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Aviation Organization Strategy Development in National Airspace Modernization

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Cover Page Footnote
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The Federal Aviation Administration (FAA) has been modernizing the National Airspace System (NAS) by developing instrument flight procedures for use by aircraft equipped with performance-based navigation (PBN) systems since the mid-1990s. The PBN systems typically utilize space-based signals from the Global Navigation Satellite Systems (GNSS) allowing users to fly area navigation (RNAV) routes without input signals from legacy ground-based VORs. The FAA has since collaboratively developed and received budgeting authority to move forward with the VOR MON initiative which seeks to reduce the legacy ground-based navigational infrastructure (FAA, 2021b).

In December 2011 the FAA issued Notice of Proposed Rulemaking (NPRM 76 FR 77939) to the public explaining the Very High Frequency Omnidirectional Range Minimum Operational Network (VOR MON). The FAA's intent was a transformational reduction of National Airspace System NAS legacy ground-based radio NAVAIDs supporting published aircraft enroute and terminal instrument procedures.

The proposal outlined an architectural schema to continue maintenance of ground-based NAVAIDs throughout the conterminous US. This is accomplished by simultaneously reducing the number of VOR NAVAIDs while extending the standard service volumes (coverage) of retained VORs to ensure seamless conventional navigation across the US for users in the event of lost (GNSS) signal ("Provision of Navigations Services," 2016). The overarching purpose of the effort was to continue transitioning the NAS from predominantly ground-based NAVAID (specifically VOR) make-up to PBN. The VORs selected for retention and consequential service volume expansion would form an optimized conventional back-up network. The FAA explains RNAV equipment supporting the PBN NAS as typically receiving navigational sourcing from either Global Positioning System (GPS)/Global Navigation Satellite System (GNSS), Distance Measuring Equipment (DME)s and Inertial Reference Unit (IRU) (FAA, 2015a; Helfrick, 2015).

Technological transitions (TT) are defined as "…as major technological transformations in the way societal functions such as transportation, communication, housing, feeding, are fulfilled" (Geels, 2002, Introduction section). Geels (2002) used punch card technology conversion to small office digital computer transition during the period 1930 - 1960 as an example.

Developing the PBN NAS appears to fit Geels' (2002) definition of TT for aviation navigation. Ground-based navigation was the basis of the NAS from the incipient years of aviation. Prior to the PBN NAS aircraft utilized ground-based navigation signals to fly along airways and approach airports during poor weather conditions. The ground-based VOR technology is considered legacy by today's PBN standards. The routings are limited to locations where ground based VORs are geographically positioned and are not always as direct as PBN point-to-point navigation. The limitations of geographic proximity and number mean they not as routing efficient as PBN. They are still considered reliable to make-up the safety navigation backup for PBN procedures during GNSS outages.

Much is said about how societies progress forward with technology, processes, and socialization of various affairs to modernize the way something is accomplished. Geels (2002) and Roberts and Geels (2019) used the examples of the shipping industry's transition from sailing to steam during the middle 1800s, along with digital technology conversion, railway to roads (United Kingdom [UK]) and mixed farming to wheat [UK]. Steam to electricity in factory production from 1880-1930 is another example whereby modernization of an entire industry support structure occurred (Devine, 1983). Contemporary TT examples include transition from hard wired telephone technology to cell phones and gasoline powered vehicles to electric (Attias & Mira-Bonnardel, 2017; Sovacool et al., 2018). Mohapatra (2013) devoted an entire dialogue on differences between process improvement and radical business process reengineering (BPR) to explain how companies modernize their production and cost management mechanisms. Table 1 presents examples of TT and relative timelines. The PBN NAS is a progression forward in the form of technological transition (TT)s and exemplifies the US modernizing the way air-navigation is accomplished.

Table 1
Examples of Technological Transition (TT)s

Technology Transformation	Mode	Industry	Time span
Sailing to Steam	Shipping	Transportation	1860-1900
Steam to Electricity	Factory Production	Power	1880-1930
Hard wire to cell towers	Phones	Telecommunication	1982-Continuing
Railway to Roads (United Kingdom)	Trains/Automobiles	Transportation	1919-1970
Mixed Farming to Wheat (United Kingdom)	Food	Agriculture	1920-1970
Punch cards to digital computers	Office Technology	Information	1930-1960
Petroleum to Electricity	Vehicles	Transportation	2001-Continuing
Ground-Based to Satellite Navigation	Aircraft	Transportation	1995-Continuing

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There is also academic examination of how-to re-engineer ‘legacy systems’ in numerous research articles. Business theorists refer to mature systems as ‘legacy’ (Brooke & Ramage, 2001; Ramage & Bennett, 1998; Ransom et al., 1998). The defined terminology “legacy systems” are confined to software re-engineering and typically exemplified within the boundaries of business organizations. Brooke and Ramage (2001) stated that “the study of legacy systems has tended to be biased towards a software engineering perspective and to concentrate on technical properties” (p. 365). Therefore, there is research on forward progressing technological transformation in society and re-engineering legacy computer software. The focus of this research article was on how organizations transform large-scale legacy public infrastructure hardware and business processes to re-make a pre-existing infrastructure sustainable as a safety back-up on a national scale.

Inquiry Statement

This study paired up the FAA Flight Program Operations (FPO) organization, with the VOR MON enterprise, as a case, to understand how a small sub-organization located within the FAA institutional framework develops processes to accomplish this large multi-year legacy infrastructure transformation. The FAA FPO directorate has a critical role in the NAS modernization initiative reducing ground-based Navigation Aid (NAVAID) infrastructure while expanding and maintaining commensurate service volumes of retained VORs. The FPO will need to accomplish this while continuing their support maintaining safe expansion of Performance-Based Navigation (PBN) navigation access as the primary means of instrument navigation in the NAS.

