Runway Monitor for closely spaced parallel runways, the delay vs. demand curve would be shifted to the right. The airlines then have a choice either to reduce delay by holding the schedule constant (moving from A to B), or to increase the number of operations (moving from A to C) while holding delay constant. Assuming that demand is growing, the change would probably occur from A to B and then gradually up the curve to C.

Delay	The difference between actual block time and ideal block time.
Demand	The number of aircraft requesting to use the system in a given time period.
Capacity	The maximum number of aircraft that can be accommodated in a given time period by the system or one of its components (throughput).

Efficiency	Ratio of the cost of ideal flight to the cost of procedurally constrained flight.
Benefit	Reduced cost to the user, in the form of savings in time and/or fuel or increased revenue.
Operational Enhancement	An operational change leading to increased capacity and/or efficiency.
Enabler	Initiative, such as new technology or procedural change, that supports an operational enhancement.
Ideal Flight	Minimum cost travel between origin and destination, assuming still air conditions and no traffic or procedural constraints.
Procedural Constraints	Airspace constraints other than those due to traffic or weather (i.e. Special Use Airspace, airway structure, altitude restrictions, etc.).

Table 3.1: Definition of Terms

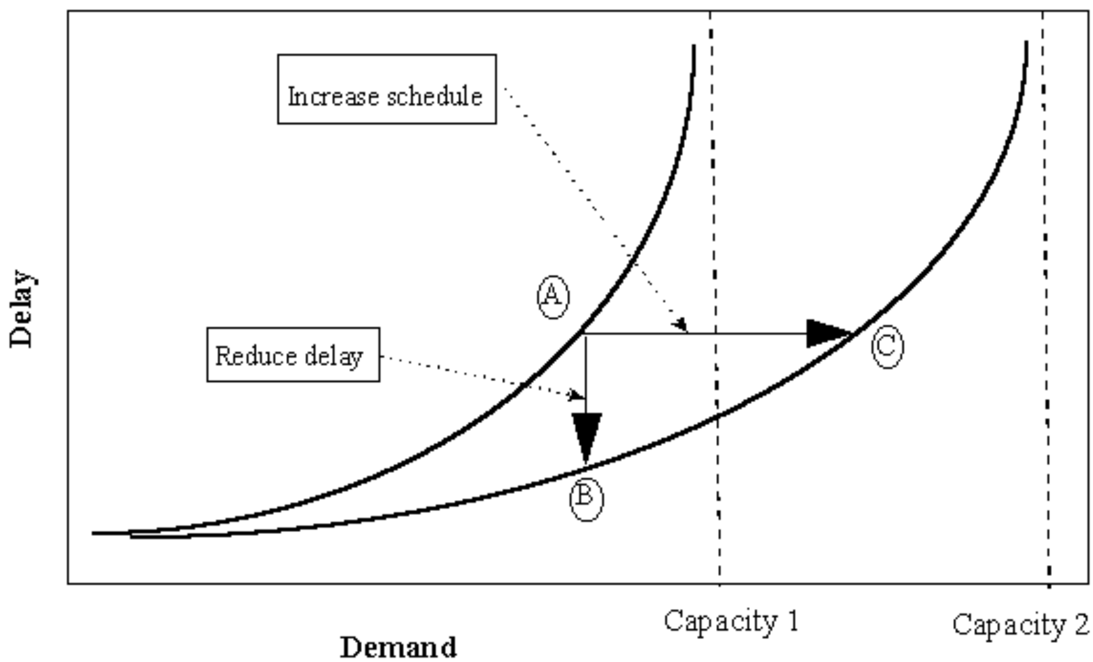

Figure 3.1: Capacity, Demand and Delay

3.3 "Waste" And The Ability to Compete

In cases where the air traffic management system does not respond to accommodate demand, the operators in the system adapt in various ways, all of which result in the system changing in some less than optimal way. The following are some examples of ways the operators may adapt to constraints:

- Schedules may spread from peak times to operating times that are less desirable for passengers.
- Aircraft size grows more rapidly than desired for economy and marketing flexibility.
- The ability to compete with frequency of service can be limited.
- Flights may be canceled in favor of flights on higher profit routes.
- Slot constraints could become more common, reducing competition in certain markets.
- Secondary hubs may be needed, resulting in increased operating costs.

All of the above means of adaptation result in increased operating costs, or "waste," with a reduction in levels of service, and consequently may result in other modes of transportation capturing a larger part of the market. Additionally, these constraints may limit the ability of system users to compete freely for markets, which will make air travel less affordable and constrain growth.

As illustrated in Figure 3.1, when traffic demand approaches the capacity level, delay or "waste" grows much more rapidly than demand. It is this exponentially increasing delay that leads to a serious concern among users that system capacity must keep up with the growth of demand. Thus, capacity constraints in the system take on a level of urgency considerably higher than efficiency constraints, which grow only linearly with traffic demand. As a consequence, when establishing priorities among the list of system problems that need to be solved, those system elements that are close to their capacity limit will inevitably be at the top of the list.

3.4 Regional Priorities

The C/AFT team is assembling a database to help derive order−of−magnitude estimates of the amount of delay and inefficiency in the air transportation system today and in the forecasted future. This database will be developed for the major air traffic flow regions of the world, incorporating a number of data sources to aid in the required system performance and economic analysis. Data from IATA, EUROCONTROL, FAA, the Air Transport Association and others will be used to estimate capacity constraints and inefficiency in the system.

Since there are major differences in infrastructure and traffic levels in different regions of the world, the database will include information by region. For example, in the United States the majority of capacity constraints are at airports and in terminal areas, and is highly dependent on weather condition. C/AFT has collected information on airfield capacity by weather condition for some of the major air carrier airports in the United States.

Once a reasonably complete database has been established, the team will analyze the performance of each of the phase of flight regions described in Section 4 for a representative set of locations and weather conditions, to establish a list of critical issues. Such a list needs to be established for each of the regions around the world that are predicted to pose constraints on air traffic growth. This will result in a list of regional priorities, which will form the basis for a more detailed operational and economic analysis of system modernization options using the methodology described in Sections 4, 5 and 6.

4.0 Constraints Analysis

The constraints analysis is the second step in the C/AFT analysis process illustrated in Figure 2.1. This analysis is applied to the regional priorities that have been identified as described in Section 3, i.e. a prioritized list of operational problems or system constraints. The most important problems on the list must be analyzed to correlate them with their causes, which is a task that is complicated primarily by two factors:

- The cause of a problem is often found in a different operating phase than the symptom.
- The removal of one problem may not be sufficient to provide the expected benefit, due to the existence of another problem of similar importance (the next "weak link" in the chain).

The constraints analysis model described in this section was developed to deal with the complexity of the ATM system by organizing system performance factors such that the causes of problems can be diagnosed and effectively communicated.

4.1 Airspace Operating Phases

The constraints analysis model divides the ATM system into six operating phases, as illustrated in Figure 4.1. Phase 1 is airspace and flight planning, which spans the other five regions. Phase 2 is the airport surface, phase 3 is final approach and initial departure, and so on through the en route which is phase 6.

The final approach and initial departure phases include the runway and refer to a phase in which air traffic control interventions are minimal due to the nature of the aircraft operation. The approach transition phase is operated differently depending on available technology and traffic density. In busy airports this is generally where air traffic controllers vector aircraft to merge traffic into properly spaced streams for final approach and landing, while in low density operations it might be a single waypoint transition to the next region. The Terminal Maneuvering Area (TMA) arrival/departure phase is generally operated through published Standard Instrument Departure (SID) and Standard Arrival (STAR) procedures. The en route phase encompasses the remainder of the flight, including published transitions from SID to cruise and from cruise to STAR. En route operations vary greatly by location, anywhere from oceanic procedural control to dense traffic in radar controlled airspace. The differences in operation can be characterized by levels of performance for the CNS components, as well as by air traffic control automation support, topography, traffic flow patterns, airspace availability and so on.

