MODERNIZING THE U.S. AIR NAVIGATION SERVICE

Abstract: The modern Air Navigation Service (ANS), also known as Air Traffic Control (ATC), is one the largest networked socio-technical systems developed and operated by humankind. The ANS ensures *safe* and *efficient* flight operations 24 hour a day, 365 days a year across continents and oceans for upwards of 15 million flights per year. Since Air Navigation Service Providers (ANSP) operate under the legal framework of a public utility (or quasi-public utility) and are subject to a range of externalities, productivity improvements and modernization initiatives are not efficiently driven by market forces and require government mandates. This paper describes the ANS modernization initiatives underway in the Europe and the United States. The enabling technologies, concepts-of-operations, and challenges to modernization are discussed.

INTRODUCTION

Air transportation is a critical component of the world-wide economy, providing affordable, rapid, and safe transportation of people and cargo. It is particularly advantageous compared with other modes of transportation for travel over long distances and to remote locations. The air transportation service is provided by the collaboration of three main agents: (1) Aircraft Owners and Operators, (2) Airports, and (3) Air Navigation Service Providers (ANSPs).

The ANSP, also known as Air Traffic Control (ATC), provides the infrastructure and processes to manage the *efficient* and *safe* flow of flights from one airport to the next, through the airspace, over continents and oceans. The flights are scheduled and operated by the Aircraft Owners and Operators (such as airlines, military, private owners) and use the infrastructure of the airports to process passengers (e.g. baggage check, security) and to service aircraft (e.g. fuel, cleaning, de-icing). Together airports and the ANSPs are known as the National Airspace System (NAS).

Modern ANSPs are one of the largest and most complex socio-technical systems ever developed and operated. For example, European and U.S. ANSPs provide service 24 hours a day, 365 days a year. In 2012, the Air Navigation Service (ANS) provided service to 513 airports in the U.S., and 433 airports in Europe (EUROCONTROL/FAA, 2012). The U.S. ANS handles approximately 15.2 million flights a year that travel on average 511 nautical miles. The European ANS handles approximately 9.5 million flights a year that travel on average 559 nautical miles.

Service is provided for an airspace covering a geographic area in excess of 5.6 million square nautical miles (see Table 1). Due to national boundaries, the European Enroute airspace (i.e. altitudes above 24,000 ft) is serviced by 63 independent ANSPs that collaborate to pass flights between regions in a seamless manner. In the U.S. a single ANSP services the U.S. airspace that is divided into 20 control Centers. The U.S. ANSP has 13,300 ATC controllers and a total staff of 35,200. The additional staff includes administration as well as technical operation specialists. Approximately 6,000 technical operations specialists are employed to maintain over 41,000 radar and navigation radio facilities. The European ANSP employs 17,200 controllers with a total staff of 58,000.

Table 1: Size and complexity of U.S. and European Air Navigation Service

Characteristic	**United States**	**Europe**
Geographic Area covered	5.62 M square nautical miles	6.21 M square nautical miles
Airports with ATC services	513	433
Number of Enroute Airspace Control Centers	20	63
Total Air Traffic Controllers	13,300	17,200
Total Staff	35,500	58,000
ATC Controlled Flights (i.e IFR)	15.2 M	9.5 M
Average length of flight	511 nm	559 nm
Flight hours controlled	22.4 M	14.2 M

To maximize efficiencies and to avoid duplication of infrastructure, ANSPs and airports operate under a regulatory framework as a form of public utility (or quasi-public utility). In this way, they provide the complex service and costly infrastructure in the "interests of the public" to *all* aircraft owners and operators, and to *all* consumers of the air transportation service. Due to this legal framework (e.g. revenue neutrality, governance by political process), enterprise modernization and productivity improvement are not driven by natural market forces. In addition "externalities" such as the effect of aviation on climate change, local air and water quality, noise, consumer protection, and affordability of air travel, have induced governments to mandate sweeping modernization programs. In the U.S. this modernization program is known as the Next Generation Air Transportation System (NextGen) (FAA, 2013). In Europe the initiative is known Single European Sky ATM Research (SESAR) (EUROCONTROL, 2013).

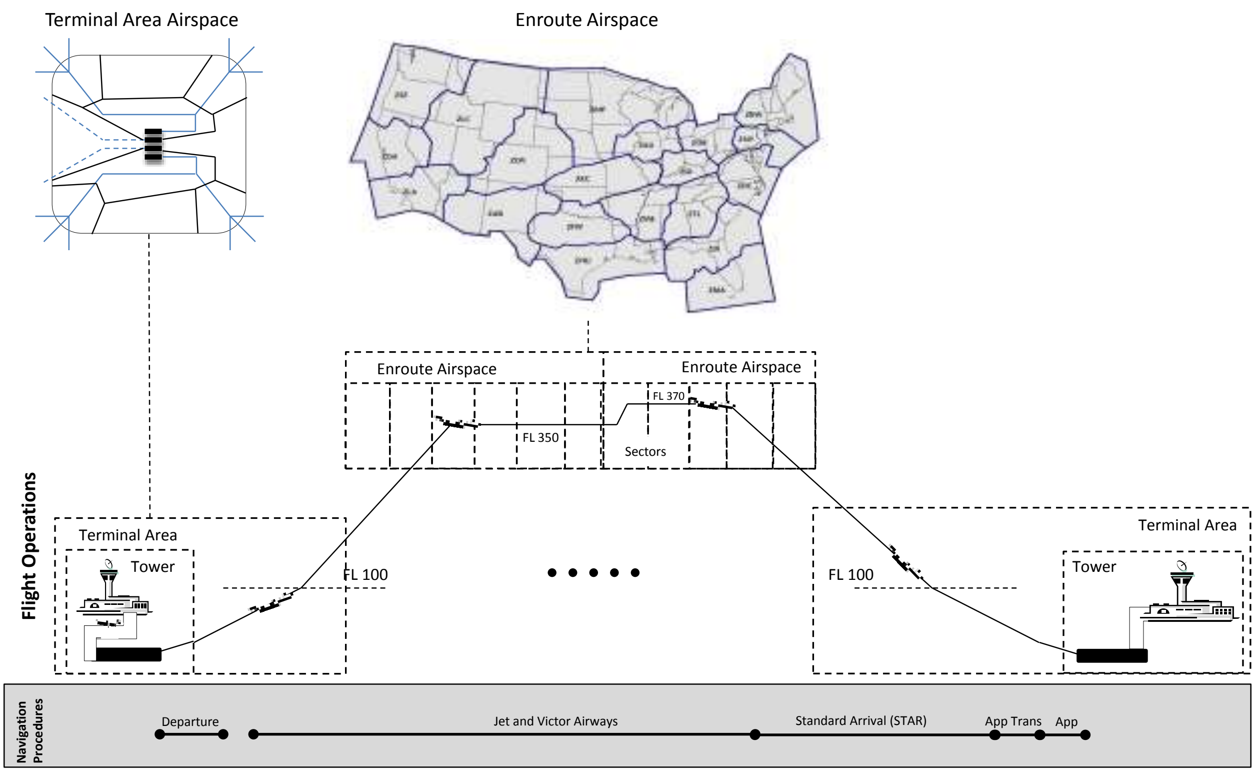
This paper provides an overview of the modernization initiatives for the modern complex networked ANSP. First an overview of the ANS and the functions of an ANSP is provided. Based on this description, the bottlenecks and opportunities for productivity improvement are identified. Next a description of the new concepts-of-operations and their enabling technologies are provided. The paper concludes with a discussion of the challenges and issues facing deployment of this modernization initiative.

