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OPERATIONAL FACTORS AND THEIR IMPACT ON SELECTION OF APPROACH SYSTEMS AT REGIONAL PUBLIC INTERNATIONAL AIRPORTS

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Resume

Regional public international airports undergo periodic modernization, including the modernization of air navigation and approach systems. In this paper is proposed a transferable decision-making framework based on the Analytic Hierarchy Process (AHP) for selecting approach systems at airports with potential mixed civil-military traffic. Its main contribution is an AHP-based procedure adapted to the operational and technical conditions of approach-system modernization. The procedure is demonstrated through a case study of Ostrava/Mosnov International Airport, assessing selected alternatives and their operational impacts on long-term airport development in the context of possible future mixed civil–military operations and national security interests.

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1 Introduction

The current push to develop the infrastructure of regional international airports (hereinafter "regional airports") stems, on one hand, from the efforts of their operators (owners) to connect regional airports to the European and global aviation network through a portfolio of scheduled passenger and cargo routes, and, on the other hand, from the growing importance of regional airports for air carriers, for whom these airports are increasingly becoming a suitable alternative to large and overloaded airport hubs.

The issue of defining the very concept of a regional airport is not uniform in professional literature. In [1], the authors state that there is still no generally accepted definition of a regional airport in Europe. The definitions used vary according to traffic volume, the airport's function within the transport network, the nature of the routes served, or geographical location.

Regional airports are currently used primarily on a seasonal basis. To mitigate this seasonal effect, it is essential for regional airports to develop and ensure year-round operations of scheduled air routes, whether passenger or cargo. Another area of focus is the possibility of military branches of the state utilizing and sharing civil airport infrastructure.

One of the most important requirements for ensuring the regularity of air transport is a high level of reliability in flight safety and the ability to operate flights at the scheduled time and to the planned destination. For this reason, as a part of the development of scheduled air transport at regional airports, increasing emphasis is being placed on equipping them with modern air navigation infrastructure that ensures this regularity to the greatest extent possible. An important component of an airport's air navigation infrastructure is formed by approach systems, which enable airport operations even under adverse weather conditions. From an economic perspective, the modernization of approach systems must be viewed as an investment. The acquisition, installation, and operation of new approach systems at an airport fulfil all the typical characteristics of an investment-it is a long-term asset whose use generates revenue over an extended period. However, its acquisition

is often associated with significant initial cash outlays.

An example of such an investment is the purchase and installation of an ILS approach system. Based on the authors' internal sources and knowledge, published articles [2] and [3], and contracts published in the register of contracts of state institutions [4] and [5], it appears that the acquisition cost of a Category I ILS system currently amounts to approximately $800,000, while the installation of a Category II/III ILS system, including the corresponding precision approach lighting system, reaches up to $1,600,000. Annual maintenance costs for Category I are approximately $75,000, while annual maintenance costs for Category II/III reach approximately $165,000. The difference is therefore twofold, and clear arguments must be presented for the purchase and installation of the more expensive Category II/III ILS system.

Investment projects, related to the selection of an appropriate type of approach system, may also be influenced by the type of operations currently taking place at the airport or being considered for the future. One such example is the so-called mixed civil-military operations (the joint operation of civil and military aircraft). The positive synergies of mixed civil-military operations may be accompanied by complications caused by the differing requirements of civil and military aircraft regarding approach systems, particularly due to differences in aircraft avionics. Airports with mixed civil-military operations can be divided into two groups. The first group consists of military airports with civil air traffic, where the primary function of the airport is military; an example is Pardubice Airport (LKPD), which is explicitly designated in the AIP of the Czech Republic as a military airport with civil air traffic [6]. The second group consists of civil public international airports with a current military presence or where part of the airport infrastructure is shared with a military unit; an example is Kraków-Balice Airport (EPKK) [7], where the operator specifies a separate civil section of the airport and the existence of a military section with the 8th Air Transport Base [8].

Selecting the appropriate type of approach system as a part of a regional airport's modernization thus becomes a significant challenge that can fundamentally affect the airport's attractiveness and its long-term viability. Since manufacturers provide precise cost estimates for installing specific types of approach systems only after assessing the individual needs and configuration of each airport, and since this information is not generally available even at a basic level, it is not possible to evaluate the economic aspects of this issue in general terms. However, it is possible to at least perform an operational analysis and evaluation of the individual options for modernizing approach systems using the AHP method.