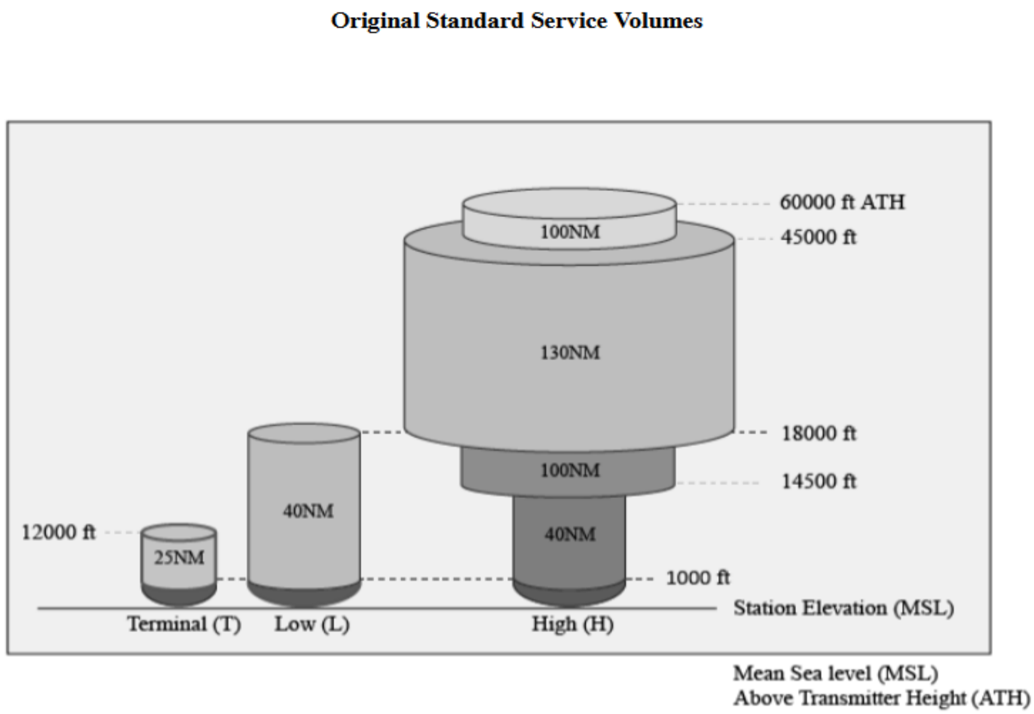
Expanding the signal service volume on the VORs identified for retention will require considerable resourcing. The retained VORs will need verification of signal reception at the expanded distances. The new signal propagation distances are nearly twice as far as the legacy circles and include an area three times the previous service volume. The signal reception throughout the proposed service volume expansion may require periodic re-verification. The VORs identified for decommission will not be simply turned off. The airways and terminal instrument flight procedures (IFP)s supported by the VORs identified for decommissioning will need to be re-developed, verified for flyability, and re-published. Then, the previous supporting VORs can be removed.

For a visual on what this means, refer to the following figures. Figure 1 displays Standard service volume (SSV) on both High “H” and Low “L” altitude designated VOR NAVAIDs. The FAA proposes in the MON to extend service on retained VORs above 5,000ft site elevation to 70 NMs lateral distance displayed in Figure 2 (FAA, 2012, 2017; 2021a). Further the FAA will retain enough ILS or VOR terminal IFPs to ensure NAS users can navigate between “MON” designated airports no more than 100 MN transit distance without using GNSS (FAA, 2012). Certain airports in the NAS are designated as MON airports and retain terminal

IFPs that can be flown solely using a ground-based NAVAID in case of GNSS outage. The consequences of extending the retained VOR's normal service volume are a multi-stage endeavor.

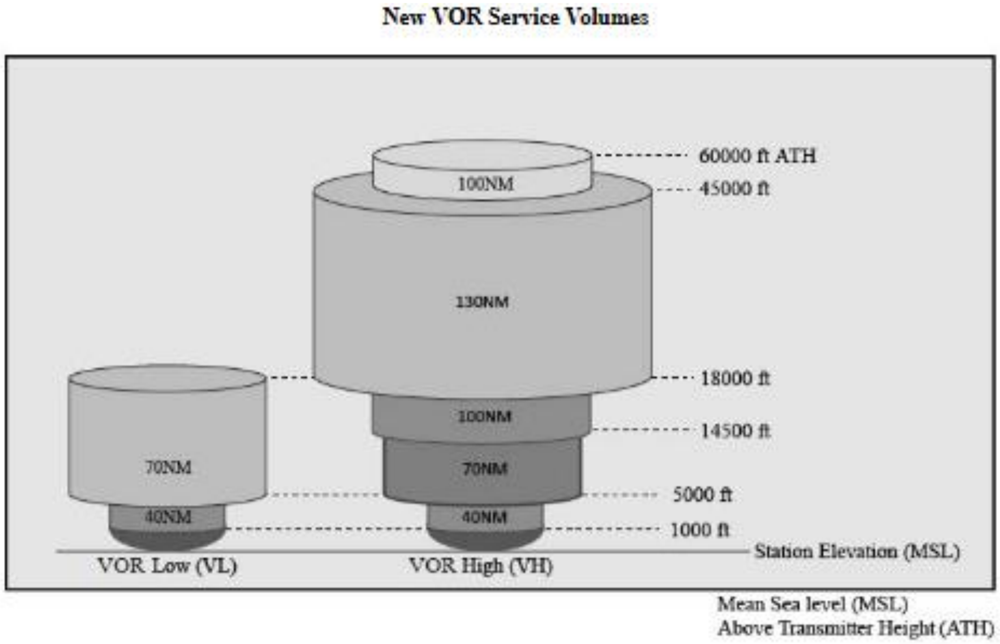
Figure 1

VOR Standard Service Volume Depiction



Note. Adapted from Aeronautical information manual official guide to basic flight information and ATC procedures, FAA, 2021a. In the public domain. (https://www.faa.gov/air_traffic/publications/media/aim_basic_6_17_21.pdf)

Figure 2
New VOR Service Volumes



Note. Adapted from Aeronautical information manual official guide to basic flight information and ATC procedures, FAA, 2021a. In the public domain. (https://www.faa.gov/air_traffic/publications/media/aim_basic_6_17_21.pdf).