This paper intentionally uses general terminology and descriptions of the ANSP, the enabling technologies, and concepts-of-operations. In this way the discussion can be decoupled from the vagaries of specific ANSP organizational structures, budget line-items, and program contracts.

OVERVIEW OF THE AIR NAVIGATION SERVICE

The ANS ensures *efficient* and *safe* progress of a flight from an origin airport to a destination airport. The design of a modern ANS is such that a flight progresses through a sequence of ANS facilities (Figure 1). These facilities are loosely grouped into three types Airport (or Tower), Terminal Area airspace, and Enroute airspace (also known as Centers).

The Tower manages flights on the airport ramp, airport taxiways, airport runways. The Terminal Area manages flights in the departure airspace, arrival airspace, and approach airspace. In the U.S. service is provided to 513 airports and Terminal Areas. The Enroute airspace manages flights above 24,000 feet and is divided into regions known as Centers (e.g. the U.S. airspace is divided into 20 Centers). The Terminal Airspace and Center airspace is further divided into smaller 3-D regions of airspace known as Sectors.



From an ANS perspective flights progress through ANS facilities from origin airport to destination. The three main groups of ANS facilities are Tower, Terminal Area airspace, and Enroute airspace. The airspace is further divided into 3-D blocks of airspace known as Sectors. Flight trajectories are controlled by Sector controllers.

Figure 1

The ANS operation is organized around the fundamental principle of closed-loop control of flights for *safe separation* and for *efficient flow*. Closed-loop control involves sensing the situation (or forecast situation) relative to desired goals, deciding on a set of actions, and then executing these actions to achieve the goals. This loop is continued until the desired end-state is achieved.

To manage the scale of the task, the modern ANS function is broken down into three nested closed-loop control systems: (1) system-wide, strategic flow management, (2) regional, tactical flow adjustment, and (3) instantaneous flight trajectory control. These three nested closed-loop control systems are illustrated in Figure 2.

The strategic NAS-wide Flow Management, with responsibility for the traffic flow across the whole NAS, lays out a plan for the day to ensure efficient traffic flow. This plan takes into account forecast flight demand and forecast airspace and runway capacity.

Facility Flow Planning (FFP), with responsibility for large groups of airspace (e.g. Centers, and Terminal Areas), executes the strategic flow plan and makes local adjustments according to local conditions to ensure safe loading of sectors and maintain efficiency goals.

Sector Control provides real time trajectory vectors to maintain safe separation. As the sole contact with the flight, the Sector Control also relays navigation instructions to the flight to reflect the Facility Flow plan and the NAS-wide Flow Management Plan.