The AHP method finds the wide application in air transport, particularly where it is necessary to evaluate options based on multiple criteria that are difficult to compare to one another. For example, in [9], the authors used the AHP method to assess the "target windows" concept as part of the modernization of European ATM; in [10], the AHP method was applied in combination with the PROMETHEE and VIKOR methods when selecting a suitable location for a military airport, and in [11], the method was used to determine the optimal service level of an airport terminal for low-cost carriers.

In summary, the aforementioned studies confirm the broad applicability of the AHP method in air transport and demonstrate its suitability for complex aviation decision-making problems involving multiple criteria and stakeholders. However, previous applications of AHP in aviation were primarily focused on airport location selection, airport service quality, airline or ATM operational concepts, or other airport-related decision-making problems. To the authors' knowledge, in no published study has been proposed a structured AHP-based methodological framework for selecting an airport approach system in the specific context of regional public international airports with expected mixed civil-military traffic. This context is important since the mixed traffic may involve different requirements related to aircraft equipage, operational minima, interoperability, resistance to interference, continuity of service and the strategic usability of airport infrastructure. The originality of this paper therefore does not lie in the AHP method itself, but in the formulation of a domain-specific decision-making framework that combines the approach-system alternatives with operational usability, aircraft equipage, installation complexity, resistance to interference and future flexibility. The proposed framework is demonstrated on the case of Ostrava/Mosnov Airport, but its structure is transferable to other regional airports facing similar modernization decisions.

2 Approach systems at regional airports

Using information from the aeronautical information publications of selected Eurocontrol member states [12], a survey was conducted of the current state of equipment at regional civil airports, including civil airports with mixed civil-military operations, designated for IFR operations in the Czech Republic, Slovakia, Poland, and Hungary. Each of the 24 analyzed regional airports certified as public international airports has a runway capable of two-way use. Of the total 48 runways, 15 are equipped with ILS CAT I, 7 have ILS CAT II, and only 2 runways at regional airports in Central European countries have ILS CAT III. The VOR approaches are available on 32 runways, and 16 runways have published NDB approaches. The most widespread type of approach is RNP, which uses GNSS satellite navigation and is published for 45 runways. If the modernization of radio navigation equipment for approach and landing at regional airports is being considered, then, considering the assumption of mixed civil-military operational use,

ILS, GBAS, TACAN, and VORTAC approach systems can be considered.

2.1 The ILS system

The ILS (Instrument Landing System) is a precision approach system that provides an aircraft with vertical and horizontal guidance information during approach and landing at an airport in adverse weather conditions. By its very nature, the ILS system can only be used for a specific runway direction. It allows for a precise approach and landing only in a direct line that follows the runway's centerline and, together with the approach descent path, intersects the runway plane at a single specific point, known as the touchdown point. At some airports, procedures are published and applied that utilize the back-course beam of the localizer for the opposite runway direction, known as the "back-course," which is a signal directed towards the opposite side of the localizer. However, this method of use has limiting characteristics. In the direction of use, it is not optimized for precise aircraft guidance, is less stable, and may have greater deviations. A significant disadvantage is that it provides only directional guidance during the approach and landing, without ensuring vertical guidance. The ILS system is divided into several categories based on accuracy, minimum required runway visibility, and minimum decision height.

2.1.1 ILS - category I (CAT I)

ILS CAT I is a standard approach system that enables precise approaches and landings for aircraft down to a decision height (DH) of 200 feet (approx. 60 m) and a minimum runway visual range of 550 metres. Where runway visibility data is not available, the minimum visibility value at which the ILS CAT I system can be used for approach and landing is replaced by an observed prevailing visibility value of 800 metres.

In terms of the usability of ILS CAT I equipment by civil and military aircraft, it is one of the most widely used approach methods. For the civil aircraft intended for IFR operations, avionics enabling approach and landing using ILS CAT I are nearly standard and rank among the basic instrumentation of most civil aircraft. Military transport aircraft in Western countries are also standardly equipped with avionics enabling approach and landing using ILS CAT I. For combat aircraft, precision approach and landing are primarily based on precision approach radar, which does not require any special onboard equipment; however, some military combat aircraft are equipped with this system.