A purposeful exploration of VOR MON assessment practice, data retrieval, and presentation provide a case on how small sub-directorates within larger organizations can develop strategies, use information, and implement modernization on legacy infrastructure. The research could be used in framing future legacy navigation modernization initiatives. FPO is a central player within the greater FAA organization to accomplish the effort to convert the legacy ground-based instrument architecture into a safety back-up for the PBN instrument NAS.

The savings realization is commensurate with a system based on more accurate, modern, and sustainable PBN navigation technology. The FAA will retain a robust system of legacy VORs allowing users to continue utilizing the conventional instrument NAS as a safety back-up during periods of (GNSS) outage. Proponents with the FAA expect that removing 311 VORs from the inventory of 896 at the start of the program will result in cost savings equating to $1 billion (FAA, 2018; Proposed provision of navigation services for the next generation air transportation system (nextgen) transition to performance-based navigation (PBN, 2011).

This undertaking is crucial because it helps the FAA fulfill it's four strategic initiatives:

- make aviation safer and smarter
- deliver benefits through technology and infrastructure
- enhance global leadership
- empower and innovate with the FAA's people (FAA, n.d.)

The FAAs flight inspection function has a history that dates to the beginning of airway development when the Post Office Department (POD) had responsibility for the nascent system. The FAA FPO has a long-standing culture of safety assurance. Their responsibilities appear to be on a significant upward trajectory as the FAA seeks to reduce yet improve the transmission and reception capabilities of retained VORs while commensurately implementing and maintaining PBN procedures. The FPO is leveraging emergent technology to manage their responsibilities with respect to signal verification on legacy VORs.

First order of significance is the responsibility of FPO inspecting the remaining 585 retained facilities for service volume extension. The additional lateral circular area between 40 and 70 NMs is 10,367 NM^2 per NAVAID. Second order of significance is the phased re-development of the IFPs within the NAS to remove 300+ VORs from the cartographically depicted terminal procedure flight publications (FAA, 2018). The FAA plans to accomplish this in thru FY 2030. The process will include identification of supported instrument procedures, followed by re-design to accommodate VOR removal from usage, then flight inspection, and finally publication.

The central question examined was how small sub-directorates within the framework of larger organizations can develop strategies, use information, and implement modernization on legacy infrastructure. This study explored processes of transitioning to the VOR MON to better understand legacy infrastructure conversion strategy on a national scale. The case examined the FPO as a small directorate within the larger FAA.

At the outset the FAA began in 2016 with 896 VORs and intent to remove 311 while retaining 585 by 2025 (FAA, 2018). This is significant in that it equates to approximately one-third (34%) of the inventory with proportionate savings on maintenance and infrastructure cost. Commensurate with the reduction is a simultaneous service volume expansion of the retained VORs from 40 NMs to 70 NMs radii (FAA, 2017). This triples the surface footprint of the former service area (40 NM) from 5,026 NM^2 to 15,393 NM^2 (70 NM) per retained VOR. The total surface area for the retained VORs (585) is 9,005,375 NM^2 compared with that of the pre-MON (896) 4,503,787 NM^2. This, essentially, appears to increase the magnitude of VOR service assessment 100% in terms of surface area. Refer to Figures 3 and 4 for a comparative depiction between the pre-MON and post MON coverage volumes. This presumably applies not only to the MON initiative initially

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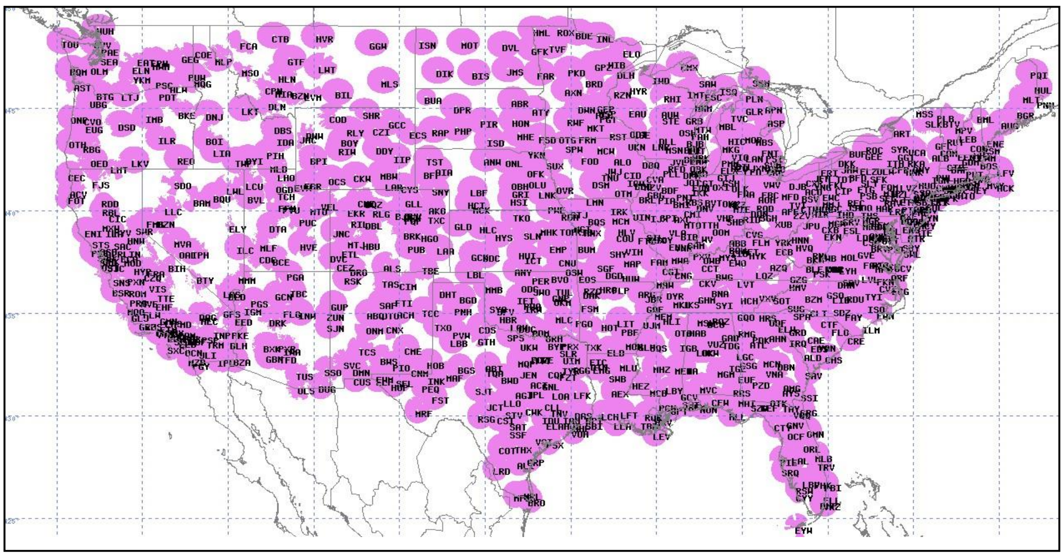
increasing the service area to 70 NMs but also to the continued periodic inspections at the 540/1080-day intervals thereafter (FAA, 2015b).