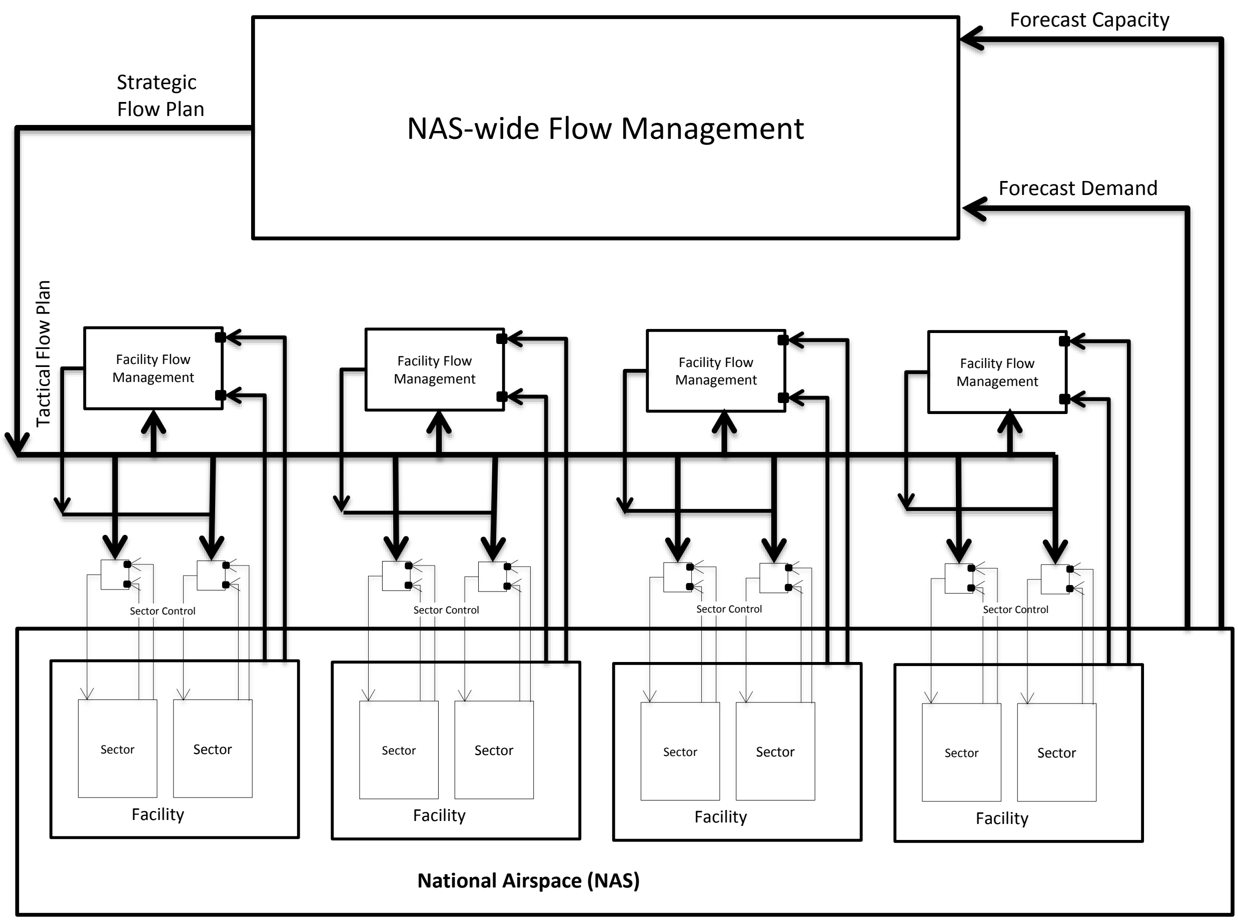


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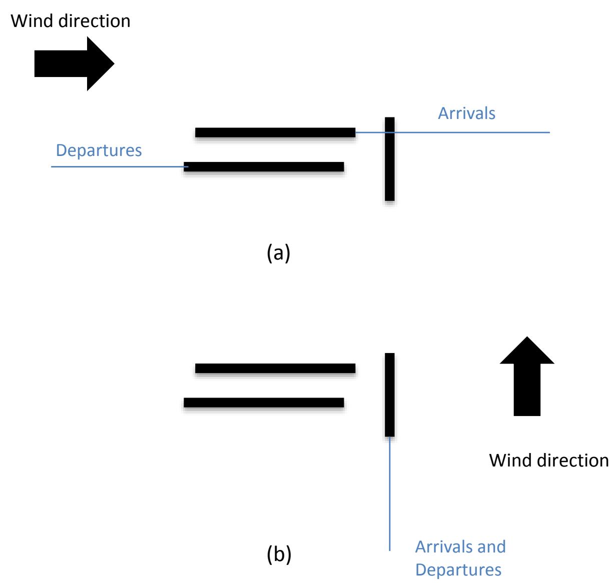
Figure 2

BOTTLENECKS AND IMPROVEMENT OPPORTUNITIES

Each of the input and output parameters, and processes in Figure 2 represents a bottleneck or provides an opportunity for productivity improvement.

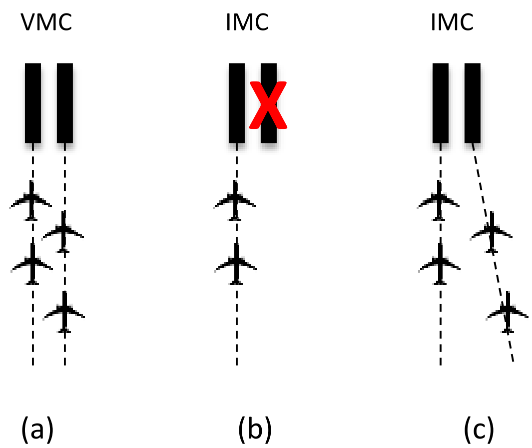
Runway Capacity

The overall flow performance of the ANS is predicated on the available *runway and airspace capacity* in the NAS. The are three main factors that determine available runway capacity. First, runway capacity is a function of the number of runways available for forecast wind conditions. When winds are calm, flights can takeoff and land using runways in any direction. When winds are in excess of approximately 10-15 knots, flights must takeoff and land into the wind. For airports with asymmetric runway configurations (i.e. more runways in one wind direction than another prevalent wind direction), certain wind conditions reduce the number of runways available (Figure 3). Addressing this issue involves the construction of new airports, new runways and extensions of existing runways.



Airport with asymmetric runway configuration goes from two independent runways (a) to one mixed sue runway (b) when conditions change.
Figure 3

Second, the height of the clouds (known as ceiling) and the visibility at the airport also impact runway capacity. When ceilings and visibility are lower than prescribed minimums, the separation distance between sequential flights is increased. This has the effect of reducing runway capacity. The same rules apply for adjacent runways. When visibility is reduced adjacent runways cannot be used simultaneously as they are with good visibility (Figure 4).



Arrival capacity is reduced from VMC conditions with independent runway operations (a) to dependent runway operations in IMC (b). new technologies could enable an alternate procedure for IMC that allows all weather conditions on both runways (c).

