# NEXTGEN HUMAN FACTORS ACCOMPLISHMENTS AND CHALLENGES IN THE FUTURE

Edmundo A. Sierra, Jr.
Federal Aviation Administration
Washington, D.C.

The Federal Aviation Administration (FAA), under the Next Generation Air Transportation System (NextGen) program, made significant progress in terms of infrastructure modernization of the National Airspace System (NAS). Development of infrastructure incorporated a broad scope of human performance considerations which this paper discusses at a high level. Since the FAA completed much of the infrastructure modernization, focus shifted to NextGen Transformation so that benefits can be realized. NextGen Transformation involves insuring that FAA systems are seamlessly integrated; that integrated pilot and controller procedures are in place; new roles and responsibilities are defined; and that stakeholders are informed, trained, and adapted to the NextGen technologies and procedures and are comfortable in their use. This paper concludes with an overview of challenges and opportunities the FAA is facing as it shifts its focus to NextGen Transformation - specifically as it pertains to human factors, safety, training, and the workforce of the future.

After a recent painful introduction I was required to provide as a student at the start of a class; the instructor asked, “Shouldn’t NextGen be done?” I sighed, rubbed my forehead, and as I formulated my answer realized it was a fair question for a program the Federal Aviation Administration (FAA) called “one of the most ambitious infrastructure and modernization projects in U.S. history” (FAA, 2007c). I told the instructor that NextGen delivered a lot of the infrastructure for modernization and is focused on operational integration. That is, NextGen delivered the physical underlying parts of a system that was adapted to meet modern needs. I elaborated on that answer in this paper for the human factors practitioner and included emerging and far-term human system challenges NextGen is facing.

## Next Generation Air Transportation System (NextGen)

To determine what NextGen has accomplished to date, I identified when it began and its objectives. In the United States, an authorization establishes a federal program (or agency). I determined that NextGen began within the law that reauthorized the legal operation of the Federal Aviation Administration in 2003. NextGen’s goals were included in the authorization language.

### NextGen Initiation

The 108$^{th}$ Congress endorsed the concept of NextGen in the Vision 100 – Century of Aviation Reauthorization Act, signed into law in December 2003. Congress found that the United States revolutionized the way people traveled by developing new technologies and aircraft. In addition, past investments in research and technology benefitted the economy and security of the United States. Congress saw continued leadership was needed, growth in aviation was necessary, and revitalization and coordination must begin. NextGen would encounter many challenges and there would be constraints by concerns related to safety, security, and environment.

### NextGen Goals

The Vision 100 – Century of Aviation Reauthorization Act set goals for NextGen. I listed the seven goals from 117 STAT. 2584 in Table 1. I would overwhelm the reader if I organized human factors accomplishments by the goals under Subsection (c) of the reauthorization. I would also find it difficult to describe human factors accomplishments at a consistent level. Therefore, I organized accomplishments by major NextGen Investments to date for a subset of domains: Communications, Navigation, Surveillance, and Automation.

Even at a high level, my analysis identified many human factors accomplishments to date. For example; human factors made numerous contributions throughout phases of systems’ research, concept development, engineering, development, and implementation. Human factors also contributed to overarching policies, standards, and guidance. Therefore, I identified the human components of systems and used their implementation as synonymous with human factors accomplishments. In the FAA, human factors must be included in planning, analysis, development, implementation, and in-service activities for systems (FAA, 2017a). The FAA verifies compliance with its policy throughout the lifecycle. For example, an in-service decision (ISD) authorizes deployment of a solution into the operational environment. A tool named the *in-service review* (ISR) *checklist* is used to identify and resolve readiness issues before the ISD. The checklist includes a human integration section with items verified by a human factors subject matter expert. The items include compliance with human factors policy, standards, and guidance; consideration of human performance; operational suitability; knowledge, skills, abilities; human error; functional design; and suitability of documentation. Systems the FAA implements meet FAA human factors goals.

Table 1.

