IMPLEMENTATION OF PERFORMANCE BASED NAVIGATION APPROACHES IN REPUBLIC OF NORTH MACEDONIA

Dr. Sc. Aleksandar Glavinov, email: aglavinov@yahoo.com
aleksandar.glavinov@ugd.edu.mk
Military Academy ″General Mihailo Apostolski″ – Skopje, University ″Goce Delechev″ – Shtip, Republic of North Macedonia
Dr. Sc. Ferdinand Odzakov, email: odzakov@gmail.com
Ministry of Defence to Republic of North Macedonia, Department of Human resources
Nikola Ivanovski, email: z3dcf@yahoo.com
Faculty of Natural and Technical Sciences, University ″Goce Delechev″ – Shtip, Republic of North Macedonia

Abstract: The continued growth of traffic and the need to provide greater flight efficiency makes it necessary to optimize available airspace. Performance Based Navigation (PBN) Concept was introduced through publication of the ICAO PBN Manual (Doc 9613) in 2008 and the implementation goals were defined by Regulation (EU) 2018/1048 laying down airspace usage requirements and operating procedures concerning PBN. PBN concept allows definition of both lateral and vertical navigation in a manner that is no longer constrained by the geometry of ground-based radio navigation aids such as VOR/DME/NDB. The geographical scope of the PBN Implementation Plan of the Republic of North Macedonia is Skopje FIR, introducing PBN approaches for both airports in Skopje and Ohrid. As seen by the SWOT analyze, the implementation will have significant benefits as: fuel savings, increased safety, time savings and predictability of defined routes flow and simplified ground NAV infrastructure, with almost no weak points. Therefore, can be concluded that PBN implementation in Republic of North Macedonia will have huge positive benefits, despite the short timeframe and initial cost regarding the training, equipment and prescribed procedures for the operational use, with a huge positive impact on the environment by reducing noise and CO2 emissions.
Key words: airspace management, traffic flow, navigation, precision approach, benefits

ИМПЛЕМЕНТАЦИЈА НАВИГАЦИСКИХ ПРИСТУПА НА ОСНОВУ ПЕРФОМАНСА У РЕПУБЛИЦИ СЕВЕРНЕ МАКЕДОНИЈЕ

Сажетак: Континуирани раст саобраћаја и потреба да се обезбеди већа ефикасност лета захтева да се оптимизује расположиви ваздушни простор. Концепт навигације заснована на перформансама (PBN) уведен је 2008. године објављивањем приручника ICAO PBN (Doc 9613), а циљеви имплементације су дефинисани Уредбом (ЕУ) 2018/1048 којом се прописују захтјеви за кориштење ваздушног простора и оперативни поступци у вези са PBN. Концепт PBN дозвољава дефинирање и просторне и вертикалне навигације на начин који више није ограничен геометријом земаљских навигацијских помагала као што су VOR / DME / NDB. Географски обухват плана за имплементацију PBN Републике Северне Македоније је Скопје FIR, увођењем PBN прилаза за оба аеродрома у Скопљу и Охриду. Као што се види из SWOT анализе, имплементација ће имати значајне предности као што су: уштеда горива, већа сигурност, уштеда времена и предвидљивост протока дефинисаних рута и поједностављена инфраструктура земаљске навигиских уреда, са скоро никаквим слабим тачкама. Стога се може закључити да ће имплементација PBN-а у Републици Северној Македонији имати велике позитивне

користи, упркос кратком временском оквиру и почетним трошковима везаним за обуку, опрему и прописане процедуре за оперативну употребу, са огромним позитивним утицајем на животну средину смањењем буке. и емисије CO2.
Кључне ријечи: управљање зрачним простором, проток саобраћаја, навигација, прецизан прилаз, бенефите

1. Introduction into PBN

Performance-based Navigation (PBN), in simple terms, redefines the aircraft's required navigation capability from sensor (equipment) based to performance based. The foundation for Performance Based Navigation is area navigation or RNAV.

With the advent of area navigation, there was a requirement to define and standardize the capability. This has resulted in a menu of performance-based navigation specifications. For each specification, there is a lateral containment value that the aircraft must be able to remain within, in order to be approved for that operation.

The advantage of this approach is that it provides a clear, standardized operational approval which enables harmonized and predictable flight paths which result in more efficient use of existing aircraft capabilities, as well as improved safety, greater airspace capacity, better fuel efficiency, and resolution of environmental issues.