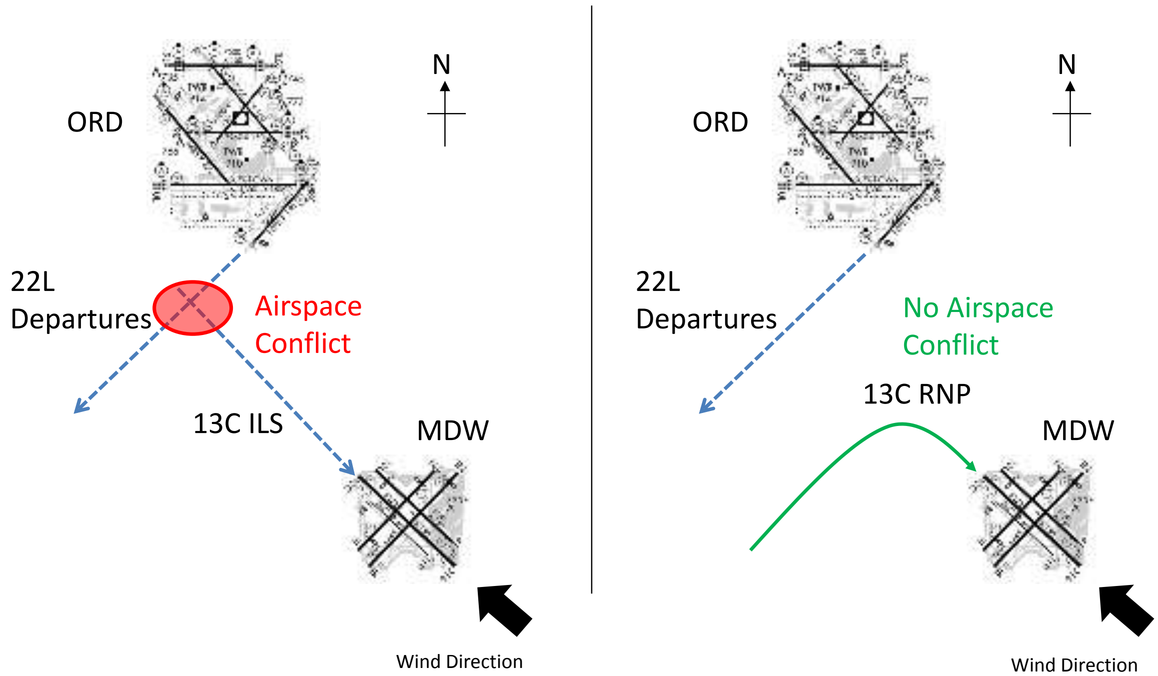
Figure 4

Navigation and surveillance technologies have historically been very successful at providing "all-weather" operations. Precision navigation and surveillance systems can reduce separation distances, and provide guidance and control in all weather conditions.

Airspace Capacity

Airspace capacity is determined by the number of "pathways" available through the airspace and the number of flights that can be controlled simultaneously by a single controller (approximately 10 – 20). The number of pathways, known as airways in Enroute airspace and procedures in Terminal Area airspace, are determined by the accuracy of the ANS navigation equipment and the ANS surveillance "radar" in determining aircraft position. The greater the precision, the more pathways can be included in an airspace.

The navigation equipment also determines the efficiency of the airways in terms of direct routing, flexible routing, and the ability to cut corners by making curved path turns. For example, for airports in close proximity, wind conditions can result in runway configurations at adjacent airports in which arrival and departure flows may conflict. Application of precision navigation and surveillance technologies facilitate more precise routing that can allow the multiple flows to operate simultaneously. Figure 5 shows an example of how a high precision, curved path approach to runway 13C at Chicago Midway (MDW) airport can de-conflict airspace with the departure from 22L at Chicago O'Hare (ORD) airport increasing the effective airspace capacity.



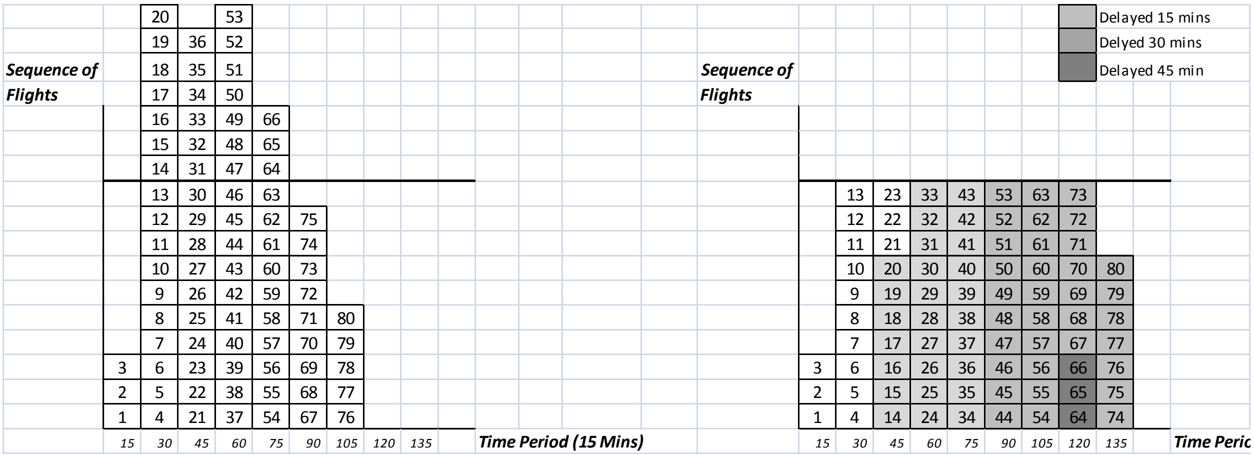
High precision, curved path approaches into Chicago Midway (MDW) airport allow simulataneous arrivals into MDW and departures from Chicago O'Hare airport

Figure 5

NAS-wide Flow Management

Given the capacity limits of the NAS, the performance of the NAS-wide Flow Management is determined by the accuracy of the *forecasted capacity* and *forecasted demand* at each NAS resource. In the U.S., where only three airports have limits on the number of flights allowed to use the airport, airlines and other users are free to schedule flights without consideration of available capacity. As a result circumstances can occur (i.e. peak hours) where more flights are scheduled than the resource can handle (Figure 6-a). Alternatively, as a result of weather (i.e. wind direction, reduced visibility) or equipage outages, the capacity of a resource can be reduced resulting in demand in excess of capacity.

