A Proposed Methodology for Operational Enhancement Integration Analysis

Kathleen Pirotte, Mary Nakasone, Robert Schwab, David Nakamura, Aslaug Haraldsdottir, Kent Loving
Air Traffic Management Services
Boeing Commercial Airplane Group
July 6, 2000

Abstract

This paper outlines a process by which CNS/ATM (Communications, Navigation, Surveillance, Air Traffic Management) elements can be broken into transitional evolutionary steps integrated by operational domains across the CNS technologies, and for which more widely-focused business cases can be used to evaluate solution set alternatives. The article in the Oct-Dec.1999 Journal of the Air Traffic Control Association, "Improving the FAA's Acquisition Management System from the Start" identifies a problem with the inflexibility and lack of traceability from operational needs through system requirements to solution alternatives with the current acquisition process, including the investment analysis. By focusing on incremental operational enhancements and by placing value on the ability of each proposed ATM solution to provide incremental value, investment decisions across different sets of technologies can be better supported.

Introduction

The airline industry at this time has two approaches to CNS/ATM economic justification: Near-term investments that are supported by a very focused NPV business case; and far-term 'concepts' that lack adequate definition to support quantitative investment analysis. What is needed is a process that recognizes that investment analysis must address multiple technologies (some competing and some complementary), their phasing/transitions and multiple integrated objectives.

The traditional industry emphasis has been on a proliferation of technology elements. Adding confusion is the fact that the acronym CNS/ATM is sometimes used as if CNS/ATM were one entity, a single technological system that can solve all of our ATM problems, and at other times each technology domain is looked at in complete isolation without evaluating the effect that one can have on another. Unsorting this complex set of technologies requires focusing on the operations first.

Taking this approach, the emphasis needs to be on operational enhancements, each of which may have multiple technology solution sets. Technologies simply offer alternative ways to achieve improvements. The significance of focusing on operations rather than technologies is that we don't get tied to a particular domain (C, N, or S) and can instead evaluate the interactions and dependencies among them. Each technology, however, can support multiple enhancements, and enhancements can support each other, so the analysis can quickly become too complex and too divergent to see the solution. The goal then, was to develop a process by which operational enhancement alternatives and their enabling technologies could be evaluated systematically and to support timely CNS/ATM investment decisions.

This process is based upon CNS/ATM Focused Team (C/AFT) transition logic diagrams which propose an incremental approach to operational enhancements, rather than an emphasis on technology elements when evaluating possible CNS/ATM improvements. A set of transition logic diagrams has been developed for each phase of flight in "The Economic Evaluation of CNS/ATM Transition". For each step, however, there may be many possible ways to achieve the enhancement, each one possible with several candidate enablers.

This paper presents a process that has been named by C/AFT the Operational Enhancement Integration Analysis (OEIA). The process was initiated and used within Boeing for a fairly narrowly defined purpose: To understand controller-pilot data link's use in the various phases of flight to increase final approach throughput. The process was intended to be general enough to apply to any technology evaluation in any phase of flight for any particular kind of benefit (e.g. increased efficiency, or increased capacity in a specified environment) or for multiple benefits.

This paper uses the specific data link analysis to illustrate the process. The example clearly shows that each potential solution cannot be evaluated solely on its ability to enable a particular operational enhancement, but also on its potential as a bridge to future enhancements.