*The Next Generation Air Transportation System shall—.*

| Paragraph | |
|---|---|
| (1) | Improve the level of safety, security, efficiency, quality, and affordability of the National Airspace System and aviation services |
| (2) | Take advantage of data from emerging ground-based and space-based communications, navigation, and surveillance technologies |
| (3) | Integrate data streams from multiple agencies and sources to enable situational awareness and seamless global operations for all appropriate users of the system, including users responsible for civil aviation, homeland security, and national security. |
| (4) | Leverage investments in civil aviation, homeland security, and national security and build upon current air traffic management and infrastructure initiatives to meet system performance requirements for all system users |
| (5) | Be scalable to accommodate and encourage substantial growth in domestic and international transportation and anticipate and accommodate continuing technology upgrades and advances |
| (6) | Accommodate a wide range of aircraft operations, including airlines, air taxis, helicopters, general aviation, and unmanned aerial vehicles |
| (7) | Take into consideration, to the greatest extent practicable, design of airport approach and departure flight paths to reduce exposure of noise and emissions pollution on affected residents |

*Note.* 117 STAT. 2584.

## NextGen Built Foundational Infrastructure (2003-2016)

NextGen implemented the foundational infrastructure for Communications, Navigation, Surveillance, and Automation domains. Communications included digital communications between controllers and pilots and between FAA systems and facilities. Navigation included precise Global Positioning System (GPS) routes and procedures in all airspace domains. Surveillance provided high update rate surveillance used by controllers and pilots. Automation was found in every Air Traffic Control (ATC) domain and included decision support. I described the domains in more detail, included examples, and human factors accomplishments in this section.

### Communications

Communications was comprised of elements that performed transmission or recording functions for voice and data communications within and external to the National Airspace System (NAS; FAA, 2017d). Communications supported connectivity between air-to-ground, NAS sub-systems and facilities, NAS and external systems and users. Air/Ground systems provided a wireless communication conduit between aircraft and other NAS users and systems.

**Communication Exemplars.** Three major programs were examples of Communications infrastructure: Data Communications, NAS Voice System, and System Wide Information Network. Data Communications (Data Comm) enabled controllers and pilots to communicate with digitally delivered messages in addition to voice. The NAS Voice System (NVS) allowed controllers and pilots to speak with each other without being limited by geography (versus radio). System Wide Information Management (SWIM) offered a single point of access to aviation data for controllers and operators including airlines, cargo carriers, business jet operators, and airports.

**Human Factors Accomplishments.** Data Communications were delivered at airport towers through Departure Clearance Tower Services (FAA, 2016b). These services allowed an Airport Traffic Control Tower (ATCT) controller to enter flight departure clearance instructions into a computer and push a button to electronically send the information to a flight deck. Flight crews viewed the instructions, pressed a button to confirm receipt, and pressed another button to enter the instructions into the flight management system. Preliminary qualitative benefits of Data Comm seen during trials included reduced communications time resulting in faster taxi outs, reduced delays, and reduced pilot and controller workload.

NAS Voice System will provide voice connectivity by linking incoming and outgoing communication lines to controller workstations (FAA, 2016b). The target users of NVS were air traffic controllers and pilots, including pilots of Unmanned Aircraft Systems (UAS). NVS successfully completed critical design review. The NVS program conducted Early User Involvement Events for Air Traffic and Technical Operations users. The program also held training manual conferences and technical manual conferences for the development of training and documentation. The program will complete NVS operational testing and evaluation, and key site testing in 2019.

System Wide Information Management implemented four key services: Interface Management Service, Messaging Management Service, Security Management Service, and Enterprise Service Management Service (FAA, 2017d). The target users for SWIM were air traffic controllers and operators including airlines, cargo carriers, business jet operators and airports (FAA, 2016a). The services supported three key domain areas and Community of Interest capabilities in the areas of Aeronautical Information Management, Weather, and Flight & Flow Management. Flight and Flow Management saw benefits when traffic managers used surface data to balance traffic demands with capacity demands across the NAS. Surface data also made it easy for Terminal Radar Approach Control (TRACON) controllers to identify departure congestion and anticipate changes that would impact their control of traffic.

**Navigation**

Navigation consisted of elements that provided visual and instrument based guidance to pilots during all phases of flight operations including airport surface navigation. Surveillance, which I included after this section, shared surface movement radar data with the Navigation element in order to aid pilots in navigating safely through airport surface, departure, and arrival operations (FAA, 2017d).