This imbalance between demand and capacity is addressed by NAS-wide Flow Management by allocating flights to a time slot for each resource. The allocation is specifically designed to bring the demand in a given time period (generally 15 minutes) within the available capacity (Figure 6-a). The allocation is accomplished using the principle of *first-scheduled/first-allocated*. The net effect is that the flights that are scheduled in excess of the slot capacity for a given time period, get pushed-back to the next time period. This creates a ripple effect of push-backs until all flights are eventually accommodated (see inset in Figure 6-b).



(a) (b)

NAS-wide Flow Management solves an imbalance between flight demand at a NAS resource (e.g. runway or airspace) during a time period (a), by allocating slots to flights within the capacity constraint at the NAS resource (b).

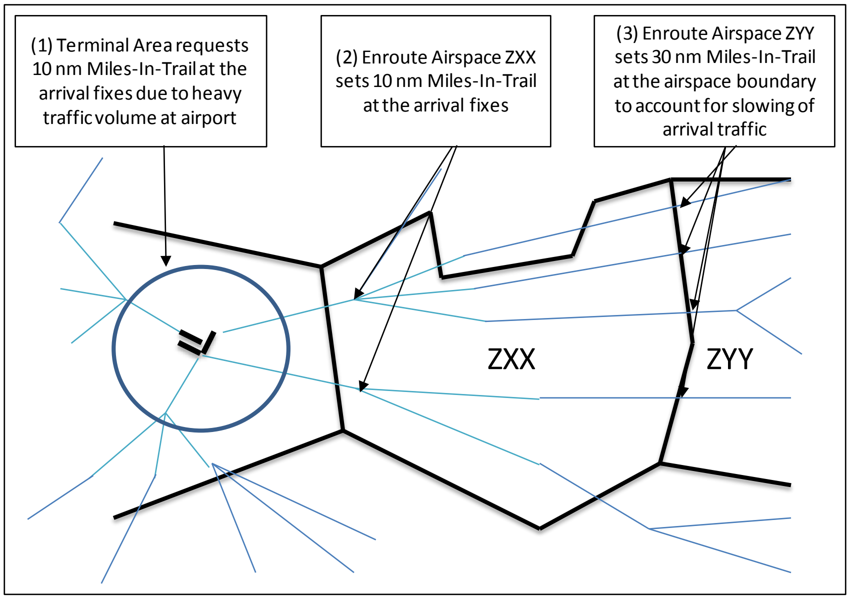
Figure 6

Flow Managemet is particularly complex due to the inherent uncertainty in the process and the limited degrees of control. There is intrinsic uncertainty in the slot capacity of the runways and the airspace. There is also some uncertainty in the progress of flights due to delayed boarding, mechanical issues, or other non-ANS (e.g. airline, security) related process. For example, fog at an airport may lift sooner than expected, or a thunderstorm may remain active for longer than expected. In the case of the fog, slots would go unused. In the case of the lingering thunderstorm, additional capacity reduction would be required. In addition to the uncertainty in slot capacity and arrival demand, there is a long lead-time for long distance flights to arrive at an airspace or runway. This requires advance planning and coordination and makes it difficult to adjust flows for last minute changes.

Productivity improvement opportunities lie in the improved accuracy of capacity forecasts (including weather) and improved actual flight demand forecasts. Another critical piece of the puzzle is the sharing of information amongst all stakeholders and a process for collaboration. For example, a flight cancellation due to a mechanical problem can open up a slot. This slot can be filled by moving all subsequent flights up one slot (known as “compression”) yielding significant time and cost savings to the aircraft operators.

Facility Flow Management

Despite the best efforts of NAS-wide Flow Management, circumstances frequently occur that require *adjustment of flows* in regions of the airspace. Examples of these circumstances include unexpected pop-up thunderstorms, inaccurate timelines for forecasted weather, restricted airspace (e.g. military flights, or flights transporting Head of State), or ATC equipment failures. These issues are handled at the local level. Facility Flow Planning (FPP) regulates flights to avoid over-crowding a specific airspace. This is achieved by airspace facilities metering the flights into the airspace with sufficient distance between flights. This process is known as Miles-in-Trail (MIT) and specifies the distance between successive flights. MIT generally results in a flight following the same route but at a slower speed. Figure 7 illustrates the application of a MIT to manage volume of arrivals into a Terminal Area and the ripple effect of facilities. Productivity improvements can be achieved by simpler and improved coordination of flow plans amongst facilities.



Example of application of Miles-In-Trail restrictions to manage excessive volume of arrivals in Terminal Area can result in a ripple of MIT restrictions.
Figure 7