The Process

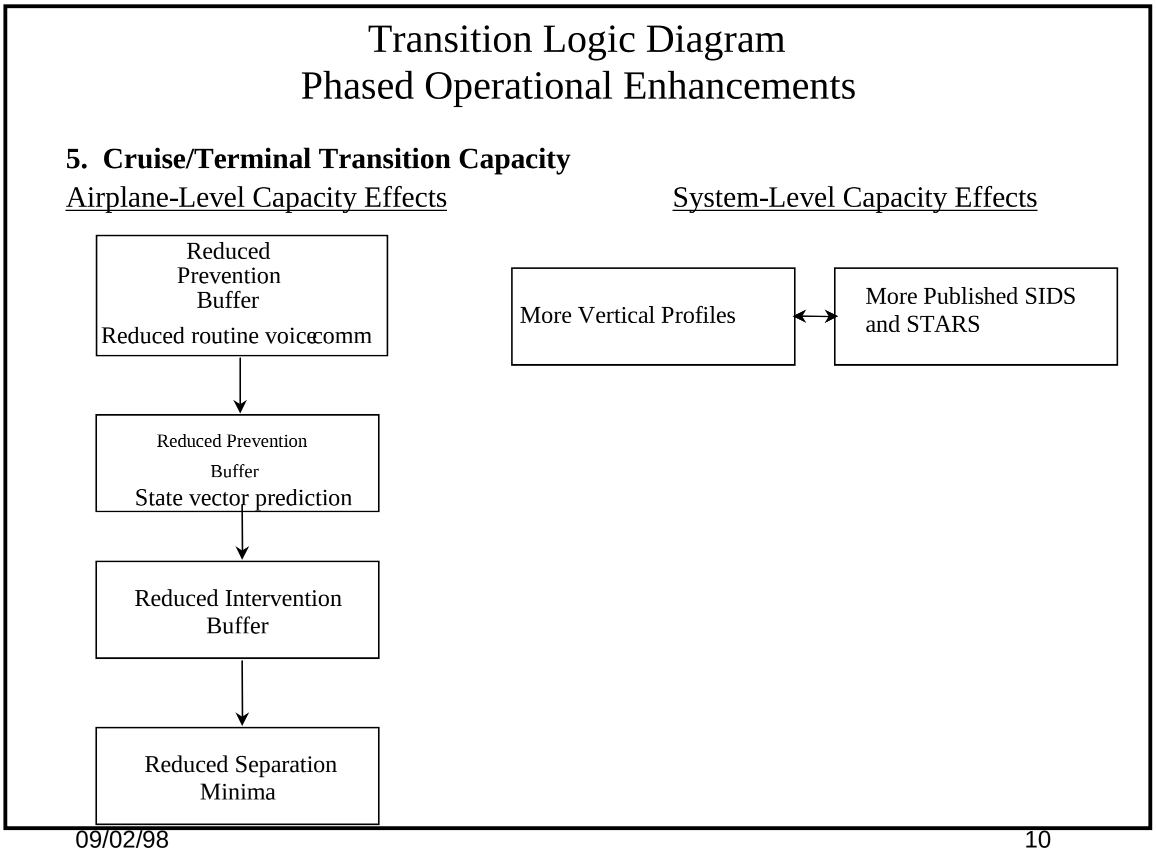
Why an integrated analysis?

C/AFT models and processes were used to develop a business case to determine the value of equipping with digital data link for AOC and ATC operations in the US NAS. The business case determined that "The initial investment, while significant, provides a positive return on investment and lays the foundation for future potential benefit" (C/AFT, "Data Link Investment Analysis"). The data link business case was focused on one possible method (digital data link) to reduce controller communication overhead, thereby reducing delay. It did not evaluate alternative methods and did not quantify the "future potential benefit". It did, however, convince some airlines that digital data link was a good investment in the near term, particularly for AOC operations, and as a result Boeing received requests from airlines to implement digital data link on their airplanes.

An important aspect of offering and pricing a customer option such as data link is to determine the required avionics architecture and human factors interface changes. Since modifying cockpit layout and avionics architecture can be very costly it is essential to ensure that the design will meet future requirements on the system. With all of the possible applications of CNS/ATM technologies being considered, a systematic process was required to identify and evaluate operational enhancement alternative solutions in the near- to far-term. A team of Boeing CNS/ATM experts was formed to establish and implement such a process, with a goal of determining the most likely evolutionary path for data link implementation on Boeing airplanes.

C/AFT Models

The traditional C/AFT process is outlined in " The Economic Evaluation of CNS/ATM Transition", including a constraints analysis, transition logic diagrams, and economic analysis. As discussed in that paper, the transition logic diagrams were originally based on data found in regional CNS/ATM plans (IATA, EATCHIP, and Free Flight), and focus on phased operational enhancements rather than on technology. The transition logic diagrams were later refined, and were based on airspace separation buffers.