**Navigation Exemplars.** Three major programs were examples of Navigation: Performance Based Navigation (PBN), Metroplex PBN Procedures, and Wide Area Augmentation Systems (WAAS). PBN used satellites and onboard equipment for navigation procedures that are more precise and accurate and enabled aircraft to fly more directly from departure to arrival (FAA, 2017b). Metroplex PBN Procedures delivered large scale integrated PBN procedures in complex interdependent airspace. WAAS equipment and software augmented the Global Positioning System Standard Positioning Service.

**Human Factors Accomplishments.** Performance Based Navigation certified, published, and implemented procedures for Area Navigation (RNAV) Standard Instrument Departures (SID) and Standard Terminal Arrivals (STAR) at airports. Target users for PBN were controllers and pilots. RNAV SIDs and STARs increased predictability of repeatable flight paths and thereby enhaced safety and controller productivity. PBN also enabled En Route Automation to enhance the controller's ability to assign clearances to a pilot to operate on performance restricted routes.

Airspace congestion and limiting factors, such as environmental noise contraints, combined to reduce efficiency in Metroplexes. Study teams that included the FAA and aviation community analyzed the operational challenges of three Metroplexes using a consistent, repeatable approach. The FAA implemented their solutions, including PBN procedures, at Washington DC, North Texas, and Northern California Metroplexes (FAA, 2016b).

NextGen produced over 4,000 RNAV (GPS) Approaches for airports. The procedures were for WAAS localizer performance (LP) and localizer performance with vertical guidance (LPV). Pilots were able to fly approaches comparable to those of an Instrument Landing System (ILS) without the need for ILS's ground infrastructure. The capability also improved access for general aviation pilots who were able to file and fly to a greater number of airports during low visibility day or night. (FAA, 2017b)

**Surveillance**

Surveillance was comprised of elements that detected and reported the presence and location of aircraft and other targets in the air and on the airport surface movement areas. The data collected and created by Surveillance supported pilots, air traffic controllers, and other users via integration and data sharing within Automation (FAA, 2017d).

**Surveillance Exemplar.** Automatic Dependent Surveillance–Broadcast (ADS-B) is the successor to radar. ADS-B features the ability for an aircraft to broadcast its current location and other important information about the aircraft. The broadcast is received by ADS-B ground stations and by other aircraft. ADS-B uses GPS satellites to determine an aircraft's location, ground speed, and other data (FAA, 2017b). The surveillance coverage that ADS-B provides is nation-wide and NextGen also extended it to remote areas in Alaska and the Gulf of Mexico. ADS-B technology has also enabled the broadcast of non-coperative (unequipped) air traffic and weather information to be received by aircraft in flight without a service fee.

**Human Factors Accomplishments.** The FAA completed nationwide deployment of ADS-B ground stations (FAA, 2017b). ADS-B was integrated into automation platforms at all en route air traffic control facilities and more than one-third of all terminal facilities. ADS-B traffic and weather broadcasts were also available nationwide. The target users for ADS-B were air traffic controllers; aircraft owners and pilots flying above 10,000 feet mean sea level, within Class C airspace, the airspace surrounding most major airports, or low altitude airspace along the Gulf of Mexico coastline; and airport surface vehicle operators (FAA, 2016a). Controllers used ADS-B to track aircraft during radar outages in controlled airspace. Airport Surface Detection Equipment–Model X, a ground-surveillance system, alerted controllers to potential runway and taxiway conflicts using ADS-B and other data sources. One ADS-B In capability gave pilots an audio alert to warn of other aircraft that might be a collision risk. Another ADS-B In capability allowed pilots to keep track of aircraft flying in front of them during a visual approach to a runway. General aviation pilots received current weather and airspace status information from the FAA's free FIS-B service.

**Automation**

ATC Automation provided air traffic control functions including ATC, flight service, traffic management, time management and information management (FAA, 2017d). It included seven sub-elements that supported air traffic controller operations and pilot situational awareness. Automation performed functions by receiving and processing data from the Surveillance, Navigation, and Weather systems. ATC Automation relied on Communications systems to send and receive both voice and data transmissions. As ATC Automation provided function to the controller workstation, Aircraft Automation Systems provided automation function to the aircraft.