Benefits of ILS CAT I:

- relatively low installation and maintenance costs compared to higher ILS categories (CAT II/III),
- sufficient coverage for most common operational and meteorological conditions,
- compatibility with the instrumentation of most aircraft and the qualifications of flight crews, who do not need to be additionally certified or specially trained for this procedure,
- lower demands on additional airport infrastructure compared to higher ILS categories (CAT II/III).

Risks of ILS CAT I:

- limited use in extremely poor weather conditions with reduced visibility (fog, heavy snowfall, heavy rain, etc.),
- possible signal interference (e.g., from terrain or ground obstacles),
- the need to establish protective sensitivity zones near individual system antennas.

2.1.2 ILS - category II/III (CAT II/III)

The installation of a Category II/III ILS system enables Category II and III approaches and landings, as well as controlled takeoffs. The decision height for ILS CAT II is lower than 200 ft (60 m), but not lower than 100 ft (30 m); for ILS CAT III, the approach may be conducted with a decision height lower than 100 ft (30 m) or without a specified decision height.

ILS CAT II/III systems significantly increase the likelihood of completing an approach and landing at an airport, thereby enhancing the attractiveness and usability of airports even under adverse meteorological conditions. Especially in the case of scheduled commercial air transport, where significant costs may arise from a potential forced diversion to an alternate airport and the associated additional costs not only for the flight itself but also for the subsequent ground transportation of passengers or cargo, the successful completion of the landing process at the original destination is essential.

A disadvantage of ILS CAT II/III systems is that they require independent backup power sources for the key components to ensure operational continuity even in the event of a main power failure. Airports equipped with an ILS CAT II/III system must also have high-intensity runway lighting systems (e.g., centerline and touchdown zone lights) that supplement radio navigation with visual guidance during approach and landing.

Aircraft are not universally equipped for ILS CAT II/III approach and landing operations. For a civil aircraft, it is common among modern airliners designed for long-haul passenger transport. For older aircraft, it is up to the airline to decide whether investing in the necessary equipment is necessary for the commercial and operational use of the aircraft. For example, in the case of cargo aircraft intended for scheduled air cargo transport, this equipment is desirable for the successful conduct of business operations. In addition to aircraft certification, special flight crew training is required to perform ILS CAT II/III approaches and landings. The situation is similar for military aircraft.

Benefits of ILS CAT II/III:

- the ability to operate even under very adverse weather conditions, which reduces the likelihood of flights having to divert to alternate airports,
- minimization of delays and disruptions to air traffic, increasing the airport's appeal to airlines seeking alternate airports in case of deteriorating weather conditions and the inability to complete the flight to the original destination airport,

Risks of ILS CAT II/III:

- high acquisition and operating costs,
- the need for special aircraft equipment and crew certification for approaches and landings in low visibility can significantly limit the number of suitable flights,
- more demanding maintenance and greater demands on adjacent infrastructure (e.g., runway lighting system),
- the need to modify the existing procedures and introduce special procedures for low-visibility operations, including regular training for all personnel (airport and air traffic control staff),
- the need to establish CAT II/III holding areas, including the installation of stop bars and ensuring their remote control,
- expansion of the sensitive area of the GP and LOC equipment and the need to prevent signal interference from aircraft, mobile devices, or airport obstacles.

2.2 GBAS (Ground-Based Augmentation System)

The GBAS is a ground-based system designed to improve the accuracy of GNSS navigation; compared to the ILS system, it enables precision approaches with significantly lower requirements for airport infrastructure. Honeywell developed a GBAS system called SmartPath SLS-4000 (for CAT I minima), which received operational certification from the FAA in 2009. This was followed in 2011 by European certification from the German Federal Aviation Authority (BAF). GBAS approach systems are designated according to the operational minimum for which they are certified. A distinction is made between GAST C (GBAS Approach Service Type C) systems, which correspond to CAT I approach minima, and GAST D systems with minima corresponding to CAT II/III [13]. The implementation of GNSS approaches must always undergo a risk assessment process related to the introduction of the selected approach type, as detailed in [14].