Transition Logic Diagram
Phased Operational Enhancements

5. Cruise/Terminal Transition Capacity

09/02/98 10

Figure 1: Cruise/Terminal Transition Logic Diagram

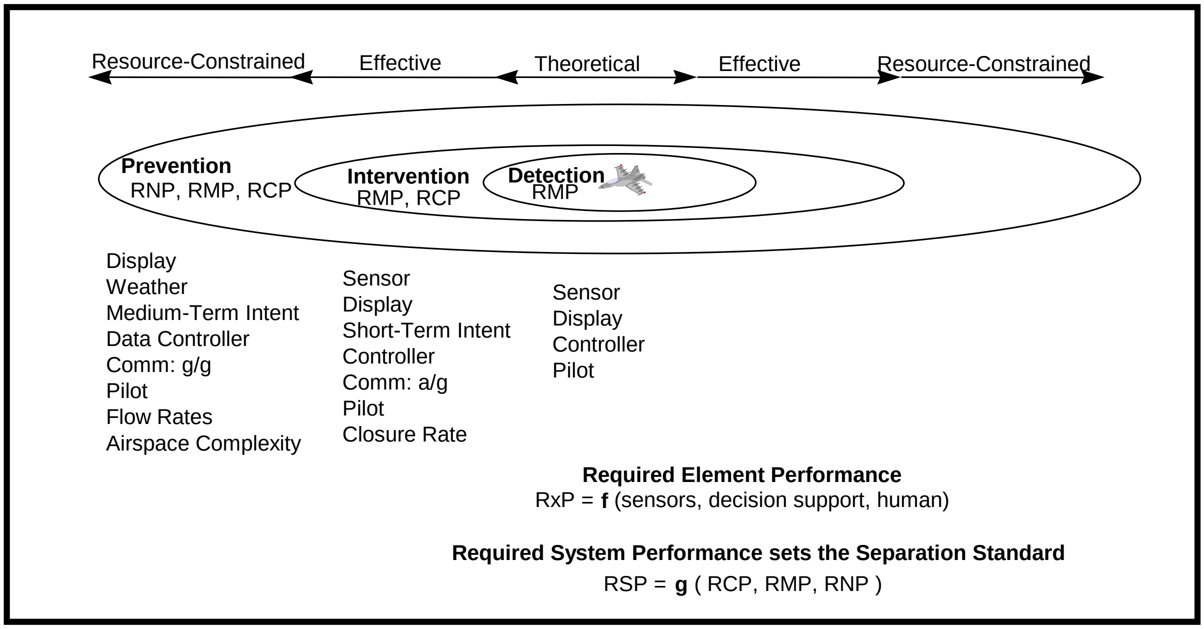


Figure 2: Required Performance for Separation Standards

Figure 1 shows a transition logic diagram for the cruise/terminal transition phase of flight, which C/AFT has defined as being from en route transition through end of STAR, and from the beginning of SID through transition to en route. The enhancements are divided into airplane-level and system-level transitions. On the right side of Figure 1 are depicted transitions related to the system-level improvements such as adding new routes. The sequence of operational enhancements on the left side is common to all capacity transition diagrams, and is based on reducing separation between airplanes. Separations between airplanes are determined in theory by the airspace separation minima, but in actual operation are determined by controller performance and traffic complexity.

Figure 2 shows the theory behind the airplane-level operational enhancement steps, including the relationships among separation minima, intervention buffers, and performance factors. The controller must provide buffers larger than the actual separation minima in order to minimize the chance of separation infractions. To increase the system throughput in busy periods it is often easier to start with the factors that influence the buffers. The size (and thus influence) of these buffers will vary with the type of airspace being considered, type of surveillance available, type and performance of communications available, and navigation capability of aircraft. Just reducing separation minima will have varying and normally limited effect unless these other factors are understood and accounted for. It should be noted that these rings are not to scale, and the size of the buffers actually change depending on phase of flight and traffic complexity (among other things). For example, Final Approach in VFR conditions typically involves only the Detection region, since airplanes are generally flying at the separation standard.

The first enhancement, Reduced Prevention Buffer (the outermost ring in Figure 2), represents a control region that can grow or shrink with time and is closely connected to potential resource limitations (e.g. high traffic density or complex airspace environments). As controller workload increases, strategies such as re-routing aircraft away from densely used airspace or instituting miles-in-trail restrictions are adopted to prevent the possibility of conflicts, allowing more time (and separation) to ensure that the number of potential conflicts is minimized. Workload may also increase as a result of voice channel congestion, lack of information on long-term pilot intent and/or trajectory information, and the ability to implement certain types of clearance at a strategic level (re-routes have to be via 'known' way points).