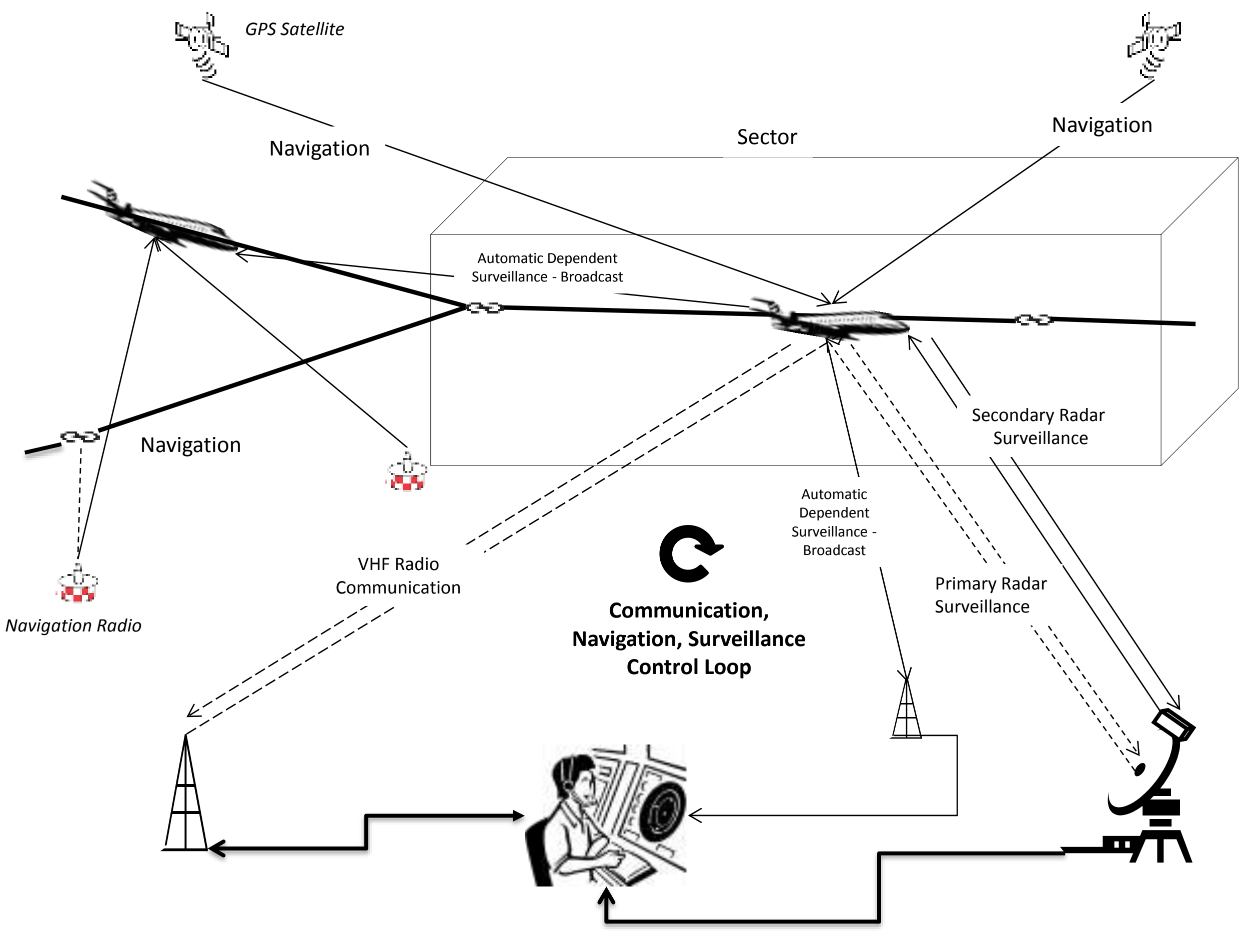
Sector Control

Sector control is the critical cog in the overall ANS scheme. Sector control has two responsibilities. First it executes the plans from Flow Management and Flow Planning by communicating the NAS-wide and Facility Flow airway and procedure navigation instructions. Second, Sector control also issues vectors to maintain safe separation.

Sector control communication currently is conducted using push-to-talk voice radio for flight clearances (e.g. permissions), vectors (e.g. heading, speed, altitude), and short navigation procedure/airway instructions. Longer navigation instructions can be relayed via a satellite or ground-based digital communication network, however this means of communication can be expensive.

Navigation and safe separation is conducted through a closed-loop control system (Figure 8). An Air Traffic Controller *communicates* directly with the flightcrews of the flights in the sector under their jurisdiction providing them specific navigation instructions. The flighcrew acknowledge the instruction and *navigates* the flight using the available navigation procedures (e.g. airways) and systems (e.g. navigation radios and satellites). The Air Traffic Controller monitors the flights under their jurisdiction to maintain safe separation between flights and adherence to navigation procedures using available *surveillance* systems.

Surveillance is achieved through "skin paint" radar (i.e. Primary Radar) and interrogation radar (i.e. Secondary Radar). Primary radar shows that location of the flight based on a radar return. Secondary radar shows the location of the flight and identification of the flight based on a radar interrogation of the aircraft's transponder that resends the interrogation with flight identification and position information from the aircraft's navigation avionics. The safe separation of flights is conducted by a manual process in which the Sector controller monitors a radar screen and adjusts flight trajectories based on picture of all the flights in the sector.



Closed-loop control of flights using the Communication/Navigation/Separation/Surveillance System
Figure 8

Existing voice communication has limited bandwidth, is time consuming (especially for routine communications), and can introduce errors. Primary and secondary radar provide a position accuracy limited by the technology. Temporal and spatial flight plan adjustments can be more easily conducted by the flight with onboard avionics functions. The same is true for separation than can be delegated to the flights.

The communication of the NAS-wide Flow Plan and the Facility Flow Plan is conducted by a system of Flightstrips. In many facilities the information is transferred in digital form to the facility, printed onto paper, and used by the Sector controller in paper form. Opportunities for efficiency can be achieved by an electronic flight strip.

ENABLING TECHNOLOGIES AND NEW ANS CONCEPTS OF OPERATIONS

The bottlenecks and opportunities for each of the parameters and processes described above are summarized in Table 2. Table 2 also identifies the concepts-of-operations and enabling technologies that are part of the modernization of ANSs. Concepts-of-operations are the combination of procedures and processes implemented across stakeholders to achieve a new paradigm in operations. Enabling technologies are the physical equipment required to enable the concepts-of-operations.

The enabling technologies and concepts-of-operations are described in more detail below.

Table 2: Bottlenecks and opportunities for each of the parameters and processes of the ANS along with the concepts-of-operations and enabling technologies that are part of the modernization of ANSs.

Parameters and Processes	Bottlenecks and Opportunity	Concepts of Operations	Enabling Technologies
Runway capacity at airports	Increase number of runways	N/A	
	Symmetric runways for all wind conditions	N/A	
	All weather operations (i.e. ceilings and visibility)	All weather operations	RNP ADS-B
	Simultaneous runway use in poor visibility	Super Dense Operation (SDO)	RNP ADS-B
	Improved spacing between sequential flights	Trajectory-based Operations (TBO)	RNP ADS-B
Airspace capacity	Increase number of pathways	Performance-based navigation (PBN)	RNP
	Eliminate conflicting flows	Performance-based navigation (PBN)	RNP ADS-B
	Improved spacing between sequential flights	Trajectory-based Operations (TBO)	RNP Data-Comm
NAS-wide Flow Planning	Incomplete information/ Uncertain information	Collaborative Decision making (CDM) with Improved Accuracy Forecasts	SWIM
Facility Flow Planning	Ripple effect of flows	Time-based Flow Management (TBFM)	SWIM
Sector Control	Providing complex navigation instructions	Digital Data Communications (Data-Comm)	Data-Comm
	Executing time-based trajectory targets	Airborne Self Separation Trajectory-based	RNP Data-Comm

		Operations (TBO)	
	NAS-wide and Facility Flow Plans	Flight Data Manager (FDM)	SWIM

Enabling Technologies

There are four main technologies that are required to overcome the limitations of the existing system and enable the deployment of new concepts of operations.