Figure 3

Prior to VOR MON implementation - More VORs with Commensurate Signal Coverage

Initial 2016 FAA VOR Network

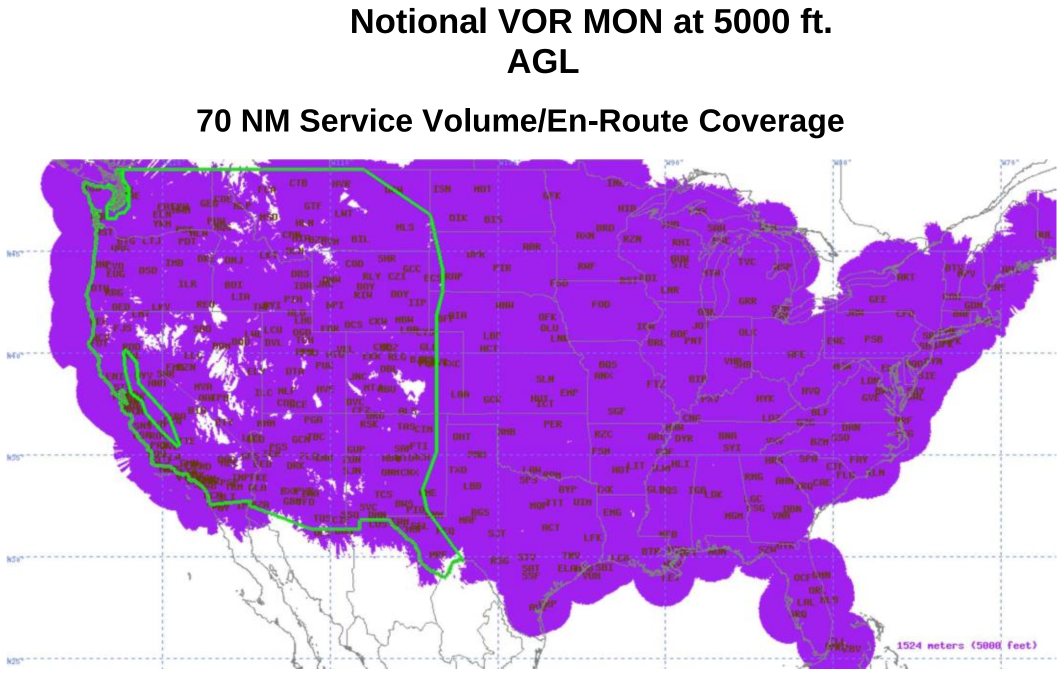
40 NM Service Volume at 5,000' AGL



Note. Adapted from *VOR minimum operational network (MON) implementation*, FAA, 2012. (https://www.faa.gov/air_traffic/flight_info/aeronav/acf/media/Presentations/12-02-Discon_of_VOR_Srvcs_presentation.pdf). In the public domain.

Figure 4

Post VOR MON Showing Retained NAVAIDs with Increased Signal overage



Note. Adapted from *VOR minimum operational network (MON) implementation*, FAA, 2012. (https://www.faa.gov/air_traffic/flight_info/aeronav/acf/media/Presentations/12-02-Discon_of_VOR_Srvcs_presentation.pdf). In the public domain.

Background

In order to further understand the impact of information on strategy development and program execution, I utilized Sanders' (1999) stance on the use of information base to identify challenges and make organizational decisions. Sanders (1999) noted that to understand and solve perceived challenges, organizations should view information as either chaotic or ordered. Specifically, Sanders used the term "interrogation" of the information base to describe how organizational decisionmakers search for constructs to organize chaotic into ordered information (Sanders, 1999, p. 37).

The information base is a collection of "…facts, events, concepts, and behavior…"that decisionmakers use to develop technology, procedures, and processes for accomplishing organizational objectives (Sanders, 1999, p. 47). Sander's refered to the previous four components collectively as data and explains one cannot escape the need to organize it without having a set of working rules to make decisions (1999). Sanders refered to management information systems (MIS) as storage and retrieval mechanisms for information. Specifically, Sanders described MIS as part of the challenge identification process that organizational users utilize to gather important information

Using Sander's discussion of interrogating MIS in mind, then, how does Flight Program Operations (FPO) leverage computer technology and automation to support accomplishment of a large initiative VOR MON? In what ways might they revise or update current computer automation processes to improve efficiency in MON implementation? The research questions examined in this study were:

Research Questions

RQ1: How does FAA Flight Program Operations (FPO) systematically develop an organizational strategy for accomplishing VOR MON service volume expansion and verification in the NAS?

RQ2: How does FPO leverage computer automation to develop a VOR MON "information base" and inform organization decision-makers

RQ3: What new automation might FPO propose to gain efficiencies in balancing their normal instrument procedure validation workload with expanding retained VOR service volumes?

Hypothesis: A small sub-directorate inside the FAA will manage a nation-wide, multi-year initiative with a combination of tribal knowledge, subject matter expertise and business re-engineering practices.

Literature Review

Sanders (1999) indicated that leaders and executives must grapple with information when faced with organizational challenges. It is the information base consisting of "…facts, events, concepts, and behavior…"that decisionmakers use to develop technology, procedures, and processes for accomplishing organizational objectives (Sanders, 1999, p. 47). Organizational decisionmakers use the 'information base' to identify and solve challenges (Sanders, 1999). The information comes in two forms that Sanders identified as either ordered or chaotic (Sanders, 1999). The ordered pertains to information that is already organized according to the standards adopted by the organization (Sanders, 1999). Examples of ordered information include, organizational reports that are routinely accomplished at periodic intervals and in standardized formats (Sanders, 1999).

Sanders (1999) noted that chaotic information is typically disorganized and un-refined. The information may be available in databases. but not stratified in a manner that allows for easy translation into trends or may place undue burden on the user to interpret. Sanders (1999) refered to this as the inability to use the information to easily make connections and use for problem solving analysis. One might presume that without the organization of data pieces, decisionmakers are unable to make accurate decisions to improve the institution.

The current VOR service volumes and navigational signal restrictions are published in the FAA chart supplement and based on a premise of periodic review and maintenance through flight validation (FAA, 2015b, 2019). This information appears to be ordered by Sanders' (1999) definition as it is periodically published for users. Expanding the service volume on nearly 600 VORs requires time and resources to validate areas then process and document appropriate findings, prior to publication. The information needed to support the validation will need to be gathered, processed, and published. This process seemingly fits into Sander's definition of chaotic and not yet fully refined.