Using the six operating phases above, Figure 4.2 illustrates how the capacity and efficiency of operations are composed of those of the various operating phases. Overall system capacity and efficiency are complex functions of the type of operation in each of the phases, along with the interactions between them, which can also be thought of as the "handoff" from one air traffic control unit to another.

The air traffic management system capacity and efficiency depend on a large collection of technological, procedural and environmental factors, all of which vary by geographical location. Thus, when using the constraints model, it is necessary to note both location and weather condition for which the analysis is being performed, as illustrated in the lower left hand corner of Figure 4.2.

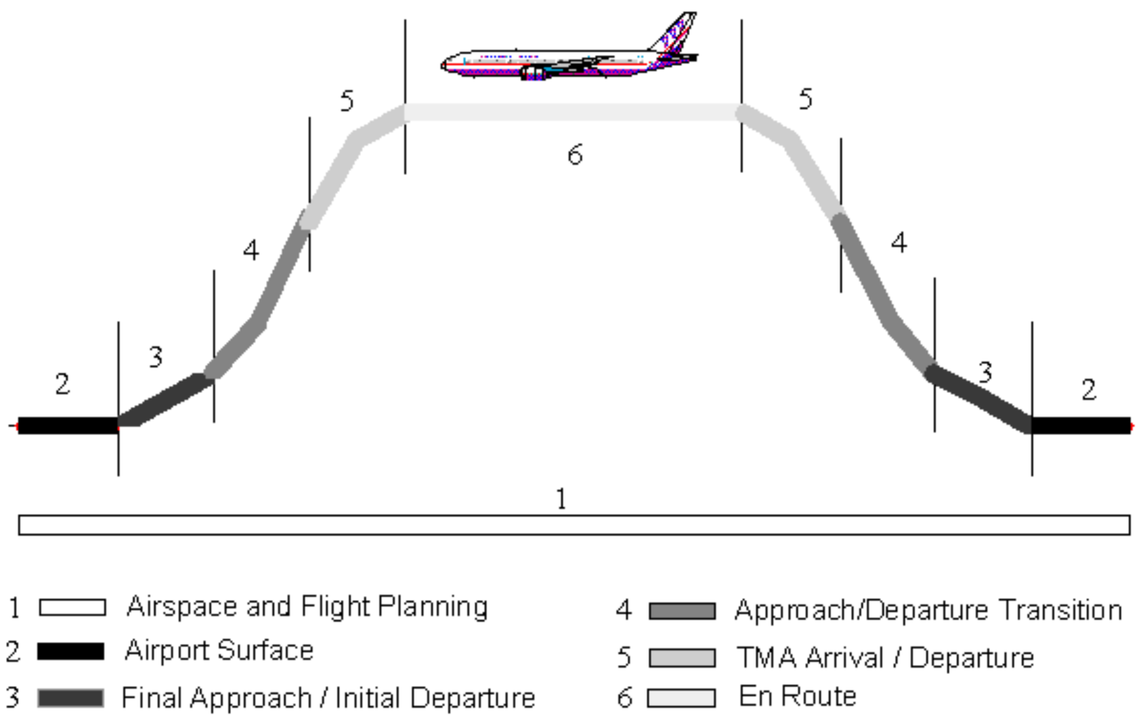

Figure 4.1: Airspace Operating Phases

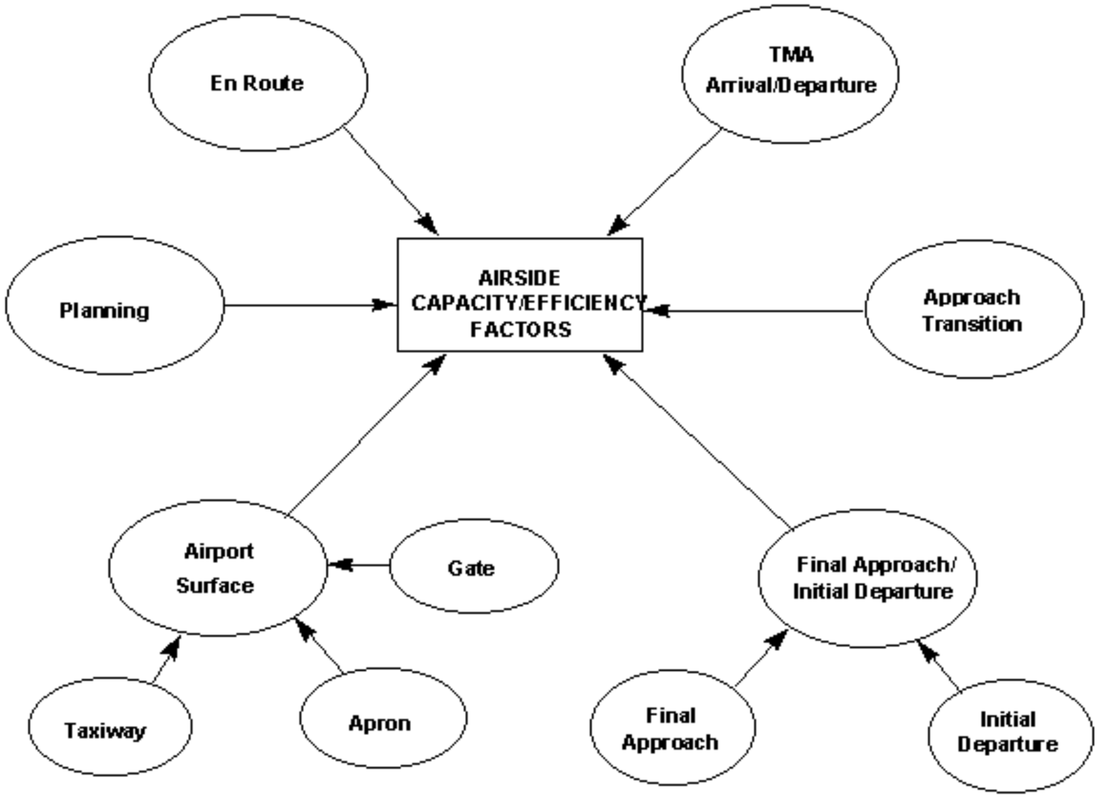

Figure 4.2: Capacity and Efficiency as a Function of Airspace Regions

4.2 Constraints Analysis Model

The airport surface encompasses gate, apron and taxiway operations, as illustrated in Figure 4.2, involving all operations on the ground except the runway. Taking a particular taxiway system as an example, all the important technical and procedural constraining factors that make up the taxiway operation need to be identified, as illustrated in Figure 4.3. For a given weather condition, the key performance factors that constrain an operation would be highlighted in the figure, taking care not to overlook any factor that contributes to the constraint. Once the performance factors have been identified, it is then possible to start postulating technical or procedural changes that would allow the constraint to be removed, and throughput or efficiency to be increased. The remaining operating phases that might pose constraints once the taxiway system throughput has been increased then need to be looked at in the same manner.