The Intervention Buffer (middle ring in Figure 2) represents the distance required by controllers to allow time for potential conflict resolution. This is the effective separation in a non-resource-constrained environment, and is dependent on closure rates and communications performance, the sensor, pilot/controller performance, and the types of clearance available. (In a radar environment a radar heading is quickly implemented; in a procedural environment a re-route is often complex and lengthy to implement.) The size of this buffer will also vary depending on encounter geometry and speed/maneuverability of aircraft. Accurate short-term intent information (by surveillance/data link functions) should help to reduce this buffer size.

The last step addresses the separation standard minimum (the Detection Region of Figure 2) being applied in a radar environment (3nm/5nm in the US), which is a function of surveillance and display capabilities. This is the theoretical minimum separation which was determined by the radar sensor and controller display performance capabilities, as well as the pilot and controller performance. This value, together with an effective intervention buffer (control loop closure time), is normally applied as the effective separation distance only in the final approach region where aircraft are in the same (or similar) direction (and closing rates are small), and under total control of ATC in terms of heading, altitude and speed.

An operational enhancement can usually be achieved in more than one way. For example, Reduced Prevention Buffer due to lower controller communication overhead could be achieved through data link communications, or through the use of FMS database procedures. Each of the enablers can come with its own set of costs, benefits and risks, and if each were analyzed in isolation each would show a strong business case. Their benefits, however, are probably not additive, and to find the real business case they must be analyzed using the integrated approach.

Creating a Means to Facilitate Evaluation and Analysis

During development of the transition logic diagrams a spreadsheet was created in order to examine dependencies between CNS/ATM plan recommendations, combinatorial effects of enabler solutions, and interdependencies across regional plans and phases of flight. This spreadsheet was a mapping of each individual operational enhancement to proposed enabler solutions for achieving the enhancement. The enabler solutions came from a variety of sources: IATA, EATCHIP, and Free Flight plans, C/AFT Focus Group recommendations, and brainstormed ideas from Boeing and industry meetings. For the

Operational Enhancement Integration Analysis the spreadsheet was transformed into a relational database structured around operational enhancements.

The first phase of the process consisted of structuring and reviewing the database. As stated earlier, each operational enhancement can have different mechanisms and enabler solutions for obtaining the benefit, thus multiple 'instantiations' of similar enhancements were created in the database. Figure 3 shows a typical operational enhancement description in the database.

101Tactical (non-loaded) clearances via data link

Use data link for TOC, IC, IC Resp. Also allow one clearance WITH the IC response. All other clearances via voice. Reducing controller workload will allow more airplanes per controller. Basically Build 1A on ground.

Simple HMI (e.g., MCDU) okay in remote airspace. More accessible HMI okay in phases 6 and 5. No known solution for phase 4.

Figure 3: Typical Operational Enhancement Description

Rating the Enhancements

At the end of the database development there existed a complicated set of complementary and competing CNS/ATM alternatives affecting all phases of flight, and rules for sorting through the alternatives were needed. In our analysis the goal of data link was to maximize final approach throughput. The first ground rule of the analysis was thus developed: **All operational enhancements/benefit mechanisms would be rated based on their ability to improve final approach throughput**. For the generic process to be developed, a set of prioritized operational enhancement goals must be established.

In the database we labeled this as "C[apacity] Benefit" and for each entry created a rating of high, medium, low, or none. The rules for the capacity benefit ratings were:

- “High" could be assigned only to enhancements affecting throughput of the final approach phase of flight;
- A maximum of “medium” could be assigned to enhancements affecting the cruise/terminal transition or approach/departure transition phases of flight; and
- A maximum of “low” could be assigned to those affecting en route or surface phases of flight.

It must be noted that the phase of flight in which a particular enhancement is implemented could be different from the phase for which the benefit is evaluated. For example, a Required Time of Arrival (RTA) clearance given in the en route phase of flight could in some circumstances lead to improved final approach throughput, thus be given a high capacity benefit rating. For each database entry, the benefit is rated for each phase of flight where the enhancement could be implemented. (The “CX-Y” field below indicates a specific operational enhancement.)

The next step was to evaluate the cost, risk, and likelihood of each alternative in each phase of flight. We again used broad rating categories to facilitate the process.

Rules for the cost ratings were (assuming costs for the industry as a whole):

- Low, for operations and maintenance costs
- Medium, for hardware/software changes with no significant development
- High, for hardware/software changes that required significant development
- Very High, if there were no known solution.