Data visualization software and automation design could play a significant role in the FAA FPOs solution on managing the ground-based NAS insfrastructure. FPO is uniquely positioned to likewise implement groundbreaking processes and technology in their remaking of the entire foundational infrastructure for reduced footprint yet improved efficiency. Research is necessary to understand what alternative resources FPO can reasonably leverage to multiply successes that speed delivery of NAS transformation while progressing their legacy of flight integrity and validation of published IFPs.

Example Infrastructure Modernization Cases

Internal Revenue Service (IRS)

Long-standing organizations with histories of process modernization have provided examples of successful technology and process adaptation. In the mid-1990s, the Internal Revenue Service (IRS) transitioned their employee compensation and benefits program to a more streamlined experience serving the organization's 800,000 employees (Khosrow-Pour, 2006). The organization formed a team utilizing three consultants along with three subject matter experts (SME)s from differing lines-of-business. Their team had 12 weeks to "…investigate, innovate, and implement" a transformation process in the employee benefit delivery architecture (Khosrow-Pour, 2006, p. 52).

The previous program of employee benefits consisted of 13 benefit and 6 compensation plans spread out among field offices located throughout the US. Information was spread throughout the government agency using physical information packages during open enrollment periods. The complex structure of organization governance created a significant amount of overlap with considerable differences among enrollment processes. The variation among the segmented programs being combined with the day-to-day operations tempo for the team SMEs in their primary duties made for significant challenges that could have easily jeopardized the programmatic timeline (Khosrow-Pour, 2006).

Fully understanding the multi-faceted dimensions of the current programming by the team members was perceived as not possible in the 12 week delivery time-frame (Khosrow-Pour, 2006). There were also doubtful perceptions as to the goal of their endeavor as the organization had recently orchestrated itself through an employee reduction-in-force (RIF). The challenging environmental conditions coupled with the double-duty job rationing for the 3 SMEs was a headwind for progress on such a complex endeavor (Khosrow-Pour, 2006).

The team persevered through the conditions and multiple iterations of professional differences in opinions. The resulting collaborative re-design of the compensation and benefits included a call center that eventually grew into a central communication hub for inquiries supported by self-help software. Khosrow-Pour (2006) rate this business technology and process re-engineering endeavor a success based on innovative development of a workable small-scale model. The model was adaptable to larger scale over time and became the national call center for IRS employee benefits and compensation. The author notes that the project management team was divided yet eventually coalesced although, there were significant mis-giving between several of the members (2006). There is also little said about how it was received by the gaining workforce. Another success of the call center may well be in its consolidation and reduction of overlapping programs. Therefore, it may have provided an equally good service for customers yet with reduction in overlapping layers of oversite.

The IRS case and the ongoing VOR MON initiative share similar constraints

- Fixed budget (programmed spending environment)
- Complex organizational structure (large government agencies with sub-agencies)
- Employees from multiple lines-of-business called on to develop program

Dissimilarities include:

- Budgets were fixed but VOR MON is recurring over program length in years
- Completion timeline (weeks vs years)
- Infrastructure complexity (Software vs. Hardware/Software)

Geodata

Another technology and business process endeavor was the transformation of three Danish Geodata mapping agencies into one centralized geodetic administration. This re-engineering effort spanned 10-years from 1985 - 1995 (Khosrow-Pour, 2006). The legacy agencies included the National Land Registry, Geodetic Institute, and Nautical Archives. All three institutions had organizational roots dating back more than 100 years each along with correspondingly unique organizational cultures. A common attribute of the three organizations was the technological precision of their product (Khosrow-Pour, 2006). The merged organization evolved into the National Survey and Cadastre.

The goal of the business transformation was not immediate evidentiary savings but reduced expenditure outlay growth over the longer run. Without organizational consolidation the Danish Minister of Agriculture explained that 25% of the country’s future investment outlay to digitize maps would be miss spent on overlapping administrative business functions and parallel map development

(Khosrow-Pour, 2006). One of the significant charter issues of the merger committee was to report on financing the activities of the new agency thru user payments economically to better align the balance between demand and supply of cartographical depictions (2006).

Another theme for the merger was the follow-on ability of the agency to produce a variety of new products by leveraging other national mapping system resources (Khosrow-Pour, 2006). The software enterprise would be named Geodata Information System (GIS) and would support the complete conversion of all geodata from analog to digital. The information would then be shared among not just the three converted agencies but throughout a database sharing system connected to multiple Danish government agencies (Khosrow-Pour, 2006).

The case author concluded that the modernization merger of the three organizations was a success. Compared to the IRS employee compensation and benefits modernization endeavor, the transformation of Danish cartographical organizations into a more centralized entity with re-engineered functions was significantly longer term and had more managerial involvement. Another significant difference was the plan evolution. With the Danish merger case, it was very difficult to foresee that processes could not be regimentally developed and adhered to but rather needed to evolve while retaining the final goal in the cross hairs (Khosrow-Pour, 2006).Researchers Khosrow-Pour (2006) say that projects of this magnitude are difficult to plan because they are "…highly complex activities often on the edge of what humans can comprehend" (Khosrow-Pour, 2006, p. 333).

Similarities between the transformation of the Danish Geodata Sector and the VOR MON include:

- Timeline (years)
- Upper Management Involvement
- Intent (optimization of pre-existing infrastructure)

Dissimilarities between the Danish-Geodata Sector and the VOR MON include:

- Purpose (new products vs. similar products)
- Systems (new vs. legacy)

The previous cases do not fully adhere to the legacy process re-engineering guidelines described by Jacobson et al. (1995). The Object Oriented model of process re-engineering is very structured and mandates standardization with pre-application diagraming of objects linked by inputs, associations, and outputs (1995). Jacobson et al. (1995) admited early on in their process guide for mapping objects that, for re-engineering processes and automation, well over 50% of organizations will fail in their modernization endeavors. The researchers are persistent that the success rate can be significantly improved by strict adherence to concrete planning mechanisms.