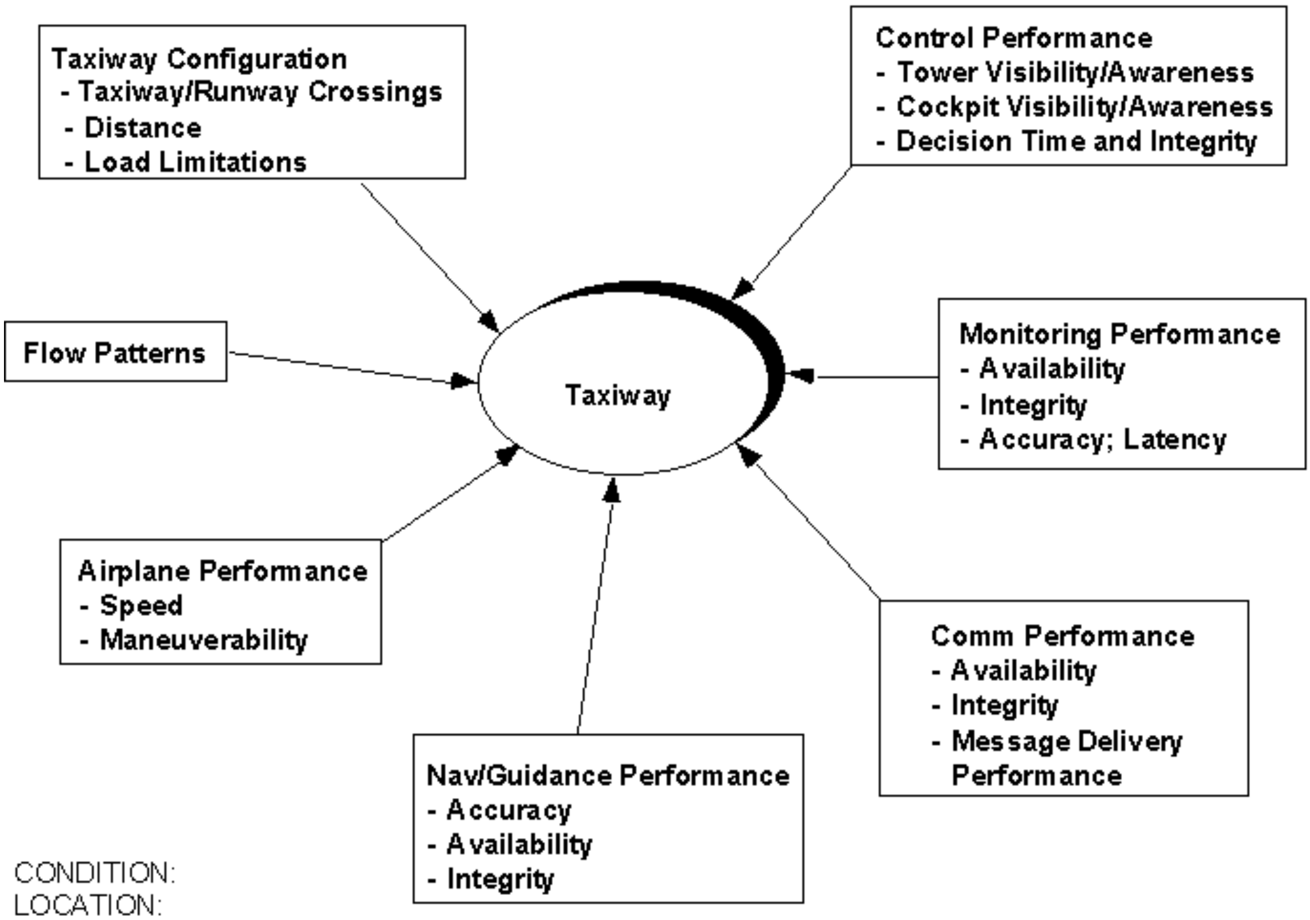

Figure 4.3: Taxiway Performance Factors

Each of the six phases illustrated in Figure 4.1 has its own set of performance factors, some of which are unique to that phase, while others, such as communications and navigation, are common throughout. Figure 4.4 illustrates the throughput performance factors for the final approach phase, and similar charts have been developed for the others.

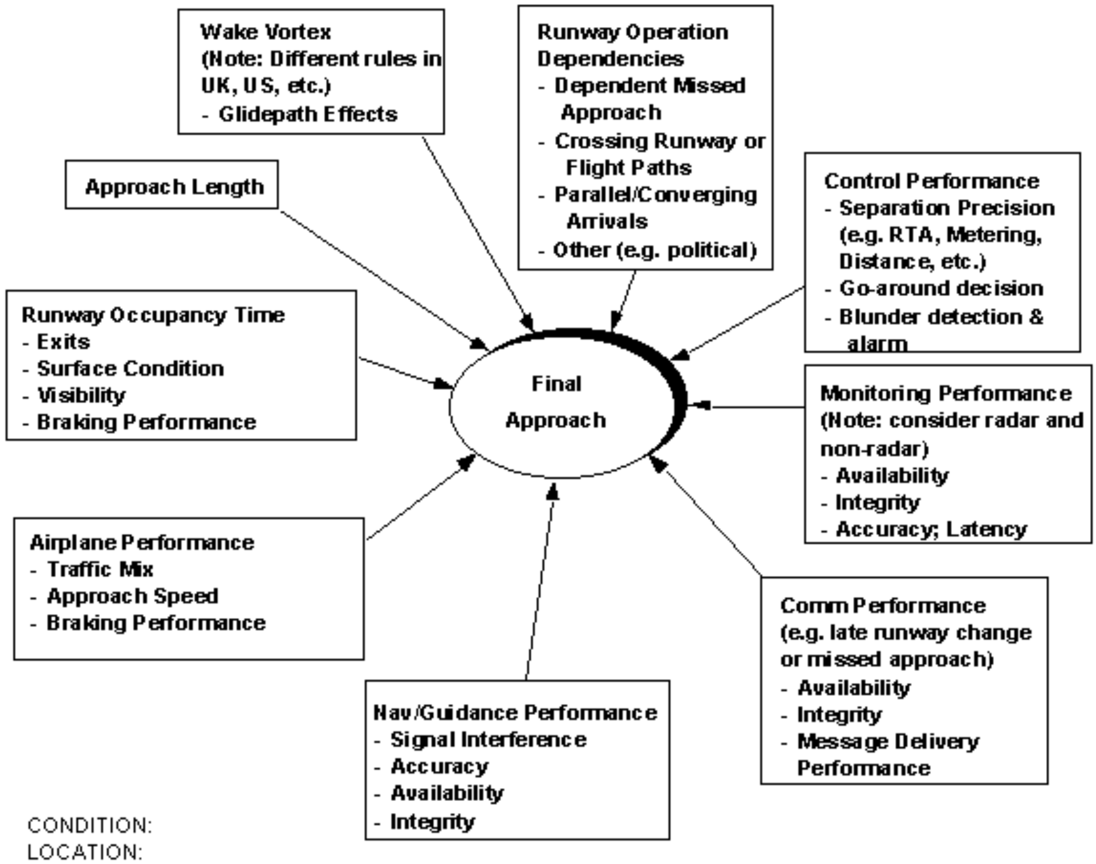

Figure 4.4: Throughput Performance Factors for Final Approach

Figure 4.4 shows navigation and guidance performance as one of the factors that contribute to the throughput on final approach, along with communications system performance. Accuracy, availability and integrity are the determining factors for both, and, on final approach, signal "interference" of the instrument landing system is an important factor. The surveillance element is broken into two components, i.e. monitoring performance and control performance. Monitoring performance here refers to the display of position and velocity information to the air traffic controller, including the performance of a surveillance system such as radar or dependent position reports. Control performance includes both controller and pilot, and includes any automation aids such as a sequencing tool, blunder detection etc.

Other factors depicted in Figure 4.4 are important as well, wake vortex being perhaps the dominant performance constraint in most instrument weather conditions. Runway occupancy may become the dominant factor in extremely low visibility where pilots have difficulty locating runway exits. In each case, when it has been determined that a phase of flight such as final approach is the constraint on throughput, it is necessary to evaluate that operation in detail, and the constraints model can be a valuable tool in focusing the analysis.