The risk assessment was a composite of risk to achieving the specified benefit and the risk of the cost estimate being accurate (i.e., high enough). The risk of the air traffic service provider's ability to field equipment and/or procedures was not included in this field; rather, it was included in the assessment of likelihood. This field could take on low, medium, high and very high.

The likelihood of each solution being implemented was rated as likely, medium or unlikely. An enhancement solution was considered:

- Likely, if it existed or was being supported by industry parties
- Unlikely, if it was being thwarted by an industry group
- Medium-likely (simply “med” in database), if it was being neither supported nor thwarted.

Rules for determination of overall favorability, called “favor” in the database, were:

- Green, if benefit was greater than cost, and risk was low or med
- Yellow, if benefit was equal to cost, and risk was low or med
- Red, if benefit was less than cost, or risk was high.

Figure 4 shows a typical database entry, with title, description, transition step, benefit, cost, risk ratings, and favor.

101 Tactical (non-loaded) clearances via data link

Use data link for TOC, IC, IC Resp. Also allow one clearance WITH the IC response. All other clearances via voice. Reducing controller workload will allow more airplanes per controller. Basically Build 1A on ground.

Simple HMI (e.g., MCDU) okay in remote airspace. More accessible HMI okay in phases 6 and 5. No known solution for phase 4.

4) Approach / Departure Transition

C Benefit	high	some controller workload savings according to Newark study.	C4-1
E Benefit	none	need loadable clearances to get eff benefit	
Likely	unlikely	pilots won't like	
Risk	high	High tech risk that data link solution will actually deliver benefits	
Cost	very high	no known solution for pilot HMI	
Favor	red		

5) Cruise / Terminal Transition

C Benefit	med	large controller workload savings according to Atlanta study	C5-1
E Benefit	none	need loadable clearances to get eff benefit	
Likely	likely	comes with Build 1A and AAL	
Risk	med		
Cost	med	new dedicated display	
Favor	yellow		

6) En Route Cruise

C Benefit	low	tiny controller workload savings	C6R-1
E Benefit	none	need loadable clearances to get eff benefit	
Likely	likely	comes with Build 1A and FANS	
Risk	low	same as #135	
Cost	very low	same as #135	
Favor	green		

7) En Route Cruise - Remote

C Benefit	low	tiny controller workload savings	C6P-1
E Benefit	none	need loadable clearances to get eff benefit	
Likely	likely	comes with FANS	
Risk	low	comes with FANS	
Cost	very low	comes with FANS	
Favor	green		

Figure 4: Typical Database Entry

Comparing the Enhancements

Figure 5 demonstrates relationships between sets of operational enhancements over time for improved final approach throughput. Each box represents a set of database entries, with a title representative of the related set of enhancements. For example, the box in the 3rd row titled "Better use of 2D, 3D, and RNP" represents database entries 118, 119, 120, and 134 each of which detail a specific application of a navigation service. The color(s) of the box represents the favor, which may change depending upon phase of flight or by individual enhancement (shown as color variations).

Within each row boxes on the left enable boxes on the right, so "Integrated RNAV" is enabled by "Better use of 2D, 3D, and RNP". Each row is independent of the another by function, but there may be enabling relationships between rows. The arrows between boxes show potential enabling relationships between functions.

Since the original goal of the analysis was to understand data link's role in increasing capacity, Figure 6 specifically breaks down the "CPDLC" box to datalink entry by phase of flight. The lighter, semi-transparent boxes represent the enhancements from Figure 5 which are enabled by data link enhancements. This figure shows that two of the data link enhancements were assessed with increased benefit in the SIDS, STARS, and Vectoring phases of flight. It also shows that an increased cost and risk is assessed on these enhancements in those same phases of flight. Returning to Figure 5 then, allows one to compare what other enhancements may provide the additional increase in benefit with potentially less cost or risk, or with additional benefit as enablers.