The PBN concept specifies aircraft RNAV system performance requirements in terms of accuracy, integrity, availability, continuity and functionality needed for the proposed operations in the context of a particular Airspace Concept.

PBN offers significant advantages over the current sensor specific method (which uses ground based navigation aids), to develop airspace, ATS routes, instrument flight procedures, and obstacle clearance criteria.

1.1. Abbreviations

APV	Approach procedure with vertical guidance
ATM	Air traffic management
ATS	Air traffic service(s)
DME	Distance measuring equipment
DTED	Digital terrain elevation data
EASA	European Aviation Safety Agency
EUROCONTROL	European Organization for the Safety of Air Navigation
FIR	Flight Information Region
GBAS	Ground-based augmentation system
GNSS	Global navigation satellite system

GPS	Global positioning system
IAP	Instrument approach procedure
LNAV	Lateral navigation
LPV	Localizer performance with vertical navigation
NAVAID	Navigation aid
NPA	Non precision approach
PBN	Performance-based navigation
RNAV	Area navigation
RNP	Required navigation performance
SBAS	Satellite-based augmentation system
SID	Standard instrument departure
SSR	Secondary surveillance radar
STAR	Standard instrument arrival
VNAV	Vertical navigation

1.2. Definitions

Approach procedure with vertical guidance (APV). An instrument procedure which utilizes lateral and vertical guidance but does not meet the requirements established for precision approach and landing operations.

Area navigation (RNAV). A method of navigation which permits aircraft operation on any desired flight path within the coverage of ground or space-based navigation aids or within the limits of the capability of self-contained aids, or a combination of these.

Note: Area navigation includes Performance-based Navigation as well as other RNAV operations that do not meet the definition of performance-based navigation.

Navigation aid (NAVAID) infrastructure. NAVAID infrastructure refers to space-based and or ground-based NAVAIDs available to meet the requirements in the navigation specification.

Navigation specification. A set of aircraft and aircrew requirements needed to support Performance-based Navigation operations within a defined airspace.

There are two kinds of navigation specification:

- RNAV specification. A navigation specification based on area navigation that does not include the requirement for on-board performance monitoring and alerting, designated by the prefix RNAV, e.g. RNAV 5, RNAV 1.
- RNP specification. A navigation specification based on area navigation that includes the requirement for on-board performance monitoring and alerting, designated by the prefix RNP, e.g. RNP 4, RNP APCH.

Note: The Performance-based Navigation Manual (Doc 9613), Volume II, contains detailed guidance on navigation specifications.

Performance-based navigation. Area navigation based on performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in a designated airspace.

Note: Performance requirements are expressed in navigation specifications in terms of accuracy, integrity, continuity and functionality needed for the proposed operation in the context of a particular airspace concept. Availability of GNSS SIS or some other NAVAID infrastructure is considered within the airspace concept in order to enable the navigation application.

Standard instrument arrival (STAR). A designated instrument flight rule (IFR) arrival route linking a significant point, normally on an ATS route, with a point from which a published instrument approach procedure can be commenced.

Standard instrument departure (SID). A designated instrument flight rule (IFR) departure route linking the aerodrome or a specified runway of the aerodrome with a specified significant point, normally on a designated ATS route, at which the en-route phase of a flight commences.

2. PBN implementation in Republic of North Macedonia

The geographical scope of the PBN Implementation Plan of the Republic of North Macedonia is Skopje FIR. The NAVAID infrastructure refers to ground- or space-based NAVAIDs.

Ground-based NAVAIDs include DME and VOR. Requirements for NAVAIDs for defined navigation specification that are formulated by ICAO Navigation Specifications in the PBN Manual. Currently Republic of North Macedonia has not sufficient DME coverage in order to apply DME/DME applications.

Space-based NAVAIDs include GNSS elements as defined in Annex 10 - Aeronautical Telecommunications.

According to EGNOS Service Provider Monthly Performance Report for November 2016 Republic of North Macedonia is within the area which is considered compliant to Safety-of-Life (SOL) requirements on availability, continuity and accuracy for NPA, APV-I and LPV-200 applications.