Compared to the ILS system, the GBAS system offers more advantages at both the technical and operational levels, and even at smaller airports with lower traffic volumes, it may be technically and operationally more feasible to implement this system. An example of the implementation procedure is included in the pre-project research report [15], and a summary of operational experience with the use of the CAT I GBAS system in actual airport operations is the subject of article [16]. The installation and operation of the GBAS system does not require the designation of critical sensitive zones to the extent required by the ILS system (e.g., relocation of holding points). The GBAS system allows for the projection of the final approach path along a curved trajectory, which is particularly advantageous when it is necessary to avoid noise-sensitive areas or to direct traffic away from densely populated areas. The system is suitable for precision instrument approaches in complex geographical areas where a direct ILS approach cannot be implemented, e.g., due to high surrounding terrain. Unlike an ILS approach, which is calibrated for only one glide path angle (typically 3°), the use of a single airport GBAS system allows for the operational application of various approach glide paths, including different touchdown points on the runway. This can also be advantageously utilized to reduce minimum separation distances between aircraft due to wake turbulence, thereby achieving an overall increase in runway capacity utilization.

Currently, the GBAS system is implemented, for example, at European airports in Bremen, Frankfurt am Main (Germany), Zurich (Switzerland), and Malaga (Spain), and in the U.S. at airports such as Newark and Houston [17]. The implementation of the GBAS system was the subject of [18]; author conducted a feasibility analysis of installing the GBAS system at Václav Havel Airport Prague, Czech Republic. In [19] was analyzed the development of Viseu Airport in Portugal over time and predicted traffic over a 10-year horizon. Study [20] was focused on assessing the feasibility of implementing a GBAS system at LinZhi Airport in Tibet, China. The study evaluated the availability of GBAS Type C (GAST C) and Type D (GAST D) approach services.

A significant disadvantage of installing a GBAS system for precision approach and landing is currently its very low penetration in the user sector, namely, in aircraft avionics. At present, very few types of civil transport aircraft are equipped with the necessary avionics. Another significant obstacle to the wider use of the GBAS system in air traffic is its certification only for operations under CAT I conditions (GAST C). This is a lower approach category than that currently offered by airports equipped with the ILS CAT II/III system.

In the case of military aircraft, the GBAS system can be used if the military aircraft in question are equipped with the appropriate onboard avionics. However, in the context of using the GNSS in a military environment, the JPALS (Joint Precision Approach and Landing System) is typically preferred for these purposes due to safety and resistance to interference. The JPALS system was developed specifically for the needs of military aviation and compared to the GBAS system, offers additional advantages such as mobility and the ability to operate in environments with limited navigation infrastructure.

The system consists of components similar to those of the civilian GBAS. The system achieves guidance accuracy of up to 200 mm [21] and is primarily used for precision approaches on aircraft carriers [22]. The system's mobility is ensured by "eJPALS," which is capable of providing precise guidance to up to 50 designated targets within a 20-nautical-mile radius [23]. The system can be activated at any location as needed within 60 to 90 minutes after deployment. The use of the GBAS system by military aircraft can be expected primarily at airports with mixed civil-military traffic, or during peacekeeping or coalition missions, when military aircraft equipped with the necessary avionics can safely use civilian airport infrastructure.

Benefits of GBAS:

- the ability to use a single installation for approaches to multiple runways, thereby significantly reducing costs, compared to using an ILS system, where each runway requires its own ILS installation,
- greater flexibility - it allows for various approach trajectories, which can reduce noise pollution or enable approaches in mountainous terrain,
- increased runway capacity - various descent trajectories and, where applicable, different touch-down points allow for reduced spacing between aircraft, considering wake turbulence,
- lower operating and maintenance costs compared to the ILS system,
- resistance to signal interference from fixed obstacles (terrain or airport-related),
- minimal extent of protective sensitivity zones.

Risks of GBAS:

- requires aircraft equipped with GBAS-compatible receivers, which is currently a very limited group of aircraft,
- aircraft operators' reluctance to upgrade avionics may limit its wider adoption,
- initial investment may be high depending on the need for additional airport equipment,
- current certification limitations to only GBAS Type C (GAST C) approaches and landings,
- dependence on the GNSS signal and all risks associated with potential GNSS signal interference.