5.0 Benefit Mechanisms, Operational Transitions, and Enablers

Benefit Mechanisms, Operational Transitions, and Enablers is the third step in the C/AFT analysis process illustrated in Figure 2.1. The constraints model described in Section 4 of this paper is used for organizing system performance factors so that the causes of problems can be diagnosed and effectively communicated. In the previous section specific technology elements were not discussed (e.g., GPS, ADS, ATN);instead, performance factors and their relationships to capacity and efficiency were considered.. In this process step, we use our constraints model as a template to map the regional technology−centered plans into specific capacity and efficiency benefit mechanisms. This mapping allows us to associate the technology initiatives with specific operational enhancements which become the basis of benefits analysis.

How can the industry find the most cost effective solutions that meet regional demands while ensuring interoperability among regions? The Benefit Mechanisms, Operational Transitions, and Enablers step of the C/AFT process proposes to answer that fundamental question through analysis of existing plans: Free Flight (U.S.), EATCHIP (Europe), ICAO, and IATA regional plans. Each of these includes recommendations for improvements to the airspace system, technological or procedural, for increased capacity and efficiency.

Most of the plans assign an overall benefit to initiatives, oftentimes with several recommendations aimed at one benefit. Missing from the plans are incremental benefits, relationships between recommendations, and correlation between specific initiatives and operational enhancements. In addition, most plans do not address how specific regional solutions fit into a global airspace system.

CNS/ATM Transition Logic Diagrams have been created to address these deficiencies. These diagrams organize regional plan inputs as they relate to the airspace regions of the constraints analysis; divided into capacity and efficiency effects; and phased from near−term to far−term. The mapping process is initially developed as a graphical representation, then converted into a relational database. The graphical representation allows analysis of individual plans for plan emphasis (e.g., phase of operation, technologies), plan deficiencies, and conflicting recommendations. The database can be used to examine dependencies between the recommendations, combinatorial effects, and interdependencies across regional plans.

5.1 Operational Enhancement Transitions and Enablers

A template for the CNS/ATM Transition Logic Diagrams is shown in Figure 5.1. The upper right corner identifies the Regional Plan represented. Separate transition logic diagrams are created for capacity and efficiency, and for each operational phase of the constraints analysis. A benefit mechanism is identified for each diagram, with incremental phasing of operational enhancements.

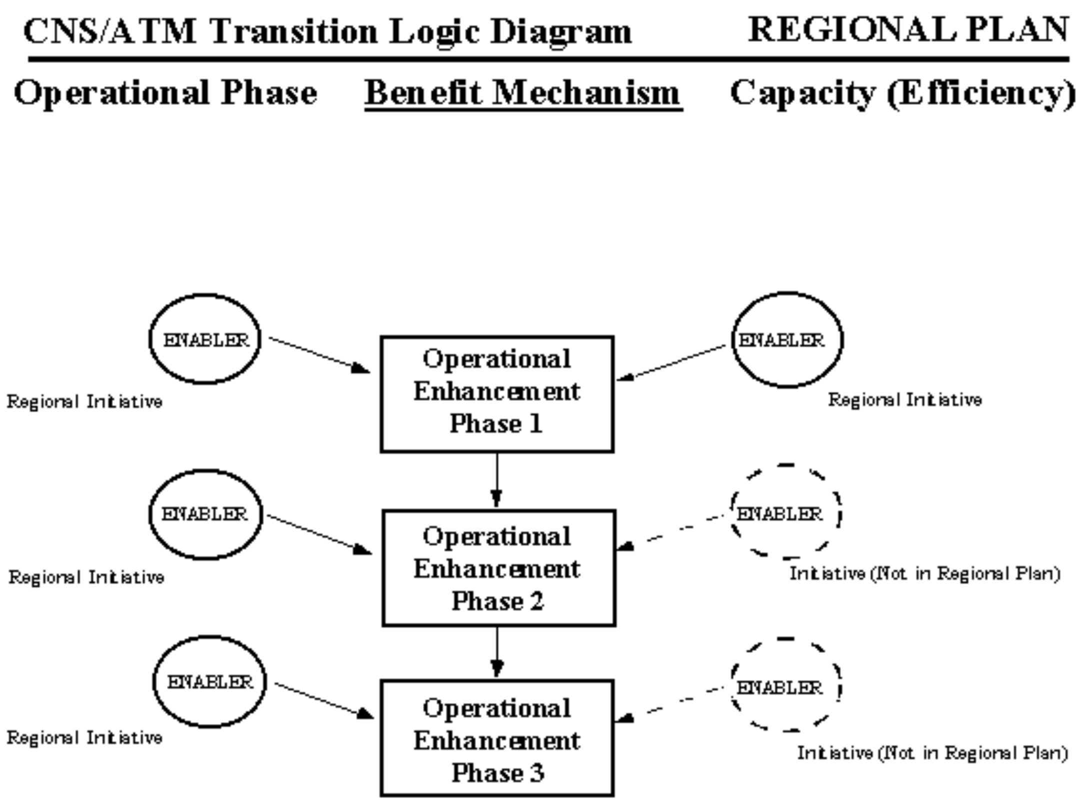

Figure 5.1: CNS/ATM Transition Logic Diagram

Regional initiatives are grouped by type of enhancement and are called enablers. The primary enabler groupings used are summarized in Figure 5.2. The groupings correspond to the performance factors of the constraints model: communications, navigation, surveillance, airspace management, air traffic management, etc. Each of the plan elements is examined to see what technical performance changes are implied by the recommendations. For example, GPS Local Area Augmentation System (LAAS) (found in Free Flight recommendation mid−term 2) represents "Navigation Enhancement" due to increased accuracy and availability of navigation. These groupings facilitate handling large numbers of initiatives and the comparative analysis between plans. Dashed circles around enablers indicate that the C/AFT identified a requirement for an enabler that was not included in the regional plan under analysis.

- Airport Enhancements
- Airspace Management
- Air Traffic Management (ATM) Tools
- Communication Enhancements
- Enhanced Flow Management
- Interfacility Communication
- Navigation Enhancements
- Reduced Separation
- Surveillance Enhancements
- Terminal Constraints
- Weather Information Enhancements

Figure 5.2: Enabler Groupings

Phasing of operational enhancements is the most important aspect of the benefit mechanism transition logic that is largely missing from the regional plans. In the diagrams and database, regional initiatives are assigned to specific operational enhancements, and an individual initiative’s impact across operational phases and regions is identified. This allows high−level, but realistic, estimation of cost and benefit. Each phase builds on the previous one, and the technology and procedures associated with one phase are required for subsequent phases. We can think of each of the enhancement steps as one specific "instantiation" of the abstract constraints model where the enablers become a specific selection of the performance factors defined by the constraints model.

The phasing of a particular benefit mechanism will often emphasize procedural elements in the initial (early) steps; existing, but not yet deployed, technology in the intermediate steps; and new technology (with developmental risk) in the later steps. Ideally all regions would be compatible and would have common transition logic diagrams, with solutions for different regions occurring at different times, depending on the base rate of operations and expected growth.

Although operational enhancements are typically not explicitly specified in the plans, data from the plans were used to develop the operational enhancement phases. The team was limited, however, to the data at hand and team members’ specific areas of study. Industry participation is needed to ensure that the benefit mechanisms and operational transitions are representative of industry directions. The C/AFT process may then be used to develop a set of consensus transitions towards which regional planning groups may converge.

Section 5.2 discusses Transition Logic Diagrams for specific regional plans. Again, these represent the team’s initial analysis of the plans’ intentions and should not be construed to represent C/AFT recommendations.

5.2 Regional Transition Logic Diagrams

The team has conducted an initial analysis of the IATA, EATCHIP, and Free Flight regional plans. ICAO plans have not yet been analyzed. En route capacity and efficiency transition logic diagrams were created for the primarily low density airspace IATA regional plans. Transition logic diagrams for all operational phases, and for both capacity and efficiency effects, were created for the high density U.S. and European regions.