<u>Automatic Dependent Surveillance – Broadcast (ADS-B)</u>: ADS-B is one-way transmission of flight position (latitude/longitude, altitude) and velocities from the aircraft to ground stations. The means of surveillance has significant advantages over traditional surveillance systems. First, the aircraft avionics has full knowledge of the aircraft state based on the fusion of Global Positioning System (GPS), Inertial Reference System (IRS), and radio navigation (e.g. VOR, DME). This aircraft position, plus the velocities, is significantly more accurate than the data generated from primary and secondary radar. Second, the ADS-B does not require interrogation by ground antennas. This simplifies the ground infrastructure requited. Third, the ADS-B transmission can be up to once every second,. This is faster than the traditional 13 second update rate for radar. Fourth, the installation of ground antennas is significantly less expensive than traditional radar systems.

For these reasons, ADS-B has been deployed in several locations. Australia was the first to deploy ADS-B on a large scale. Australia has continental coverage above FL300 (30,000 feet) with 57 ground stations operating from 28 sites. Canada use ADS-B to provide coverage in northern airspace around Hudson Bay, which previously had no radar coverage. The service is also being extended to cover some oceanic areas off the east coast of Canada, and over the Northern Atlantic including Greenland, Iceland, and the Faroe Islands. ADS-B has also been implemented in central China in an airspace that spans 1,200 nautical miles.

There are two services provided by ADS-B: ADS-B Out and ADS-B In. ADS-B Out periodically broadcasts aircraft information including identification, current position, altitude, and velocity, through an onboard transmitter.

ADS-B In receives ADS-B Out broadcasts from nearby traffic providing the flighcrew with detailed traffic information in the vicinity of the flight. In addition, ADS-B In features include reception by aircraft of Flight Information Services – Broadcast (FIS-B) and Traffic Information Services-Broadcast (TIS-B) from ground stations. FIS-B provides The FIS-B broadcast includes graphical National Weather Service products, temporary flight restrictions (TFRs), and special use airspace information. TIS-B, provides free traffic reporting services to aircraft from the ground station (as opposed to air-to-air).

<u>Required Navigation Precision (RNP)</u>: RNP is an avionics suite with increased accuracy in position fixing. This is achieved by fusing data from multiple GPS satellites along with IRS and radio navigation data. RNP

RNP refers to the level of performance required. An RNP of 10 means that a navigation system is able to calculate its position to within a circle with a radius of 10 nautical miles. An RNP of 0.3 means the aircraft navigation system is able to calculate its position to within a circle with a radius of 3 tenths of a nautical mile. Actual Navigation Performance (ANP) refers to the accuracy of the navigation at any moment based on the availability of sensors at that time.

The increased precision of RNP enables increased airspace capacity. For example, additional parallel tracks can be squeezed into an airspace. Also crossing tracks with a vertical separation can be created. RNP also is the basis for precise three-dimensional curved flight paths through congested airspace, around noise sensitive areas, or through difficult terrain. The designation RNP – X refers to the accuracy required for a given block of airspace or a specific navigation procedure. For example, some oceanic airspace has an RNP of 4 or 10. RNP approaches with RNP values of 0.3 or 0.1 allow aircraft to follow curved approach paths that would not be feasible with existing navigation and surveillance technologies.

To enable RNP capabilities, aircraft must be equipped with the necessary GPS and navigation algorithms. In addition, navigation procedures for RNP must be developed and published by ATC or the regulatory authority, and ATC controllers procedure’s must be updated and trained.

<u>Data-link Communications (Data Comm)</u>: Dat Comm is a digital communications channel between aircraft and ground station, and aircraft-to-aircraft. Data Comm infrastructure includes terrestrial circuits and very high frequency data links.

Data Comm enables air traffic controllers and pilots to communicate more effectively by supplementing traditional voice communications with data. . This can improve the accuracy of the transmission reducing communication errors. It can increases ATC efficiency and reduce workload by reducing the time spent on routine tasks, It also enables the transmission of long complicated instructions and complex weather data.

not possible with voice alone. to enhance departure clearances, weather route, and other air traffic procedures. These enhanced procedures will save fuel, reduce flight times, and increase air traffic capacity.

<u>System-wide Information Management (SWIM)</u>: SWIM is a secure communications infrastructure that enables real-time information sharing amongst all users. It uses commercial, off-the-shelf hardware and software to support a service-oriented architecture that facilitates the addition of new systems and data exchanges.

SWIM will radically change the ability and speed with which data is shared by stakeholders. SWIM overcoes the limitations of silo’ed, proprietary information networks that could not be accessed outside the enterprise. In addition, SWIM enable additional users to share and access information from different kinds of systems, such as airport operational status, weather information, flight data, status of special use airspace and airspace system restrictions.

New Concepts of Operations

New concepts-of-operations for ANS are headlined by improved coordination of approved flightplan trajectories to ensure that flights arrive at NAS resources with sufficient capacity to accommodate them, and that their trajectory is conflict free. This concept-of-operations is known as *Trajectory-based Operations* (TBO). The TBO concept issues each flight a detailed flightplan that includes not only waypoints and altitudes (i.e. 3-D), but speeds and time at waypoints. This four-dimensional flightplan will deconflicted with the trajectory of other flights prior to approval. This will to provide the flight an unimpeded flight trajectory with minimal vectors from ATC. This concept is enabled by at by RNP for position and time accuracy, Data-Comm for complex clearances and flightplan modifications, and SWIM for flight and airspace status updates.