A research snapshot of a small directorate organizing to transform legacy infrastructure into a more optimized, back-up navigation network on a national level can provide value in understanding how organizations manage long-term legacy infrastructure transformation and achieve successful outcomes. FPO is part of an integrated effort to complete the implementation of the VOR MON by 2030. The FAA conceived the initiative in 2011 and intends to complete the conventional (ground-based) NAS re-design in 19 years. The FAA FPO is a sub-organization consequentially affected long-term and had decisions to make with reference to their own hardware, software, and processes compared to the larger VOR MON. That is to either re-engineer or replace.

Methodology Overview

Individual qualitative interviews in a case study format were use to gain an in-depth understanding of the practical context pertainining to large-scale infrastructure re-engineering within the FPO. The VOR MON initiative is a bounded system and offers an information rich opportunity to reveal practical examples of strategy development and information ordering. Case studies are hinged on a real life system that can offer practical example(s) within a contemporary context (Creswell, 2013). The case was the VOR MON and the context was Flight Program Operations.

Semi-structured interviews, FAA public documents, emergent interview opportunities, and member checking were utilized as a way to gain a deeper understanding of how the FPO utilized the information base to develop policy and strategy to accomplish the VOR MON initiative. The opportunity to qualitatively interview participants from other FAA directorates beyond the the FPO was an emergent prossess (Creswell, 2012, p. 130). Creswell (2012) and Patton (2015) describe the emergent process as following the direction set by the study candidates. In this case, the FPO candidates advised contacting several people from other FAA directorates that were conversant in the FPO role accomplishing the VOR MON initiative.

Findings

The emergent themes were organized from the data gathered with the14 study participants (SP)s and 700 minutes of transcribed discussion. There were 6 emergent themes and 14 sub-themes. A depiction of the emergent themes and sub-themes appears in Table 2.

Table 2
Themes and Findings

Findings	Emergent Themes	Sub-Themes
Strategic	FPO Organization	Pre-consolidation Post-consolidation (2018)
	FPO VOR MON Strategy	Work Priorities VOR MON Program Leadership Phasing
Operational	VOR MON DATA Strategy	FPO DATA Collection Mechanisms DATA Policy External Directorate Support
	VOR MON Process Strategy	Aircraft Equipment
Tactical	VOR MON Automation Strategy	FIAPA FIAPA Lite

Strategy Development for Legacy System Modernization-Hypothesis

The following hypothesis was analyzed for conclusions on how the FPO sub-organization within the larger FAA organization developed strategy to execute legacy infrastructure modernization program for the VOR MON initiative.

> -A small sub-directorate inside the FAA will manage a nation-wide, multi-year initiative with a combination of tribal knowledge, subject matter expertise and business re-engineering practices

Tribal Knowledge

Tribal knowledge is "any unwritten information that is not commonly known by others within a company. This term is used most when referencing information that may need to be known by others to produce quality product or service" (Henderson, 2010, p. 12). For the purposes of this analysis unwritten information is assumed to be FPO's strategy development with respect to the VOR MON programming initiative. FPO has pre-existing regulatory guidance (Federal Aviation Administration Order 8200.1D) that explains all aspects flight inspection procedures (FAA, 2015b). The last revision of the manual was released on 11-06-2016. The regulation explains every aspect of a VOR inspection but does not specifically mention the service volume expansion effort with respect to new distance coverage within the MON program.

The existence of regulatory guidance to assess VORs on a periodic basis was not necessarily indicative of how to permanently expand low altitude service volume out to 70 NMs for the VOR MON initiative. The policy and technology for accomplishing the safe expansion of new published service volume had to evolve from the expertise within the FPO on what could constitute a final determination of safe service volume limits. Study participant(s) (SP)s referred to this process as a completely new coverage orbit and advised the FPO had to develop a process that was different than typical periodic alignment orbits. The FPO's inherent knowledge on how the VOR MON expansion process could be designed was an implicit example of tribal knowledge in action.

Subject Matter Expertise

Subject matter expertise is an understanding of task criticality when accomplishing a process (Lievens et al., 2004). For the purposes of this analysis, this definition implies that the subject matter expertise is utilized to craft policy and procedures with respect to a program requiring formal guidance. In the FPO's VOR MON expansion case, it meant that the tribal knowledge had to evolve into formal policy and technological support based on understanding the critical tasks necessary to accomplish the expansion. The FAA could then demonstrate that signals would be safe at 70 NMs supporting users in case of regional GNSS outage.

Business Process Re-engineering Cycle

The four steps of a business process re-engineering cycle identified by Mohapatra (2013):

- Identify processes
- Review, update, analyze what is
- Design To-be
- Test & Implement To-Be

This framework was used for analysis of the FPO's process re-engineering practice with respect to the VOR MON initiative. It implies that the FPO had processes to conduct periodic alignment orbits on VORs but they would need to transition into an efficient process to fly completely new coverage orbits at 70 NMs. Five of fourteen SPs indicated that the focus on modern PBN procedure flight inspections means that all VORs in the NAS have been maintained thru the periodic alignment orbit inspection process. Coverage orbits to validate service volume distance are only required in the case of major equipment replacement which is not often. One of the reasons the major equipment replacement is not often replaced is because these navaids were built with significant safety resiliency 70 years ago (SP9). Therefore, the process to maintain had to evolve into an executable process to expand.