The following tables represent the current Navigation specification status in the Republic of North Macedonia in en-route, terminal and final approach areas:

Table 1. Enroute

Airspace	Navigation Specification
EN-	RNAV-5

Table 2. Terminal

Airspace	Navigation Specification
SKOPJE	CONVENTIONAL (VOR/DME)

Table 3. Final approach

Airspace	Navigation Specification
LWSK	IAP (ILS)
LWSK	NPA
LWOH	IAP (ILS)
LWOH	NPA

2.1. Constrains and required navigational infrastructure

A number of constrains (challenges) exist associated with the introduction of PBN, most notably in the fields of:

- **Pilot training**. Globally, pilots do not have the same knowledge and skill level with regard to PBN. Since no worldwide standardization exists on this, the scope, length and methods of training, as well as trainer knowledge and skills, may vary considerably.
- **Navigational infrastructure**. There is currently sufficient navigation infrastructure for en route flights above FL 195 which is represented by the Eurocontrol study, however on the other side for TMA area there in currently no sufficient DME coverage for DME/DME applications. In order to fulfil requirement for adequate DME/DME application there is need to define additional DME that could provide coverage in Skopje TMA, or possible re-allocation of existing facilities or commissioning of additional DME(s) may be required.
- **Aircraft systems**. Aircraft automation is becoming more precise and more complex resulting in divergent user platforms based on the operator's avionics and aircraft manufacturer requirements. The systems should preferably made upgradable, have common "look and feel" characteristics with common procedures between applications and aircraft, and be intuitive for the pilot to readily interpret the information displayed.
- **Names, definitions and charts**. As with any new technology there are many definitions, names and criteria and these are still evolving. This may create confusion among pilots, airlines and regulators.
- **Global harmonization and implementation**. The lack of standard ICAO SARPs leads to different implementation approaches in different countries. For example, SESAR and NextGen (USA programme) have provided regional implementations of PBN but these are not globally harmonized. There is also a lack of harmonized state implementation of PBN phraseologies.

2.2. Training and aircraft equipment requirements

The introduction of PBN can involve considerable investment in terms of training, education and awareness material for both flight crew and controllers. A PBN workshops should be organized in order to enable all stakeholders to come together and discuss their particular vision of PBN and its implementation in Republic of North Macedonia.

Except from publishing all relevant PBN information in the Republic of North Macedonia AIP, Aeronautical Information Circular should also be issued with description of the application of PBN in the Republic of North Macedonia Airspace. AIC should outline the timeframe within which navigation capabilities are likely to be available such that; airspace planning should

utilize these capabilities and, airline operators should expect a requirement for them to be equipped and certificated to operate to defined navigation performance standards.

Air traffic controllers providing control services in airspace where there will be new navigation specifications have to be trained based on the new needs and requirements. Initial and recurring training represent a critical step in ensuring that new knowledge is incorporated, and that existing knowledge is current and retained. Air traffic controllers should be trained on simulator in order to reinforce routine PBN, mixed-mode operations, and contingencies including runway changes, NAVAID/GNSS failure or interference, and emergencies.

PBN concept is applied in most of Europe and aircraft crew are usually trained, however there could be increased need for PBN approvals. The following provisions for pilot licensing are introduced with Regulation (EU) 2016/539:

- Applicable from 25 August 2018, pilots may only fly in accordance with PBN procedures after they have been granted PBN endorsement to their instrument rating (IR).
- Until 25 August 2020, IR pilots without PBN privileges may only fly on routes and approaches that do not require PBN privileges and no PBN items shall be required for the renewal of their IR.
- After 25 August 2020, PBN privileges shall be required for every IR.

A PBN endorsement is granted after:

- the pilot has successfully completed a course of theoretical knowledge including PBN.
- the pilot has successfully completed flying training including PBN.
- the pilot has successfully completed either a skill test or a proficiency check.

PBN Operators equipage analysis was performed by using EUROCONTROL CNS Dashboard. The CNS dashboard analyses declared capabilities of flights and aircraft flying in Europe.

It does so by:

- analyzing CNS and PBN information in the ICAO Flight Plans available to the Network Manager (in Item 10 and 18 according ICAO FPL 2012), and
- correlating this with data in PRISME Fleet 2 (EUROCONTROL Worldwide fleet aircraft database) where relevant.