The low density charts have common operational enhancement phases and common enablers. The team developed common operational enhancement phasing for the high density charts, but they have diverse enablers and areas of emphasis. The EATCHIP plans emphasize en route capacity and GPS, ADS−B, and Data Link initiatives, while the Free Flight plan stresses en route efficiency and Required Navigational Performance (RNP), radar, and VHF/ATN initiatives.

5.2.1 IATA Regions

Individual en route transition logic diagrams were created from the IATA FANS CNS/ATM Implementation/Transition Plans for Asia & Pacific (including eight sub−regions), Middle East, and North Atlantic. The African and Latin American plans were reviewed, but found to be too incomplete for analysis (safety, rather than capacity or efficiency, may be a dominant concern in some of those areas).

Figure 5.3 shows a "composite" en route capacity transition logic diagram that was created from the individual regions (a composite efficiency diagram could not be created due to inconsistencies between plans). This chart depicts the operational enhancement steps for en route flight in the transition from current vertical and horizontal separations through successive reductions, with the vertical and horizontal as separate operational enhancement branches. This was done because the individual plans had different phasing for reduced vertical separation versus horizontal separation enhancement steps. The first two steps in the horizontal separation branch, 50/50 and 30/30, require enablers that use technology available today, such as Traffic Display, AEEC 622, ADS and RNP, and are fairly well defined. There is more uncertainty in terms of enablers and operational requirements in the later steps.

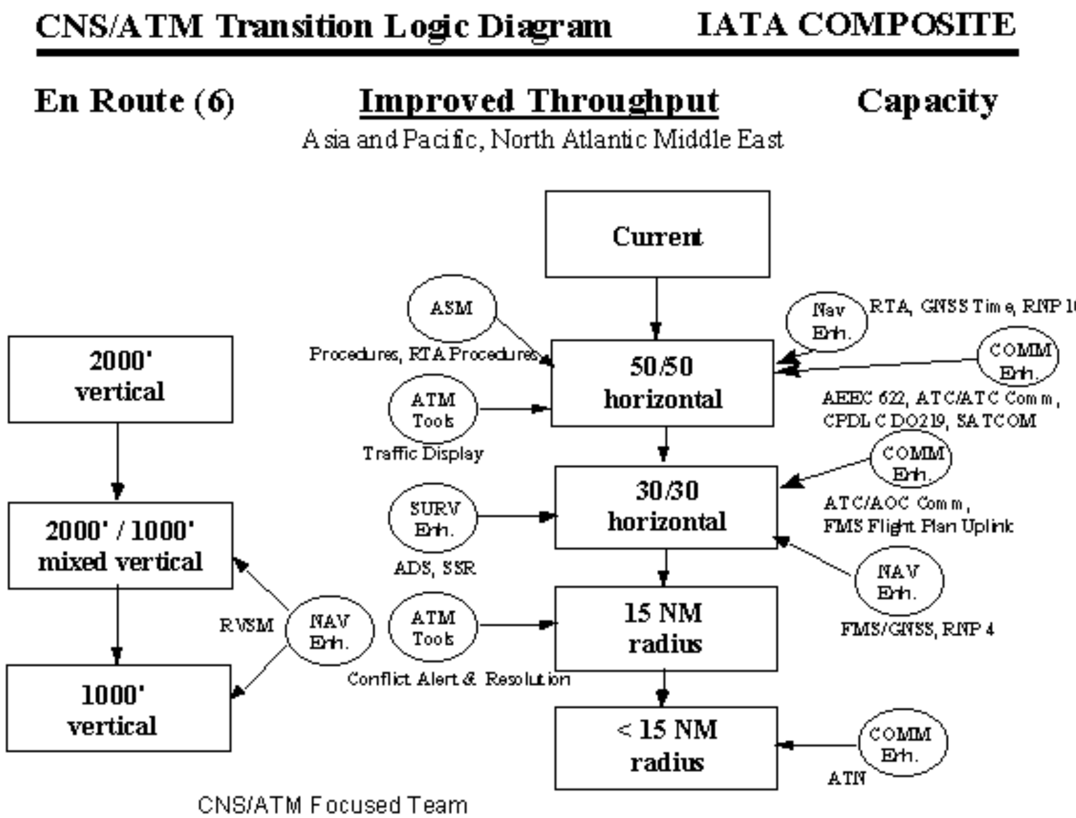

Figure 5.3: IATA Composite Transition Logic Diagram

There were some differences in the plans. For example, the Central Asia and Indian Sub−Continent (CAISC) plan did not include ATC/ATC Communication, had additional enablers of Track Generation, and dynamic flight plan generation, and had different phasing of ATC/AOC Communication and FMS Flight Plan Uplink (see Figure 5.4). The transition logic highlights these differences and can be used to evaluate commonality among plans.

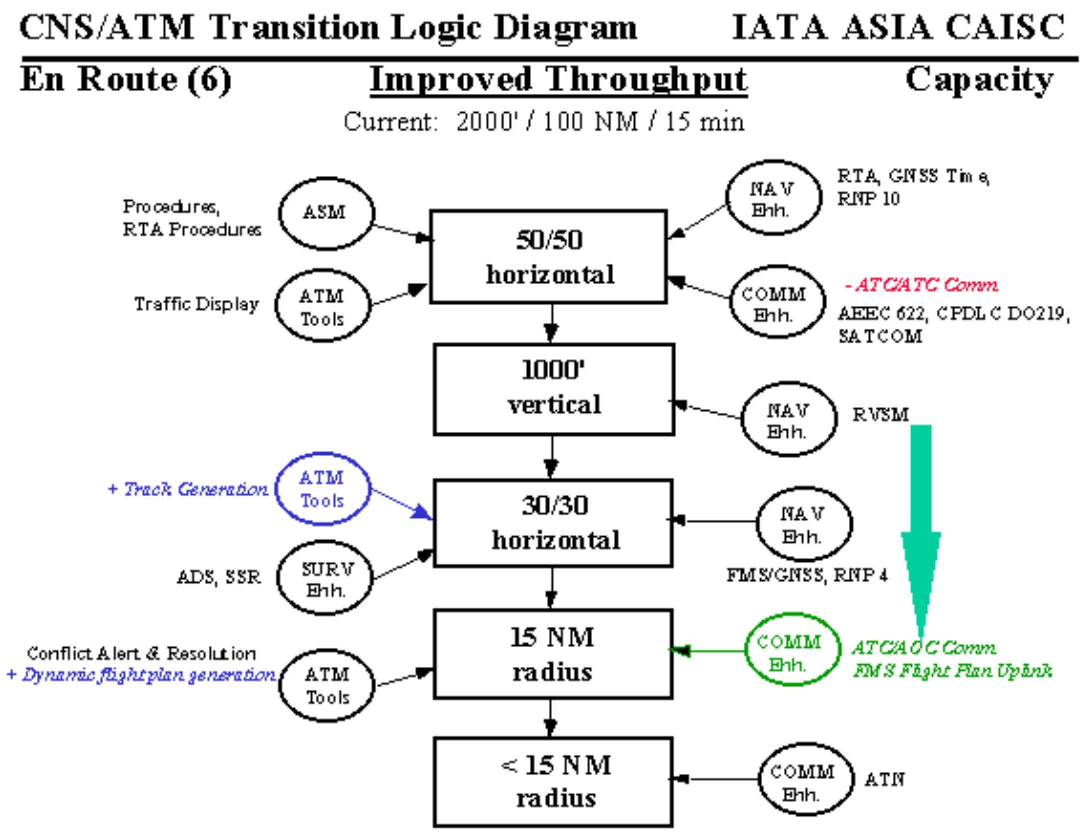

Figure 5.4: IATA Asia CAISC Transition Logic Diagram

5.2.2 Europe – EATCHIP

European transition logic diagrams were created from the EUROCONTROL Convergence and Implementation Programme, Part 2, Status Report, and EATMS Concept: Progress Report, Edition 1.1. As previously discussed, the emphasis of these plans is en route capacity improvements and harmonization. Figure 5.5 shows the EATCHIP TMA Arrival/Departure and En Route capacity transition. The majority of enablers are associated with the first step of uniform application of 5/10/15 NM separation, with regional initiatives such as: ATC coordination, flight plan and data processing, upgrade voice communication, and full radar coverage. The enablers that apply to the subsequent operational enhancements, Improved Airspace Access & Reduced Separation, and Increased Sector Capacity, are primarily tools to reduce controller workload. The last step of Self Separation is less well−defined, and may require future technology enablers, such as Global Navigation Satellite System 2 (GNSS 2), ADS−B, and ATN.