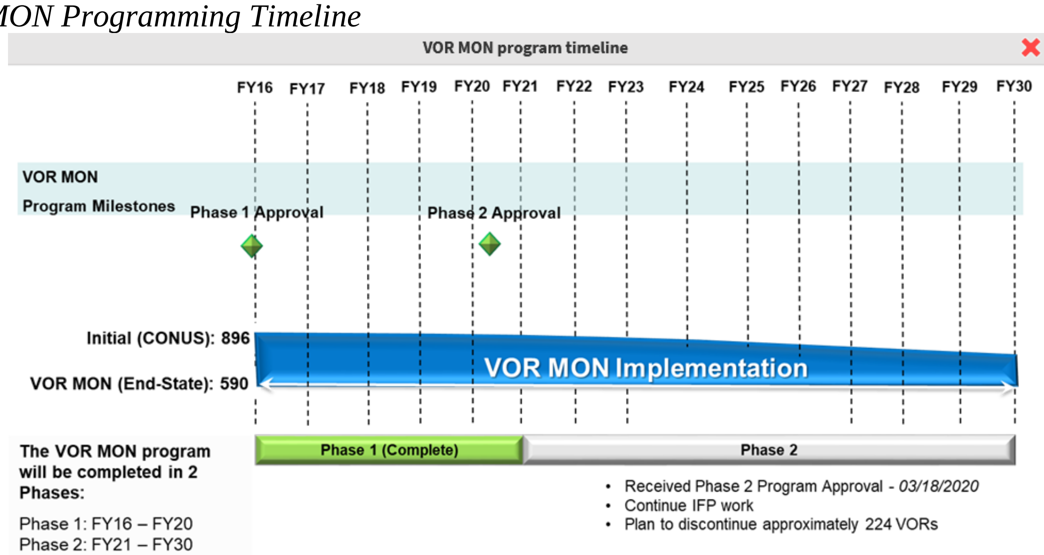
Application to FPO

SP9 indicated that at the very inception of the VOR MON program in 2010 the VOR MON program office engineers flew with flight inspection to determine the usable range of candidate VORs. This testing phase to determine feasibility at various distances cemented the flight inspection directorate as the tribal knowledge experts within the FAA on matters pertaining to measurement of VOR signal health for safe aircraft navigation. Ultimately, the initial modeling conducted by the VOR MON program office had to have practical evidence to support the retained VOR service volume expansion to the new radius distance.

Once the usable VOR service volume was confirmed at 70 NM, flight inspection has been the final authority in the signal assessment and confirmation of every VOR planned for retention. SP8 and SP9 confirmed that flight inspection discretionary capacity to verify VOR expanded service volume and published IFP amendments to remove decommissioning VORs was a primary determinant in the development of the VOR MON program timeline presented in Figure 5. FPO assumed responsibility for expanding every retained VOR in the NAS. The FPO personnel assigned to the VOR MON expansion effort had to understand the task criticality of components that supported each VOR's eventual publication for use to 70 NMs. The FPO had developed the subject matter expertise (criticality of tasks) to expand each VOR to 70 NM during the initial testing phase for application in execution Phase 1 (Figure 5).

Figure 5

VOR MON Programming Timeline



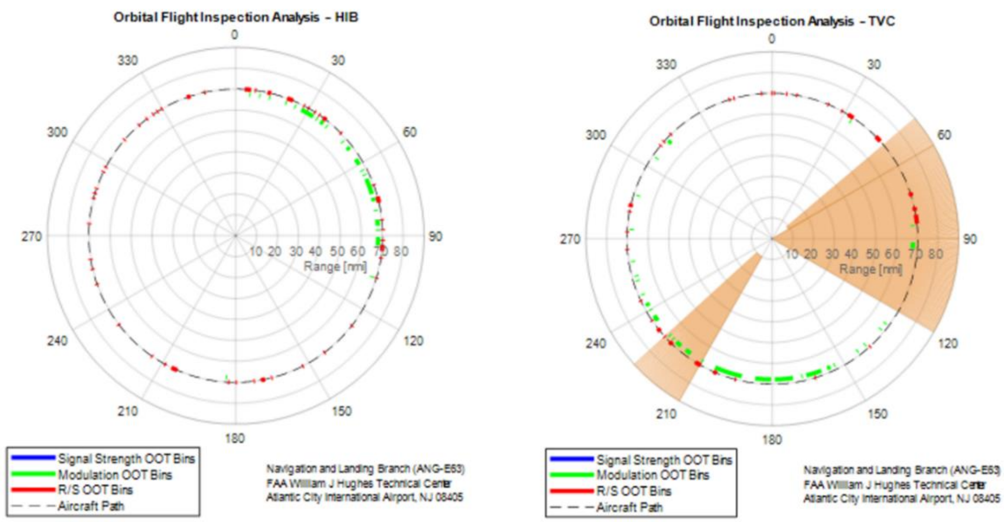
Note. Adapted from *Navigation Programs - Very High Frequency Omnidirectional Range Minimum Operational Network (VOR MON)*, FAA, 2021c. In the public domain. (https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/transition_programs/vormon/)

The FPO has comprehensively re-engineered their processes tactically, operationally, and strategically to support the VOR MON programming since 2017. The tactical components consisted of automation evolution from Flight Inspection Airborne Processor Application (FIAPA) to FIAPA Lite. The process evolution was automation re-design from all ground-based navigation assessment to tactically process VOR signal assessment only using revised hardware and software (FIAPA Lite).

Operational process re-engineering components included the FPO evolving their sub-directorate data collection policy and mechanisms to ensure more efficient and focused 70 NM signal confirmation. They improved their discretionary resourcing by retrofitting recently acquired C90 aircraft and re-developing their data collection process for signal strength with acceptance of broader VOR quadrant restrictions. It was not necessary to completely refine the restrictions as was typically the case when processing legacy periodic alignment orbits at 6-10 NMs. The FPO and VOR MON program office developed a resourceful plan to leverage the 'system' by utilizing other nearby VORs to fill in the GNSS back-up coverage. They collaborated with the FAA Navigation and Landing Branch to develop VOR performance visualizations (Figure 6) thus informing VOR MON program leaders using the information base (Sanders, 1999) The VOR MON program leaders are able to use this information to manage signal gaps and build forward to the back-up navigation coverage picture depicted in Figure 4. The resource intensive probing process evolved into a more focused effort to assess the expanded VORs as a 'system' rather than ensuring un-necessary signal perfection of each particular NAVAID. Strategic FPO updates supported the operational and tactical process modernization efforts. Four of fourteen SPs discussed the sub-directorate re-alignment to the Air Traffic Organization, fleet modernization, work prioritization, leadership, and program phasing as being aspects that facilitated changes at the operational level. Examples of this were the resource efficiencies intended to produce more discretionary capacity within the work prioritization along with acquisition of C90 aircraft for VOR MON orbital assessments.