The statistics for the flights/aircrafts equipage for the traffic arriving at Skopje (LWSK) and Ohrid Airport (LWOH) are as follows:

- Total number of arriving flights at Skopje airport between the analyzed periods of 2016 and 2018 was 12 658. Most of the aircrafts arriving at LWSK Airport have been equipped with the following navigation specifications: RNAV 1 all permitted sensors, RNAV 5 all permitted sensors and RNP APCH with BARO-VNAV (with more than 70% of equipage). The most significant increase in the aircraft navigation specification equipage, when comparing the 2018 vs. 2016 analyzed period, have the following navigation specifications: RNP APCH with BARO-VNAV increase of almost 44%.
- Total number of arriving flights at Ohrid airport between the analyzed periods of 2016 and 2018 was 1 184. Most of the aircrafts arriving at LWOH Airport have been equipped

with the following navigation specifications: RNAV 1 all permitted sensors, RNAV 10 (RNP 10) and RNAV 5 all permitted sensors (with more than 70% of equipage). The most significant increase in the aircraft navigation specification equipage, when comparing the 2018 vs. 2016 analyzed period, have the following navigation specifications: RNP APCH with BARO-VNAV increase of almost 42%.

An aircraft equipage assessment has been made and it has to be noted that all major commercial aircraft manufacturers since the 1980's have included RNAV capabilities and also the commercial aircraft currently produced incorporate an RNP capability, almost 80-90 % of the new IFR fleet strength are RNAV and RNP capable.

3. Implementation process of the PBN approaches in Republic of North Macedonia

The implementation of the PBN concept in Republic of North Macedonia is a key enabler for increasing capacity, improving efficiency, reducing environmental impact, and improving access to airports. Implementation roadmap is used for defining the general goals in the implementation of PBN in en route, terminal areas and in approach.

PBN IR is requiring from ATM/ANS Provider to develop transition plan in order to be consistent with the European ATM Master Plan and the common projects and consulted with relevant stakeholders (aerodrome operators, airspace users, Network Manager, adjacent ATM/ANS Providers) and it shall be submitted to competent authority for verification of compliance with PBN IR requirements.

The PBN implementation process should be done completely in accordance with the PBN Manual.

The PBN Manual (ICAO Doc 9613) comprises of two Volumes.

Volume I of the PBN Manual is made up of two parts:

1. Part A describes the PBN Concept, The Airspace Concept and how the PBN Concept is used in practice.
2. Part B provides Implementation Guidance for ANSPs in the form of three processes.

Volume II of the PBN Manual is also made up of three parts. Part A describes on-board performance monitoring and alerting and Safety Assessments, whilst Parts B and C contain ICAO's RNAV and RNP specifications which are to be used by States as a basis for certification and operational approval.

3.1. Provisional dates for phases of implementation

In the tables below you are able to see the provisional dates of the PBN implementation plan for each phase of the complete process set by CAA. The whole process should be completed by 5 June 2030 latest, with the first phase of the plan accomplished by 03 December 2020. The implementation plan will affect en route, terminal area and the final approach for both the airports in Skopje and Ohrid.

Table 4. Enroute airspace implementation plan

NAVIGATION SPECIFICATION			
AIRSPACE	Short term plan (by 03 Dec 2020)	Medium term plan (by 25 Jun 2024)	Long term plan (by 6 June 2030)
EN-ROUTE	RNAV	RNAV	RNAV
NAVIGATION INFRASTRUCTURE			
AIRSPACE	Short term plan (by 03 Dec 2020)	Medium term plan (by 25 Jun 2024)	Long term plan (by 6 June 2030)
EN-ROUTE	Main: GNSS Back up: VOR/DME, DME/DME, ATC	Main: GNSS Back up: VOR/DME, DME/DME, ATC	Main: GNSS Back up: VOR/DME, DME/DME, ATC

Table 5. Skopje Terminal Area implementation plan

NAVIGATION SPECIFICATION			
TERMINAL AREA	Short term plan (by 03 Dec 2020)	Medium term plan (by 25 Jun 2024)	Long term plan (by 6 June 2030)
Skopje TMA	RNAV	RNAV	RNP 1
NAVIGATION INFRASTRUCTURE			
TERMINAL AREA	Short term plan (by 03 Dec 2020)	Medium term plan (by 25 Jun 2024)	Long term plan (by 6 June 2030)
Skopje TMA	Main: GNSS Back up: DME/DME, VOR/DME, ATC	Main: GNSS Back up: DME/DME	Main: GNSS Back up: DME/DME