2.3 TACAN (Tactical Air Navigation System)

TACAN is a military radio navigation system that provides data on the direction and slant range to a TACAN ground radio navigation station [24]. Its operating principle is similar to that of VOR/DME. The TACAN operates in the UHF band (962-1213 MHz) and combines both functions-azimuth navigation (determining the direction to the transmitter) and distance measurement, which provides data on the distance from the transmitter.

The TACAN is not commonly installed at civil airports. If implemented, it is typically in a hybrid version, known as a VORTAC station. The advantages of the TACAN system include, above all, greater accuracy than that of a VOR/DME combination (TACAN has smaller directional deviations than a classic VOR and a higher update frequency and accuracy than a classic DME), better performance in challenging conditions (it operates even in difficult terrain and in environments with high interference), and the ability to encrypt it or operate it in a secure mode, which makes it ideal for military use. A major disadvantage is the incompatibility of civilian aircraft with its use.

2.4 VORTAC (TACAN + VOR)

VORTAC is a combined navigation system that integrates the military TACAN system with standard VOR (VHF Omnidirectional Range) navigation equipment. It therefore provides both directional guidance (VOR for civil aviation and TACAN for military purposes) and distance measurement (DME, available to both sectors). The VORTAC system is primarily used at airports with mixed civil-military traffic. It can be used, for example, as a backup system for approach systems

Table 1 *Comparison of selected approach systems in terms of their basic technical and operational characteristics*

Features	ILS	GBAS (Ground-Based Augmentation System)	VORTAC
Function	It provides precise guidance during approach and landing in both the horizontal and vertical planes.	By correcting the GNSS signal, it enables the precise guidance during approach and landing in both the horizontal and vertical planes.	It provides bearing (course (*)) and distance (DME) information.
Usage	Precision approach and landing (3D) under CAT I, CAT II, or CAT III conditions	Precision 3D approach and landing (currently CAT I certification only)	En-route navigation and non-precision instrument approach (2D) without vertical guidance (*)
Accuracy	Extremely precise horizontal and vertical guidance	High-precision positioning with GNSS error correction (to within centimetres)	High accuracy for directional guidance (*) and distance
Frequency range	VHF (LOC: 108-112 MHz) + UHF (GS: 329-335 MHz)	GPS L1 (1575.42 MHz) + VHF Data Broadcast (VDB), 108–117.975 MHz	VOR: VHF (108-117.95MHz) TACAN (*) and DME: UHF (962-1213 MHz)

(*) Note: The TACAN component is usable only for military or government aircraft

Table 2 *Comparison of selected approach systems in terms of their operational resilience, implementation requirements, benefits, limitations, and compatibility*

Features	ILS	GBAS (Ground-Based Augmentation System)	VORTAC
Interference resistance	Susceptible to interference and signal reflections from obstacles	Dependent on availability and quality of the GNSS signal - susceptible to interference and spoofing	Interference-resistant TACAN (*) component, encryption capability
Signal availability	Limited range (approx. 25-30 km) for a single runway only	Wide coverage - can serve multiple runways at a single airport	Limited range; line of sight required
Difficulty of installation	High (each runway requires its own ILS); CAT II and CAT III installations require additional equipment	Lower than ILS - a single, strategically located station that can serve the entire airport	A central, suitable location allows for approaches to two-way runways (two runways, one VORTAC)
Advantages	Reliable and proven, CAT II/III suitable for use in extremely low visibility conditions	Versatile, more affordable than ILS, compatible with modern avionics	Suitable for both civilian and military use; TACAN section resistant to interference; option for shielded mode; option for military use
Disadvantages	Costly maintenance, each runway direction requires its own system and a wide, sensitive area to protect the signal	Dependence on availability and quality of the GNSS signal requires equipment on board aircraft (currently a small percentage of aircraft)	It does not provide vertical guidance during approach, which is only 2D
Compatibility	Universal, standard-issue avionics for all aircraft in commercial service	So far, only modern aircraft equipped with GNSS and SBAS/GBAS receivers; a small percentage	Most military and civil aircraft are equipped with the necessary avionics as standard (*)