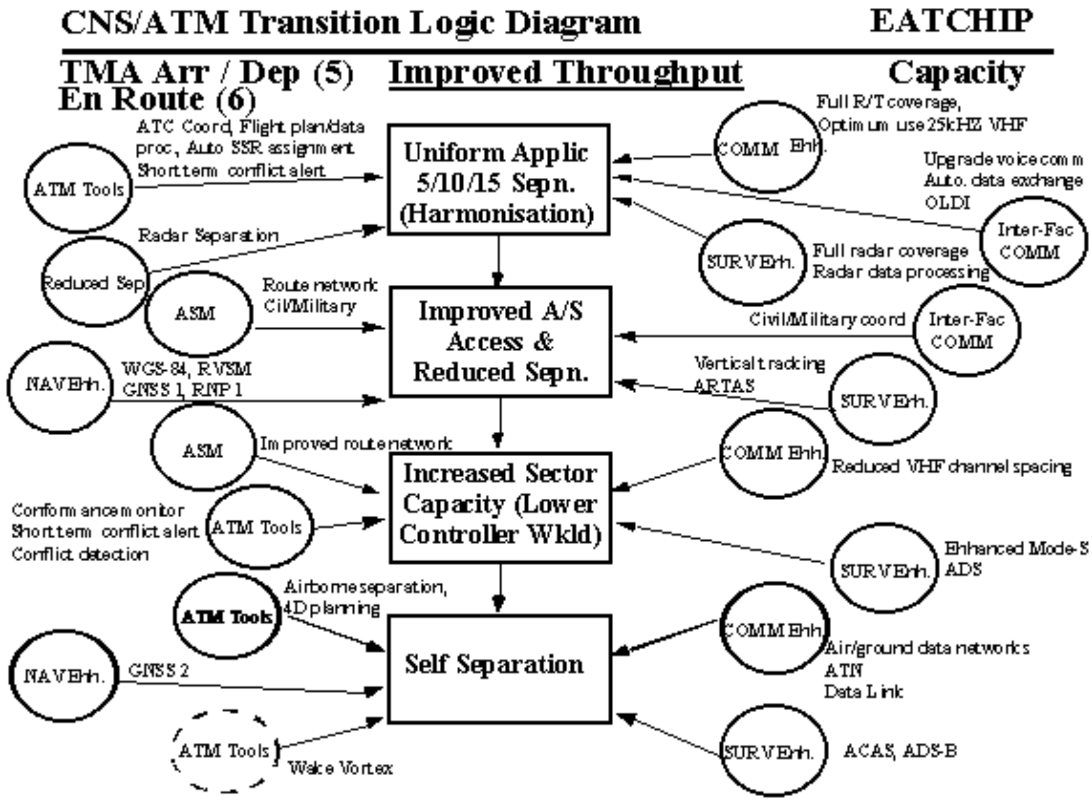

Figure 5.5: European En Route Capacity Transition Logic Diagram

5.2.3 U.S. – Free Flight

U.S. transition logic diagrams were created from the RTCA Task Force 3, "Free Flight Implementation," Final Report and the Free Flight Action Plan. Figure 5.6 is shown to illustrate the difference in emphasis between the EATCHIP and Free Flight plans. The operational enhancement phases are the same, but there are no initiatives proposed for the first three phases. These operational enhancement phases are considered to be already in place in the U.S. The last phase of Self Separation shows enablers similar to those shown for the EATCHIP diagram.

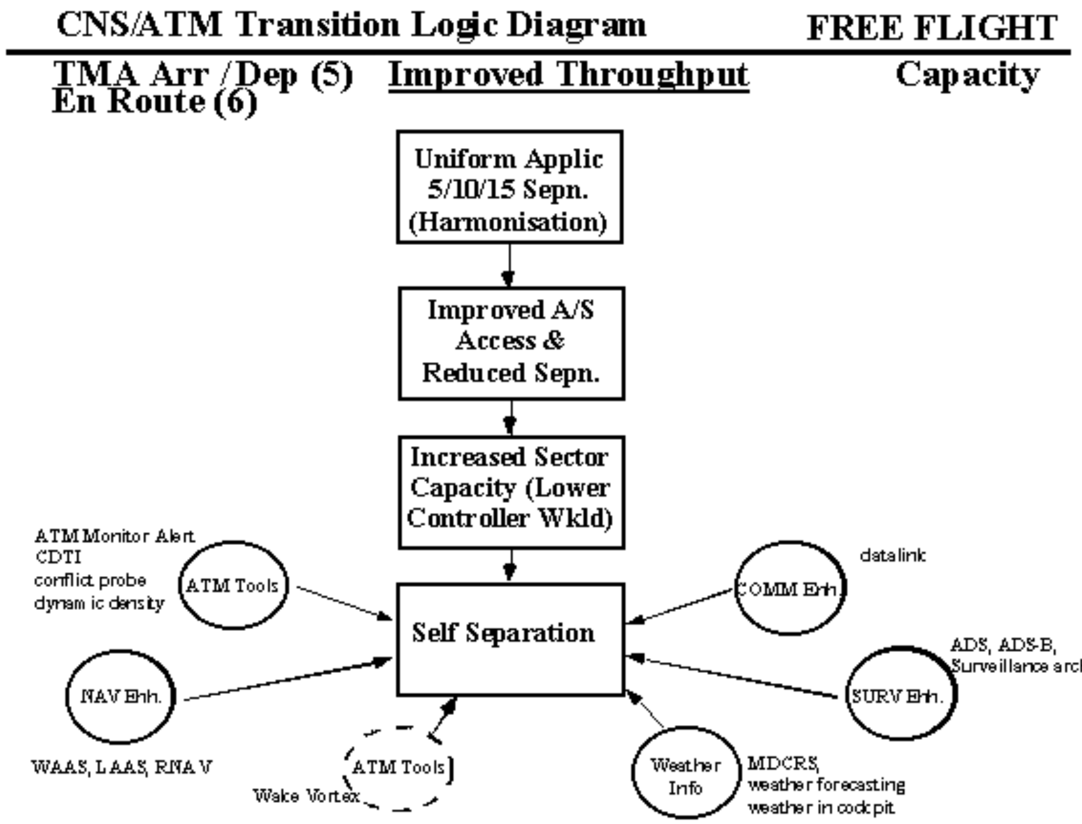

Figure 5.6: U.S. En Route Capacity Transition Logic Diagram

The Free Flight en route efficiency reduced path length transition logic diagram is shown in Figure 5.7. The first operational enhancement phase More Efficient Routing System is considered to have been accomplished in the U.S., as opposed to Europe where there are regional initiatives to improve the routing system. The two subsequent steps, Limited User Preferred Routing and User Preferred Routing, require enablers that are available today. User Preferred Trajectories is analogous to Self Separation in that the initiatives are future technology and operational requirements are not defined.