Figure 6

Example of Orbital FAA Flight Inspection Analysis at 70 NMs on two VORs (HIBBING [HIB] and TRAVERSE CITY [TVC])



Note. *Visual depicts signal strength and presumed out of tolerance (OOT) radials. (R/S - Roughness and Scalloping). Adapted from VOR Polar plots, FAA, 2021b. VOR MON Program AJM-324, Navigation Programs, Federal Aviation Administration, 800 Independence Avenue SW., Washington, DC 20591: FAA. Adapted with permission.*

The strategic updates were not entirely under the control of the VOR MON expert SPs within the FPO organization. Two of fourteen SPs noted that there were decisions reserved for upper management. SP1 and SP13 provided advisory on the strategic issues however, they were certain that the VOR MON program was not the single catalyst for each of the themes. This is an indication that upper management was focused on forthcoming work for FPO above and beyond the VOR MON.

Therefore, the process to periodically review VORs at 6 - 10 NMs using alignment orbits evolved. The new process was to expand the VOR coverage safely to 70 NMs. This evolutionary cycle was completely dependent on FPO tribal knowledge at its inception. The FAA VOR MON office connected with FPO on what was going to constitute safe signaling for the VOR MON. The process to fly the MON orbits was not explicitly stated in any of the regulatory guidance. SP1 advised that the policy and technology branches within the FPO connected on the issue to develop and document Temporary Flight Inspection Guidance (TFIG)s that contained the accepted process for expanding the VORs. The TFIGs are indicative of FPO VOR MON subject matter expertise to develop policy based on critical tasks.

This was a complete evolution of the process. They identified the process to conduct periodic alignment of VOR facilities as it was explicitly documented in FAAO 8200.1D. At the incipient phases of the VOR MON program there was no formal process to expand retained VOR signal coverage to 70 NMs. The FPO utilized their tribal knowledge of VOR inspection to determine the critical tasks and identify a “to-be” process (Mohapatra, 2013). The FPO developed a TFIG that explained the process. The FPO tested the process in 2013 and implemented in 2016 to accomplish Phase 1 (Figure 13).

Hypothesis Conclusion

The FPO organization demonstrated that their tribal knowledge evolved into formal business policy based on subject matter expertise; thus, validating the research hypothesis - all three components of the hypothesis were utilized synergistically to solve the VOR MON challenges - this evolution is a good example of the “whole (VOR MON program) exceeding the sum of its parts (tribal knowledge, SMEs, and business re-engineering practices)”.

The evolved, formal policy was codified so that the process to periodically inspect VORs could be re-engineered into a process to expand the signaling to 70 NMs. The impact of the VOR MON program has cemented the FPO sub-directorate’s role as tribal knowledge experts in VOR signal verification, allowed them to evolve their subject matter expertise of that verification, and precipitated strategic, operational, and tactical process changes throughout the sub-directorate.

This case indicates that the FPO, a small sub-directorate within a large organization (FAA) developed strategy to execute legacy infrastructure modernization by leveraging tribal knowledge first to determine critical tasks. They used their subject matter expertise to develop critical tasks then formulate policy and re-engineer existing processes into new ones. The FAA FPO is effectively re-engineered and re-purposed a large legacy VOR system to safely support TT as a safety back-up.

It is reasonable to use VOR MON as a template for future legacy infrastructure endeavors. There are multiple, large, legacy system re-engineering endeavors on the horizon. The presumed conversion of our national road system to support automated vehicles is a future case where geographically expansive architecture will be modernized. It is understood that the road and highway architecture will need to be modernized to support automated vehicles. That transition will likely require legacy road re-engineering to support transition to traditional safety back-ups during localized automated system outages allowing traffic flow in a safe and efficient manner.

Another Department of Transportation Agency (Federal Highway Administration) will likely be at the center of that effort along with a similar group of user interests that include the private sector. They will collaboratively move forward with initiatives for safely managing the transition in a similar manner as the FAA and user groups demonstrate with the VOR MON. And there will be future opportunities for sub-directorates within large organizations to apply tribal, knowledge, subject matter expertise, and accepted business process re-engineering steps that facilitate large legacy infrastructure modernization.

Summary

Tribal knowledge, subject matter expertise and business re-engineering steps were visible in the FPO's strategy development to accomplish the VOR MON. The findings from this inquiry could can be used to assist other organizations that will need to re-develop legacy infrastructure as safety support mechanisms for future technological transitions (TT)s.

Specifically, small directorates within a largergovernment organization embarking on a legacy infrastructure modernization program should consider:

1. Building related and clear strategic, operational, and tactical components
2. Computer automation must be value added, or do not employ
3. Care and management of resources (funding, personnel, and equipment) is critical to successful, on-time outcomes

Small sub-directorates within larger organizations are connected to executive level decision-makers that manage the overarching operation thru funding and resource allocation (strategic). These interactions produce the framework to develop and populate operational and tactical strategies. Smaller organizations can leverage benefit by connecting to similar size sub-directorates using operational strategies that capitalize on shared information and assets. Tactical strategy formulation is connected to job accomplishment. In the case of this inquiry, the job was the VOR MON initiative and how the FPO VOR MON aircrews tactically employed technology and policy to finalize results from recorded signal information. Automation can be a force multiplier but should be employed where development and usage are feasible to fund and technologically practical. Automation and visualization were operationally leveraged between the larger organization sub-directorates. Finally, small sub-organization can manage resources for legacy infrastructure modernization initiatives by connecting tribal knowledge to subject matter expertise and re-engineering processes.

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