(*) Note: The TACAN component is usable only for military or government aircraft

based on GNSS signal reception. In the event of GNSS signal interference, VORTAC can provide alternative navigation [25]. For a civil aircraft operated under IFR, navigation equipment must correspond to the planned route, airspace requirements, and procedures used. In its Acceptable Means of Compliance for commercial air transport, EASA lists, among other things, a VOR receiver as part of such equipment [26]. For a military and government aircraft, TACAN equipment is widely used, with EUROCONTROL noting that most government aircraft are equipped with DME and TACAN systems for conventional navigation [27]. The use of VORTAC equipment is negatively affected by the fact that it allows only for imprecise, so-called 2D, approaches due to the lack of vertical guidance.

Benefits of VORTAC:

- wide compatibility - allows for use by both civil and military aircraft,
- provision of navigation data for mixed civil-military traffic - VOR provides civil directional guidance, while TACAN ensures higher accuracy and the option of encryption for military use,
- DME availability for both sectors - both civil and military aircraft can use the same distance information,
- navigation redundancy - VORTAC provides a backup navigation system in the event of a failure of other GNSS systems.

Risks of VORTAC:

- higher maintenance costs - the combination of two systems requires more complex servicing and is more technically and organizationally demanding than a purely civil VOR/DME (interconnection of civil and military technology),
- lower accuracy than GBAS or ILS - although it provides reliable data, it is not as accurate as modern landing systems and does not allow for approaches and landings in low visibility,
- does not provide vertical guidance like GBAS and ILS,
- risk of premature decommissioning before the end of its planned service life due to the transition to modern satellite navigation - if the technical and security issues associated with GNSS (vulnerability to jamming and outages) are resolved, as has already been done with the military JPALS system, and the use of GNSS-based technologies subsequently expands, some VOR equipment at VORTACs may be used less frequently and their operation could become uneconomical.

2.5 Summary - comparison of different types of approach systems

Tables 1 and 2 present a comparison of the selected approach systems-ILS, GBAS, and VORTAC-in terms of their different characteristics. The standalone TACAN

Table 3 *Price comparison of systems in 2015 (based on [28] and supplemented by the authors from public sources)*

Approach Technology Comparison				
Feature	ILS	GBAS	SBAS	VORTAC
Coverage	One runway end	All runways at the installed airport	Continental (based on number of installed reference stations)	Both ends of a bidirectional runway (depending on ground station location)
Equipment and installation Cost (capital)	$1,500K per runway end	~$3,300K per airport	TBC - $1,000M+ per country	~$500K-$1M per station (includes both VOR and TACAN subsystems)
O&M Annual cost	>$140K per ILS Flight test/ calibrate once per year	$85K - $135K per station, parts, and labour; annual flight inspection not req.	$50M-$100M per country	~$50K-$100K (maintenance, calibration, power, testing)
Users per approach	1 (plus other in sequence)	Unlimited	Unlimited	Unlimited
Number of approaches	1	26 (48 w/Cat III) approaches from one ground station (approaches broadcast from ground station)	Unlimited non-precision approaches (airborne database contains approaches)	Limited non-precision approaches, usually 1 (based on radials DME arcs and position of MAPt)
Aircraft equipage	ILS receiver	GLS avionics	SBAS capable GPS receiver, approach data base	VOR/DME or TACAN receiver (military); VOR receiver (civil)
Capabilities	One approach per ILS; Cat I, II, and III	Flexible approaches: multiple glide slopes, thresholds, offsets; No ILS critical area; Cat I, growth to Cat II/III	Flexible non-precision approaches including LPV	Non-precision approach; lateral guidance only (no vertical guidance)

system is not included in the tables. Given its very limited use in civil aviation, it makes sense to consider installing it only in combination with a VOR system, i.e., as a VORTAC system. From the civil aviation perspective, the ILS CAT II/III system remains the key system for approach and landing in low-visibility conditions. However, the system is expensive and requires a separate installation for each runway. The GBAS system is a modern alternative that uses GNSS signals with corrections. Additionally, the system is not yet widely adopted, due to the higher cost of receivers, the potential for GNSS signal interference, and insufficient certification (only CAT I). VORTAC is a system particularly suitable for airports with a military presence, where the VOR component and distance measurements using the TACAN component are utilized by civil aircraft as a supplementary navigation system or for VOR/DME approach purposes.