The ability to accurately generate conflict-free trajectories is based on the accuracy and degree of completeness of information about the current and future states of the NAS and it's resources. This is enabled by SWIM.

Performance-based Navigation (PBN) is the concept that allows more flights to use limited airspace. For example, flights funneling into the Terminal Area airspace for airport arrivals and departure can be de-conflicted (see Figure 4). RNP approach and departure procedures provide the means to fly precise curved path approaches, and precise departure trajectories

Flights would also be sequenced for landing on parallel runways in configurations considered unsafe using past generation technologies and procedures. For example, at an airport with parallel runways which operate as independent runways in Visual Meteorological Conditions (VMC), but become dependent runways with lower capacity in Instrument Meteorological Conditions (IMC). SDO operations leveraging ADS-B for self-separation, and RNP for precision approaches can enable simultaneous parallel landings (see Figure 3).

Coordination of Tactical Flow Planning can be significantly improved with Time-based Flow Management (TBFM). TBFM is used for improve ATM by better adjusting capacity/demand imbalances at select airports, departure fixes, arrival fixes and en route points across the NAS. It uses time-based metering capabilities to flow flights in an optimal sequence with required spacing in the Terminal Areas. For example, in the enroute phase, TBFM provides metering points further out from arrival airports, allowing controllers to provide earlier integration of arriving flights. TBFM will enable optimized descents during metering operations, increase flexibility, and accommodate dynamic reroute operations in response to changing weather conditions.

In many of the operations in the ANS, and in particular in NAS-wide Flow Management, decisions must be made that can have a large impact on the scheduled network operations of individual airlines. The ANS does not readily have information about the economics of specific airline network operations. Given choices in TMI's, the ANS may unwittingly select an option that degrades or even unravels the airline operations. For example, out of 6 flights forecast to arrive at a capacity constrained airport in 15 minute period, one of the flights may be critical to the airline due to the number of connecting passengers, duty hours of the flightcrew, and availability of specialized ground crews or equipment for aircraft gate turn-around. Given a choice, the airline may choose to maintain the schedule of this high-value flight and swap an EDCT delay to another less critical flight.

The process of information sharing and coordination between airlines and ANSP is known as Collaborative Decision Making (CDM). CDM has been deployed in the U.S. since 1996 and has several successful precedents. Ground Delay and Air Flow programs use CDM to allow airlines to identify cancelled flights (e.g. mechanical problem) and open up the slot that would have gone unused. In return, the airlines have the option of swapping flights within it's schedule to minimize the impact on their network. CDM is also used in departure management in which flights are allowed to hold at the gate rather than form than long queues on the airport surface blocking the flow of surface traffic.

Flight Data Manager (FDM) provides an mechanism to transfer all NAS-wide and Facility Flow Plans to all facilities in electronic format. Sector controllers will be able to use the electronic flight strips (in place of paper flight strips).

MODERNIZATION ISSUES

One of the major challenges in the modernization of ANSP is the sheer magnitude of the modernization and the coordination of simultaneous investment in equipage and procedures by all stakeholders. For example, many of the modernization concepts of operations require equipage, procedures, and personnel training to occur simultaneously amongst airlines, ANSPs, and regulators. Even within airlines this significant investment that can impact flightcrew training, simulator capabilities, maintenance training, dispatch training, aircraft maintenance procedures, standard operating procedures, aircraft delivery and acceptance, and quality assurance. Each one these processes has it's own supply chain. Further, many of these processes require approval from regulatory authorities for new procedures and training equipment. If any one of the links in the chain is absent, the benefits cannot be accrued. This is particularly a challenge for ANSPs that have to develop and deploy multi-year initiatives that are funded incrementally on annual government budget cycles. There have been several examples in recent history in which the airline timeline for investment in equipage and procedures fell out of synchronization with the ANSP timeline.

One of the ways to provide ANSPs with more authority for modernization is through commercialization of the enterprise. Over the last several decades, economic deregulation of public utilities in several industries has yielded improvements in economic efficiency. In air transportation, airlines deregulation started in 1978 in the U.S. and has lead to widespread deregulation of the industry culminating in the Open Skies agreement between the United States and the European Union (EU) in 2008, Deregulation of ANSPs has occurred since the late 1980's resulting in the privatization of 14 national ANSPs. New Zealand was the first ATC system commercialized in 1987 with the creation of a state-owned enterprise that pays dividends to the state. Australia followed in 1988 and was restructured in 1990. NavCanada was commercialized in 1996 with the creation of a non-share, not-for-profit corporation that is able to set user fees.

Preliminary results indicate that commercialization of ANSP has been a mixed success. It has been successful in moving the costs of operating a very expensive enterprise off the books of government budgets during an extended period of government budget austerity. Commercialization has ANSPs to set user fees consistent with the costs of services. This has provided the means to directly address productivity and modernization independent of political constraints. Studies have shown that during this period safety has remained the same or improved, and new technologies have been implemented to improve productivity (Neiva, 2013). However, geographic fragmentation of the airspace (e.g. European airspace), inconsistent regulations across governments and government agencies, and issues not related to the legal framework continue to limit economies-of-scale that could be achieved and inhibit reaching the full potential of self-sustaining productivity improvement to meet future growth in demand.

Another significant roadblock to investment in modernization is the cooperation of the aircraft owners and operators to invest in equipage. In a competitive airline marketplace, benefits accrue to all users of the airspace, when one airline equips. The increased predictability and additional slots created can be used by the non-equipped flights. For this reason, in some cases, the benefits to the non-equipped outweigh the benefits to the equipped (Belle, 2013). This *asymmetry in benefits* is a major stumbling block. Some of the approaches that have been proposed to overcome this issue are mandating equipage, and a best-equipped/best-served. Mandates are highly politicized and essentially ensure that all stakeholders are penalize equally. Although best-equipped/best-served incentivizes equipage, it can result in inequity in service intended as public utility.

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