**Automation Exemplars.** Five major programs were examples of Automation: En-Route Automation Modernization (ERAM), Terminal Automation Modernization and Replacement (TAMR), Terminal Flight Data Manager (TFDM); Collaborative Air Traffic Management (CATM), and Time Based Flow Management (TBFM). ERAM replaced aging Air Route Traffic Control Center (ARTCC) automation systems (FAA, 2017d). The TAMR program modernized the air traffic control systems that controllers used to control traffic approaching or leaving the United States' major airports. TFDM automated the flow of flight and other tower data between ATCT and other ATC domains, and provided decision support capabilities to improve airport surface traffic management. CATM coordinated flight and flow decision-making by flight planners and FAA traffic managers. TBFM leveraged the capabilities of the Traffic Management Advisor (TMA) decision-support tool system that was deployed to all contiguous United States ARTCCs.

**Human Factors Accomplishments.** En-Route Automation Modernization and its associated hardware, software and backups were the backbone of en route operations. Instead of 20 separate systems, the FAA has a single system and ERAM was designed to support the evolution to NextGen. The target users for ERAM were air traffic controllers at en route centers. ERAM accommodated increased air traffic flow and allowed air traffic controllers to handle traffic in greater geographic areas. ERAM processed flight and surveillance radar data, enabled controller-pilot communications, and generated display data to air traffic controllers (FAA, 2016a). ERAM enabled controllers to coordinate traffic beyond the boundaries of the airspace controlled by their center so they could more efficiently transition traffic from one airspace sector to another. ERAM automated traffic conflict alerts and minimum safe altitude warnings. ERAM added capabilities to allow controllers to separate aircraft with variable separation standards. ERAM increased flexibility in routing around congestion, bad weather, and other airspace restrictions.

The TAMR program upgraded multiple terminal ATC technologies into a single platform, the Standard Terminal Automation Replacement System (STARS; FAA, 2016a). Controllers used STARS to provide ATC services to pilots in the airspace immediately surrounding major airports. The target users for STARS were air traffic controllers at towers and TRACON facilities. STARS significantly improved flight plan processing with a four-dimensional trajectory (lateral, vertical, horizontal, and time) of every flight which improved a controller's situational awareness, decision making, and routing of aircraft.

The Terminal Flight Data Manager program implemented the Surface Visualization Tool (SVT) and Advanced Electronic Flight Strips (AEFS). SVT allowed TRACON controllers to spot departure congestion and anticipate changes. AEFS replaced paper flight strips and manual tracking of incoming and outgoing flights with an electronic flight data display (FAA, 2017b). AEFS is updated with a touch screen or mouse and a finger swipe sends the data to another station allowing controllers to stay engaged with traffic at all times.

Collaborative Air Traffic Management delivered Pre-Departure Reroutes and Airborne Rerouting to controllers (FAA, 2017d). Pre-departure reroutes enabled controllers to more quickly execute revised route clearances needed to accommodate changing weather. ERAM added the capability to receive amended reroutes pre-departure and provide controllers with updated flight data so they can monitor and react to non-compliance issues. Airborne Rerouting allowed a traffic manager to propose trajectory modifications to meet flow constraints for an airborne flight to the appropriate sector controller for action. Controllers may amend the intended trajectory for the flight, deliver the route clearance to the cockpit via voice, and the traffic manager may track the amended trajectory when considering further constraint adjustments for the flight.

Time Based Flow Management implemented Extended Metering, Groundbased Interval Management Spacing, and the Integrated Departure/Arrival Capability (FAA, 2016a). Target users were air traffic controllers and pilots. Extended Metering enabled metering to begin further from the airport so controllers can manage aircraft with minor speed adjustments. Groundbased Interval Management Spacing (GIMS) introduced automation support for en route controllers to sequence and schedule en route arrival flows at one or more meter points upstream from terminal arrival meter fixes such that the schedules were deconflicted at all meter points and fixes. GIMS also provided en route controllers with speed advisories to help deliver aircraft to meter points and fixes in accordance with the arrival flow schedule. Integrated Departure/Arrival Capability (IDAC) provided decision support capabilities for departure flows to controllers that automated the process monitoring departure demand and identification of departure slots, and deconflicted departure times between airports with traffic departing to common points in space. IDAC provided situational awareness of available departure times to air traffic control tower personnel so they could select and plan their operations to meet the times. TBFM also implemented Traffic Management Advisor's (TMA) Adjacent Center Metering Capability and the ability to use of RNAV Route Data to calculate trajectories used to conduct Time-Based Metering operations.