A price comparison of the systems is presented in Table 3; it was conducted by Honeywell in June 2015 and supplemented with information obtained by the authors from public sources [28].

When deciding on selection of a suitable approach system, one cannot evaluate only the purchase costs of the equipment and its installation. The economic suitability of individual options must be assessed within a broader life-cycle framework, which includes not only initial investment costs but also operating costs, routine and non-routine maintenance, flight verification, replacement of technical components, ensuring operational readiness, and costs associated with potential system unavailability or an inadequate category of operating minima [29-30]. Furthermore, it is necessary to consider the broader economic impacts on carriers, passengers, cargo shippers, air traffic service providers, or other entities involved in the air transport system [31-32].

The lower acquisition costs for an approach system may, without a broader assessment, represent a more economically advantageous solution; however, if such a system does not provide sufficient operational usability under degraded meteorological conditions, it may lead to frequent diversions to alternate airports, delays, flight cancellations, or a reduction in the ability to attract new carriers and business opportunities. In its standard inputs for economic analyses, EUROCONTROL provides separate values for the costs of delays, flight cancellations, and diversions, and specifies recommended cost values per diverted flight [31].

3 AHP-based methodological framework for approach-system selection

The proposed framework consists of a structured sequence of decision-making steps that adapt the general AHP procedure to the operational and technical specifics of approach-system modernization at regional public international airports. It is intended for cases in which several technically feasible approach-system

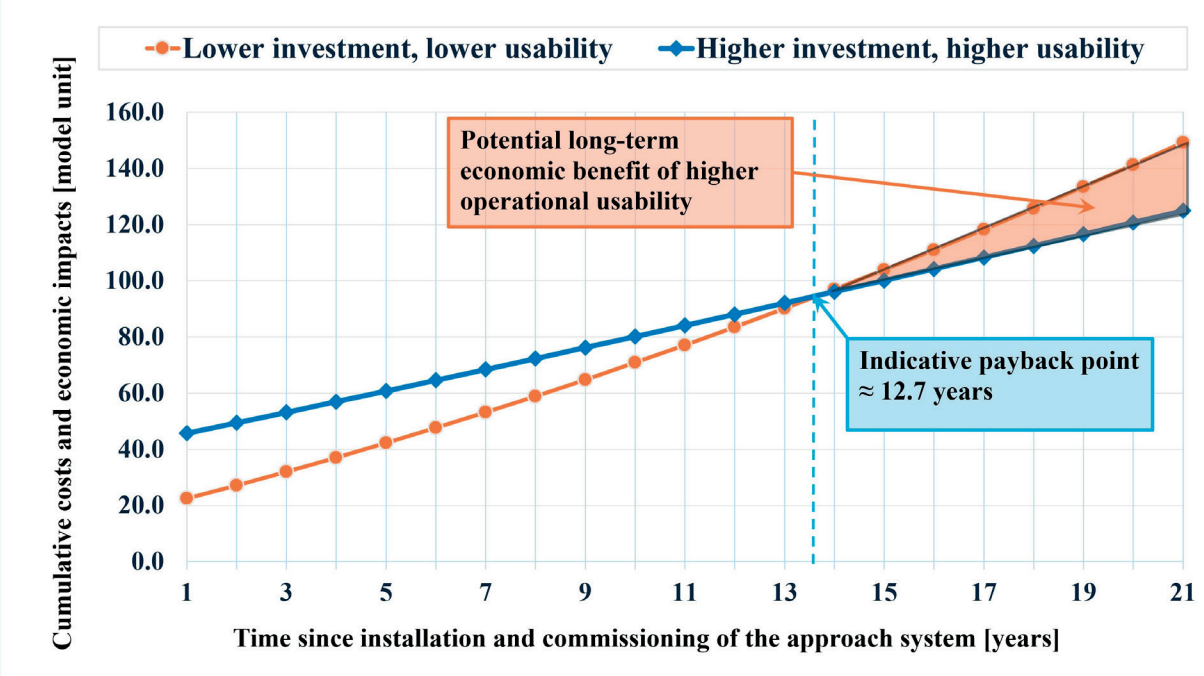

Figure 1 *Illustrative trend of cumulative costs for the approach system over time*

alternatives must be assessed with respect to expected traffic structure, including potential mixed civil-military operations, aircraft equipage, operational usability, installation constraints, resistance to interference and future flexibility.