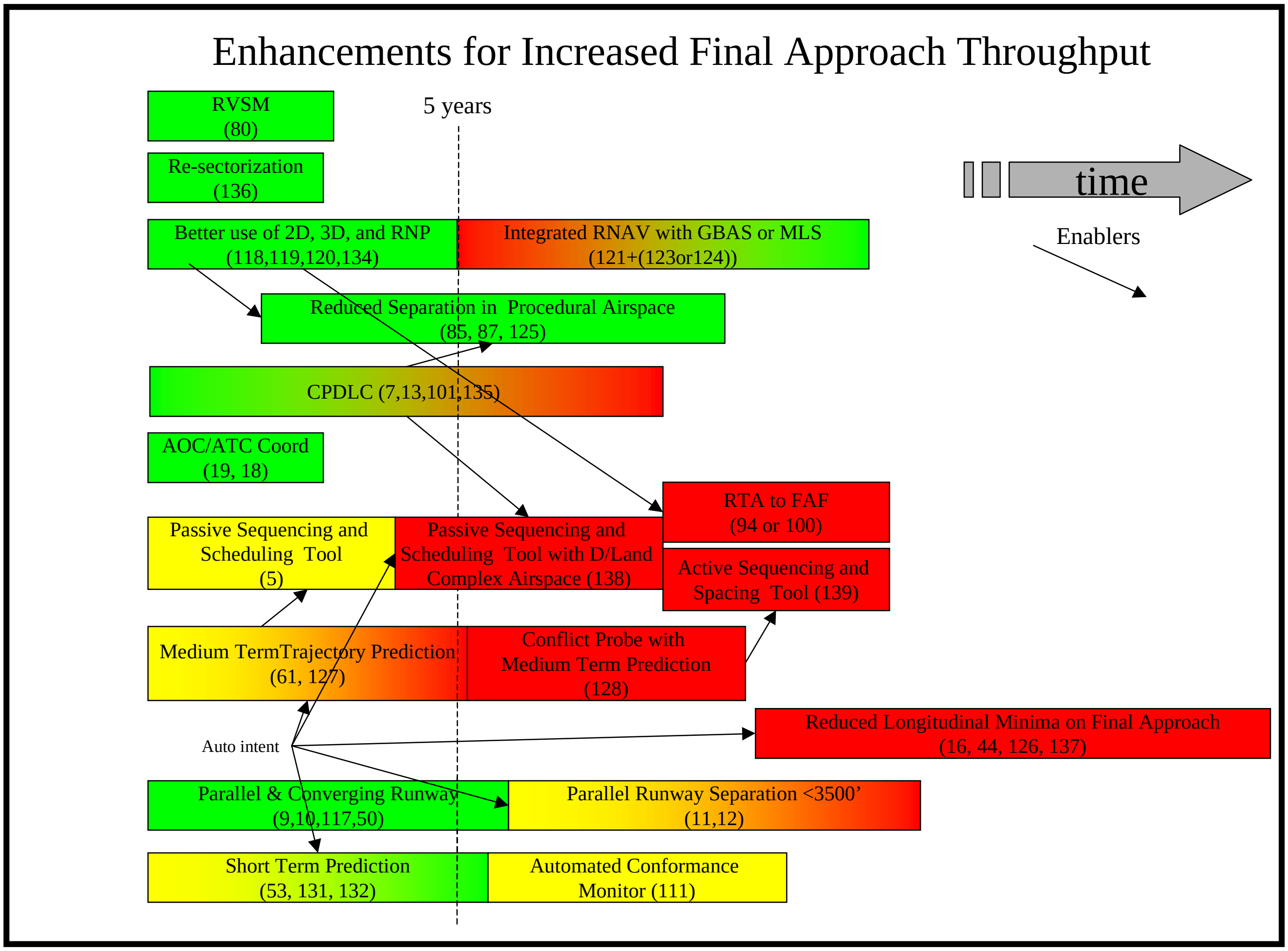


Figure 5: Enhancements for Final Approach Throughput

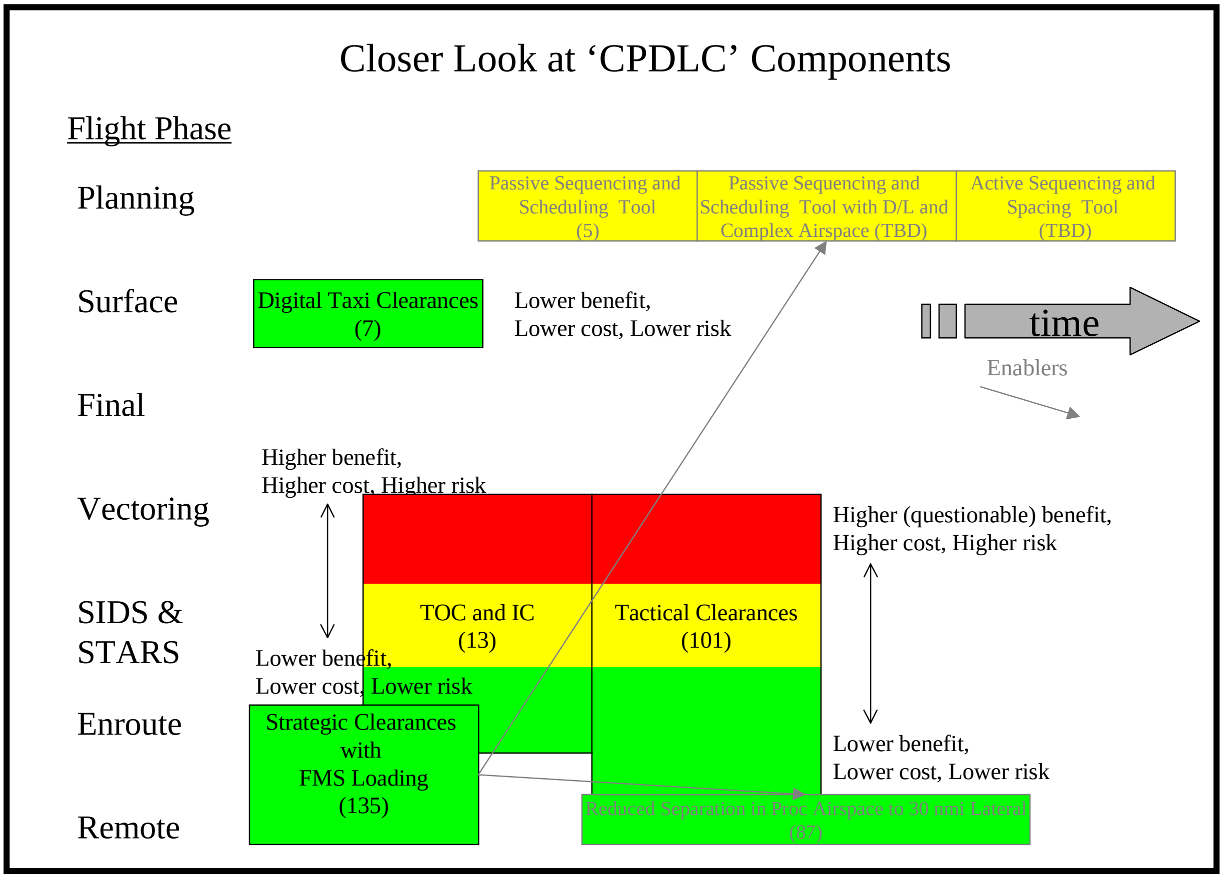


Figure 6: ‘CPDLC’ Components by Flight Phase

Conclusion

This analysis is our first application of the summarized process. Emphasizing operational enhancements over technology enablers to analyze integrated solutions proved to be successful. The relational database will allow further evaluation of interactions and dependencies between enablers, enabler solutions, and operational enhancements.

We expect to refine and apply the integration analysis across additional objectives and domains, and to maintain and expand the data base of enhancements upon which the analysis is based. The OEIA Focus Group of C/AFT is being formed, and will work with airlines, air traffic service providers and other airspace users. The objective is to provide integrated business cases to evaluate CNS/ATM solutions across flight phases, and for different airspace use objectives (e.g. en route capacity vs. final approach throughput).

References

Allen, David L, et al, "The Economic Evaluation of CNS/ATM Transition", *Proceedings of the Global Navcom Conference*, sponsored by the International Air Transport Association, June 1997. Available on the World Wide Web at http://www.boeing.com/commercial/caft/reference/documents/caft_paper.pdf.

CNS/ATM Focused Team, ATS Data Link Focus Group, *Data Link Investment Analysis*, April 9, 1999. Available on the World Wide Web at http://www.boeing.com/commercial/caft/cwg/ats_dl/tocpaper.pdf.

Washington, James, et al, "Improving the FAA's Acquisition Management System from the Start", *Journal of Air Traffic Control*, v. 40, no. 4, October-December 1999, pp. 17-21.