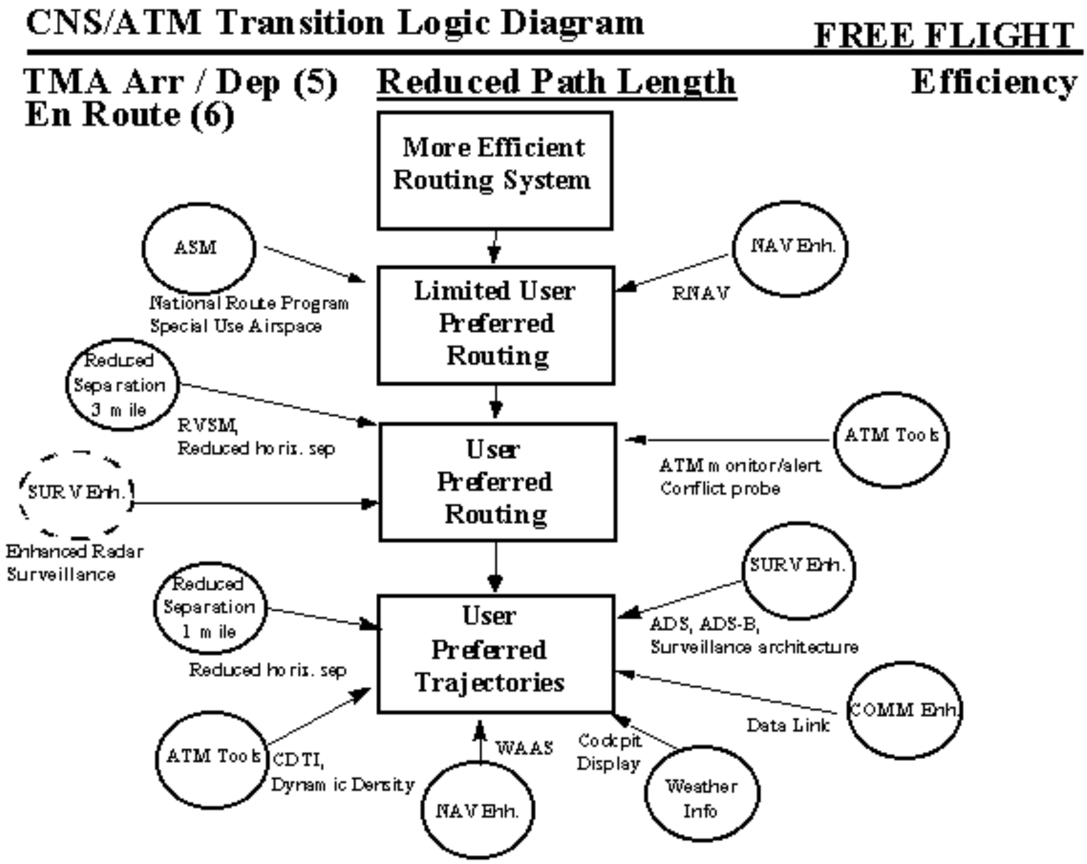

Figure 5.7: U.S. En Route Efficiency Transition Logic Diagram

5.3 Economic Modeling Inputs

As previously discussed, the allocation of the total ATC costs into the operational phases and sub−phases, allows us to think of "cost−buckets" for each operational phase. These buckets are organized into capacity costs and efficiency costs. The plan phases allow recovery of some part of the costs in each bucket. The next phase works on the residual operational cost (the benefit of the next step). The cost, benefit, risk and schedule data is used in the economic modeling to evaluate alternative transitions and to compare regional implementation plans. Timing can be inferred from the operational enhancement phasing, while cost, benefit, and risk are attributes of the enablers associated with each phase.

- **6.0 Economic Analysis**

As stated earlier in this paper, the economic issues transcend the technical issues with regards to CNS/ATM enhancement implementation. The C/AFT decided to incorporate some well known decision analysis techniques in the economic analysis required to support the implementation of CNS/ATM. This methodology had to have the capability to look at the business case from an industry level and from individual stakeholders' view. This methodology must:

- Quantify risk
- Quantify costs
- Quantify benefits
- Model "rules" for realizing benefits

Many existing methodologies do not specifically address one or more of these aspects.

Figure 6.1 provides an overview of the economic modeling process. The problem statement and potential solutions (alternatives) and the assumptions which surround them are used to assess the risk associated with each alternative. Then for each alternative:

- Assess the investment and operational cost differences.

- Convert the benefit mechanisms to dollars.
- Develop the rules for modeling the benefits.

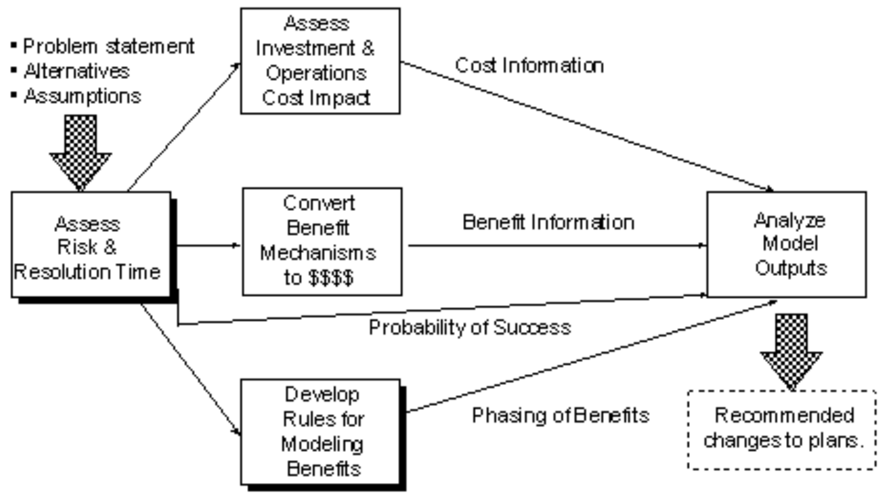

Figure 6.1: Economic Modeling Process

6.1 Quantify Risk

For the purposes of the C/AFT, risk is defined as follows:

- The chance that a CNS/ATM improvement is denied, delayed, or significantly degraded for a technical reason or because of opposition from an interested party.

There is generally a cost associated with the mitigation of the risk, whether it is technical or political in nature. These costs need to be included in the overall assessment of cost, but the real challenge is quantifying the impact of the risk on the potential benefits. Examples of risk to a CNS/ATM implementation might be:

- CAA fails to meet commitment to field a capability.
- Safety.
- Funding uncertainty.
- An airline blocks an improvement for competitive reasons.
- Community blocks an improvement to an airport.
- Technical committee does not reach agreement on standards.
- Difficulty in validating system changes.

These risks can be categorized as having "success" impact on the project or "schedule" impact on receipt of the benefits. The "success" impact might be Boolean (i.e., either we will get all of the benefits or none). The "success" impact might also have a percentage impact; for example, safety constraints on lateral separation might constrain us to only 30% of the benefits. "Schedule" impact might mean that the ATC service provider might be late in infrastructure implementation, thus delaying impact. That type of risk is calibrated in percentage confidence. For example, we are 20% confident that ATN infrastructure in the United States will be in place by 1998, 50% confident for 2004, and 90% confident for 2010.

6.2 Assessing Cost

Two kinds of cost must be examined to obtain a complete cost picture.

> Investment is a one time charge to effect a CNS/ATM improvement. It includes a credit for the decommissioning and sale of CNS/ATM assets.

- Airplane equipage
- ATC procedure development

- Controller work station
- Decommissioning of VOR/DME

Operational cost is the recurring expenditure of money to maintain and operate the CMS/ATM system.

- Avionics maintenance
- Data link use charges

Studies tend to become unnecessarily obsessed with cost. That is because the figures are usually available and easy to quantify. The impact of cost is usually well understood as well. This, however, tends to divert the analyst from the work necessary to develop the complete story, that is the benefits and the "rules" behind how the benefits are obtained.