### NextGen (2016-2020)

NextGen's mid-term is through 2020. NextGen will continue implementing parts of several key enabling technologies to realize additional operational improvements. Key technologies include data communications, digital voice switching, performance-based navigation, network-enabled information sharing, satellite-based surveillance, integration of weather into decision-making and collaborative air traffic management (FAA, 2015). NextGen will continue to meet human factors challenges throughout these systems' development lifecycle as well as those of integrating new entrants, Unmanned Aircraft Systems and Commercial Space Operations.

### NextGen Transformation (Beyond 2020)

When NextGen was initiated, controllers provided air traffic services tactically based on the location of the aircraft and distance to other aircraft to ensure safe separation. The FAA will transition the NAS to more strategic time-based management. Air traffic will be controlled strategically based on what the location of the aircraft will be at designated times along its projected path, thereby ensuring safe separation.

Trajectory Based Operations (TBO) will enable time-based management. TBO will leverage the technologies and operational improvements made during the mid-term. The target users of TBO will be pilots, controllers, air traffic managers, airlines, and other NAS operators. For strategic planning, users will share four-dimensional information about the aircraft: lateral (latitude and longitude), vertical (altitude), and time. Users will have better knowledge of the estimated departure and the arrival time at waypoints along the route of the flight. Strategic planning will decrease the need for tactical intervention (FAA, 2016c). When it occurs, air and ground automation systems will quickly share clearances provided to the flight deck resulting in a consistent view of the four-dimensional trajectory across the NAS.

NextGen Transformation will face human factors challenges. Time-based management will require more reliance on automation. Seamless integration of automation platforms will be needed as users share information to make safe and efficient use of time-based services. User culture will need to transition from legacy operations: the transition will require procedural changes, training, and methods to achieve user acceptance. There will be new sources for safety hazards such as knowledge of and performance with automation reversionary modes, human automation interaction, and maintaining situational awareness in a system of systems.

## Acknowledgements

I express my gratitude to Drs Paul Krois and Charles Buntin who assisted in critiquing this paper. I based this paper on a variation of related reports on NextGen progress. The views of the paper are my own and do not reflect the views of the Federal Aviation Administration.

## References

Federal Aviation Administration. (2015). *National Airspace System Enterprise Architecture (NAS EA), Mid-Term Overview and Summary Information (AV-1), Version 4.0, January 30, 2015*. NAS-EA-AV-1-Mid-Term-v4.0-013015. Washington, DC.

Federal Aviation Administration. (2016a). NextGen Implementation Plan 2016. Retrieved from https://www.faa.gov/nextgen/media/NextGen_Implementation_Plan-2016.pdf

Federal Aviation Administration. (2016b). NextGen Priorities Joint Implementation Rolling Plan 2017-2019 Executive Report. Retrieved from https://www.faa.gov/nextgen/media/NG_Priorities_Joint_Implementation_Plan.pdf

Federal Aviation Administration. (2016c). The Future of the NAS. Retrieved from https://www.faa.gov/nextgen/media/futureOfTheNAS.pdf

Federal Aviation Administration. (2017a). Acquisition Management Policy. Retrieved from http://fast.faa.gov/docs/acquisitionManagementPolicy/AcquisitionManagementPolicy4.7.pdf

Federal Aviation Administration. (2017b). Delivering NextGen. Retrieved from https://www.faa.gov/nextgen/

Federal Aviation Administration. (2017c). FAA Statement [Press release]. Retrieved from https://www.faa.gov/news/press_releases/news_story.cfm?newsId=21435

Federal Aviation Administration. (2017d). NAS Systems Engineering Portal (SEP) [Data]. Retrieved from https://sep.faa.gov/

Vision 100—Century of Aviation Reauthorization Act, Pub. L. No. 108–176 (2003).