Table 6. Final approach implementation plan

NAVIGATION SPECIFICATION			
RUNWAY	Short term plan (by 03 Dec 2020)	Medium term plan (by 25 Jun 2024)	Long term plan (by 6 June 2030)
LWSK RWY34	LNAV/VNAV (APV Baro)	LPV	
LWSK RWY16	LNAV/VNAV (APV Baro)		LPV
LWOH RWY01	LNAV/VNAV (APV Baro)	LPV	
LWOH RWY19	LNAV/VNAV (APV Baro)		LPV
NAVIGATION INFRASTRUCTURE			
RUNWAY	Short term plan (by 03 Dec 2020)	Medium term plan (by 25 Jun 2024)	Long term plan (by 6 June 2030)
LWSK RWY34	GNSS	GNSS	GNSS
LWSK RWY16	GNSS	GNSS	GNSS
LWOH RWY01	GNSS	GNSS	GNSS
LWOH RWY19	GNSS	GNSS	GNSS

There should be an adequate representation of the members of the PBN implementation team available in the operations, in order to:

- Monitor the implementation process;

- Provide support and information to operational controllers and pilots.

After the implementation of the airspace change, which has introduced PBN, the system, needs to be monitored to ensure that safety of the system is maintained and determine whether strategic objectives are achieved. One of the most important monitoring activities is the verification of safety objectives coming from safety assessments for PBN implementation. If during post implementation phase an unforeseen event occur and safety objectives are no longer met, a mitigation measures should be put in place as soon as possible. In exceptional circumstances, this could require the withdrawal of RNAV or RNP operations while specific problems are addressed.

4. SWOT analysis of the PBN implementation in Republic of North Macedonia

Table 7. SWOT analysis of the PBN implementation in Republic of North Macedonia

STRENGTHS (+)	**WEAKNESSES (-)**
- Safety - Fuel savings - Time savings - Improved route flow - Increased capacity - Environment impact	- Training for ATC personnel and flight crew - Standardisation worldwide - Cost for equipment and publications for operational use
SWOT analysis of PBN implementation in Republic of North Macedonia	
OPPORTUNITIES (+)	**THREATS (-)**
- Precision navigation - Increased number of airways - Improved efficiency - Direct routing in FIR - Higher number of approach options	- Short timeframe for implementation - Flight crew training level - Higher initial cost

According to the SWOT analysis, it can be seen that the positive impact of the PBN implementation in Republic of North Macedonia greatly overcomes the negative impact. The main positive impact is on safety, savings both in terms of fuel and time, as well as the environmental impact of reducing the noise pollution and CO_2 emissions as a result of the shorter time spent by the aircrafts overflying the FIR or approaching the airports. As the navigation will not be based on NAVAIDs, there will be direct routing and increased number of airways available. Skopje and Ohrid airports will benefit from the implementation of the PBN approaches and approaches will be made from both directions, which was not the case till now. RWY 16 in Skopje and RWY 20 in Ohrid will get LNAV/VNAV by 03 December 2020 and that will greatly improve the traffic flow and better utilization of the airports during southern winds. On the other side, the only negative impact will be felt by the short timeframe and the development of training programmes both for the ATC personnel and the flight crew

(pilots), as well the need of new publications for operational use before the PBN implementation initial phase has been completed.

CONCLUSION

The PBN implementation in Republic of North Macedonia will be a process of approximately 10 years. The implementation process will have to deal with a number of constrains and challenges in terms of equipage, training of personnel and publications for the PBN operational use. Therefore, can be concluded that PBN implementation in Republic of North Macedonia will have huge positive benefits, despite the short timeframe and initial cost regarding the training, equipment and prescribed procedures for the operational use, with a huge positive impact on the environment by reducing noise and CO2 emissions. The positive impacts greatly overcomes the negative impact of the process, noting that the PBN implementation has almost no real weak points. The main benefit will be for Skopje and Ohrid airports, adding additional approaches for their runways making the airport utilization better and accustomed to more operators and aircraft fleets.

The PBN concept represents a shift from sensor-based to performance-based navigation, reducing the need to maintain sensor-specific routes and procedures, and their associated costs. For example, moving a single VOR ground facility can impact dozens of procedures, as VOR can be used on routes, VOR approaches, missed approaches, etc. Adding new sensor-specific procedures will compound this cost, and the rapid growth in available navigation systems would soon make sensor-specific routes and procedures unaffordable;

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