6.3 Assessing Benefits

For air traffic management changes, benefits need to be quantified in terms of capital, either direct or derived from time/fuel savings. For the purposes of C/AFT, the quantification of economic benefits is based on capacity and efficiency considerations. Capacity is a measure of the maximum number of operations accommodated in a given airspace for a period of time, while efficiency is a measure of the cost per operation within a CNS/ATM system.

Examples of benefits are as follows:

- Capacity Related
    - Reduction in separation standards
    - Decision aids
- Efficiency Related
    - Direct routing
    - Optimum trajectory

In either case, the benefits need to be converted into money. The process for doing that is shown in Figure 6.2.

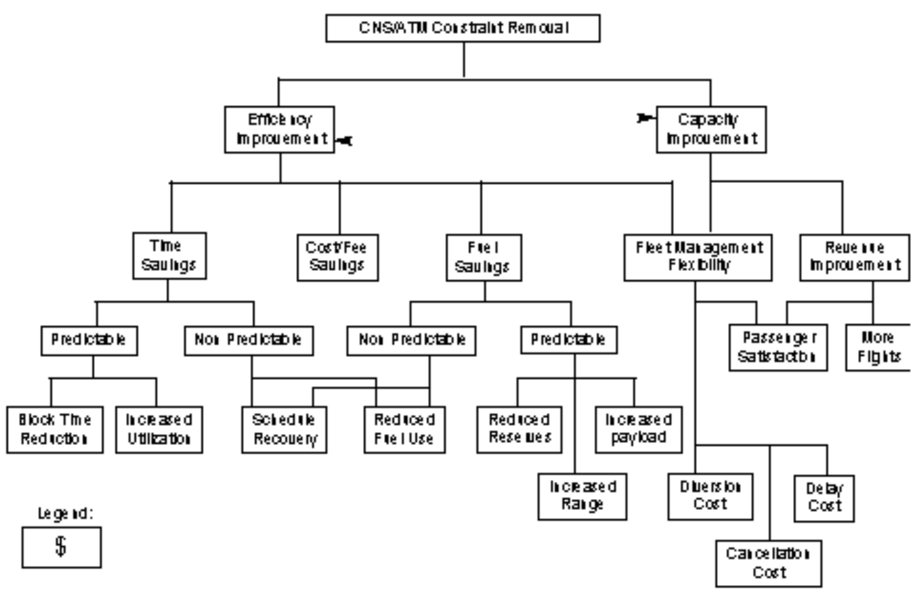

Figure 6.2: Converting Benefits to Dollars

Basically, these mechanisms fall into the following categories:

- Deterministic
    - Predictable time/fuel savings
    - Non−Predictable time/fuel savings

- Non−Deterministic
    - Marketing impact
    - Revenue increase

The term deterministic involves the conversion of the benefits mechanism to dollars. It is fairly easy to translate pounds of fuel not burned into savings. It is much more difficult to calibrate the effect of better on−time performance on marketing via passenger satisfaction. It is also difficult to make estimates of the financial impact of reduced delays and diversions that are acceptable to airlines.

Under the deterministic heading, we make a differentiation between predictable and unpredictable savings. Unpredictable fuel savings essentially provide only the direct savings associated with the fuel not burned. However, if these savings turn into predictable savings, it could be that the fuel would not be loaded and the weight replaced with payload.

6.4 Modeling the Benefits

Many cost benefit studies simply model the benefits associated with the end state. This is to say, the main assumption is that all benefits "turn on" on a certain day. This is unrealistic and generally unacceptable to the airline financial departments. The benefit calculations must account for all implementation assumptions such as: fleet incorporation rates, infrastructure implementation dates, procedural change dates and other factors. These assumptions need to be documented in the regional plans. Examples of such implementation assumptions are as follows:

- Benefits will be phased in over a five year period.
- Equipped aircraft will qualify for preferred trajectories.
- Equipage during the first five years will be subsidized.
- Non−equipped aircraft will be assigned to less efficient airspace.

6.5 Economic Model Outputs

There are four primary outputs from the economic modeling process. Figure 6.3 gives examples of each.

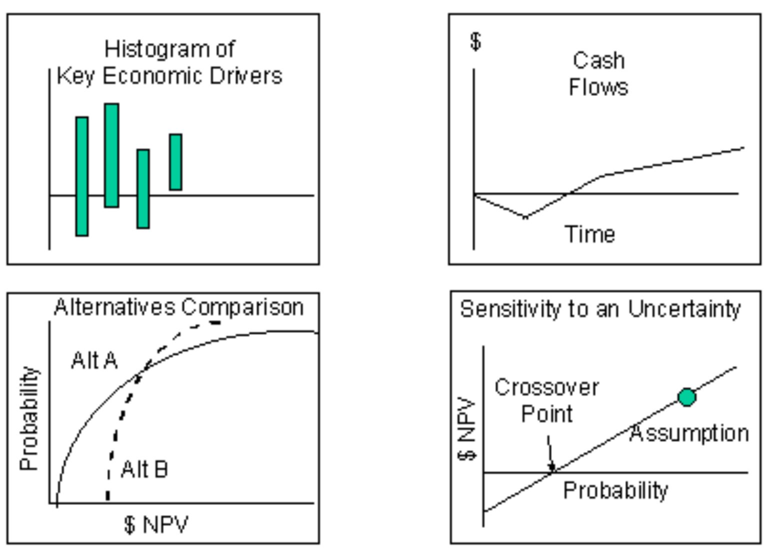

Figure 6.3: Model Outputs

The histogram of key economic drivers gives the user an indication of the influence of each uncertainty on the final outcome. Basically, each column will represent the effect of one factor on the net present value. This gives the analyst the chance to spend most of the time reducing the uncertainty associated with key factors. For example, one might find that the uncertainty surrounding the incorporation date of key infrastructure enablers (such as ground−based CNS/ATM applications for a route) has the greatest influence. The model will focus attention on that factor and draw attention away from such factors which have less influence. This type of chart is done for each alternative implementation.

The cash flow chart is also done for each alternative implementation and gives an indication as to when benefits outweigh costs. The alternative comparison gives an indication as to the net present value performance of each alternative implementation. It maps the NPV as a factor of the probability and allows direct comparison between alternative solutions.

The sensitivity to an uncertainty indicates how much the probability of assumptions would have to change before the alternative model becomes uneconomic. It is a measure of the economic robustness of the alternative.

7.0 Summary

The main obstacle to further CNS/ATM enhancements is the lack of business cases which are acceptable to senior financial officers. Recognition of this deficiency led to the formation of the CNS/ATM Focused Team. This team is tasked with the development of a methodology to support business case development.

The process described in this paper has been used to evaluate a number of technology alternatives for CNS/ATM implementation. The process supports "macro" analysis of regional plans and their comparison across regions, as described in this paper, as well as specific CNS/ATM technology trade studies. For example, the process has, is, or will be used to evaluate such subjects as: (1) Instrument Landing System, Microwave Landing System, and GPS−based approach and landing systems, (2) North Pacific FANS−1 and −A investment return, (3) U.S. terminal area airport capacity alternatives, (4) GPS augmentation alternatives evaluation, and (5) the business case for an ATN system.

Industry tends to think of technical factors as being the prime determinant between competing initiatives for enhancements. In reality, the marketplace determines the "winners" based on economic factors. As CNS/ATM evolves, there will be new opportunities for airlines to compete for markets. Those who best understand how to turn technical capability into competitive schedule advantage will thrive. The air traffic industry must recognize this environment. Rather than continuing to exercise "pet technological solutions," we must develop a credible business case or drop them and move on. The need for credible business cases to guide our CNS/ATM investments has never been greater.

Acknowledgments

The authors would like to thank all CNS/ATM Focused Team members for their participation in refining the methodology presented in this paper. Their insight into various aspects of ATM system operations and aviation economics has been truly invaluable. The growing interest of the aviation community in joining the team demonstrates the need to continue the activity to develop credible business cases for ATM system modernization options.

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