The selection of an appropriate approach system for airport modernization is influenced by a range of operational, technical and strategic factors that must be assessed simultaneously. Given the complexity of the issue, the AHP method, which enables multi-criteria decision-making, was selected for the purpose of evaluating the suitable approach-system alternatives [33]. This method allows for structuring a complex decision-making problem into a hierarchy of simpler elements, including the objective, criteria, and alternatives, and subsequently determining their relative importance through pairwise comparisons [34].

Figure 1 provides an illustrative chart showing that an option requiring a higher initial investment may be more cost-effective in the long run due to lower losses resulting from diversions, cancelled flights, and missed business opportunities.

3.1 Proposed decision-making procedure for selecting an approach system

The proposed decision-making procedure is divided into consecutive steps that guide the airport operator or decision-maker from the initial operational assessment to the final ranking of approach-system alternatives:

1. An evaluation of existing approach systems, including the preparation of an overview of current approach systems, taking into account their expected service life, ranking the equipment based on actual operational use and minimum OCH/OCA altitudes, which determine the probability of completing the approach and landing, and the preparation of a list of the advantages and disadvantages of the individual installed approach systems.
2. Establishment of a uniform time horizon for which the decision is implemented. This depends, for example, on the design life of the runway, or on the time that has elapsed in the past between the introduction of the two previous consecutive and technologically significantly different approach systems. For example, the average interval between technologically significant implementations in the field of approach systems-from NDB, VOR, ILS, and MLS to GBAS-is 19 years [35].
3. Determining the scope and type of anticipated operations within a defined time horizon. This depends on the planned operational and commercial focus and use of the airport. If mixed civil-military operations were expected, it is necessary to specify the intensity and composition of military operations and coordinate further steps with the military.
4. The expected fleet structure should be assessed according to the anticipated composition of aircraft types most likely to use the airport under the expected business model within the assessed time horizon. Particular attention should be paid to the anticipated avionics and navigation equipment of the aircraft and their compatibility with existing and proposed approach systems. The approach systems and equipment considered for modernization should then be defined, including an assessment

of currently available systems that could improve the airport's usability in the context of the expected type and mix of traffic over the planned time horizon (v_1 to v_p).

5. Establishment of evaluation criteria. Their definition should take into account the information obtained in the previous steps (1-4). Before defining the final evaluation criteria, it was also necessary to consider whether economic aspects should be included directly in the AHP model. Although the acquisition and operating costs are undoubtedly important for the final investment decision, they were not included as a separate AHP criterion in this study. Reliable and comparable life-cycle cost data for all evaluated alternatives were not available, since the costs of installation, certification, maintenance, flight inspection, protection zones, power supply backup and integration into existing airport systems strongly depend on the specific configuration of each airport, procurement conditions and national regulatory requirements. Including only approximate or incomplete cost estimates could therefore distort the operational and technical comparison of the alternatives. The proposed AHP model is therefore intentionally limited to operational and technical suitability, while economic feasibility is considered a necessary subsequent step before final investment approval. On this basis, within the framework of the presented methodology, five criteria were defined (K_1 up to K_5), which can be applied to other airports or modified as needed. These criteria are as follows:
   a. Aircraft equipped with this technology (K_1) - an assessment of the extent to which aircraft are equipped with specific equipment (e.g., how many of the aircraft expected to operate at the airport have the necessary onboard equipment compatible with the systems proposed in the alternatives) and how significant it is for the selected alternative to take into account the avionics of the expected aircraft types that will use the airport most frequently;
   b. The complexity of the placement and installation of technology at the airport (K_2) - an assessment of the scope of the establishment of protection and sensitive zones for the proposed system or facility, and the associated procedural and operational restrictions; how significant these restrictions are for the selected option; and how significant their impact is on airport operations;
   c. Equipment immunity to interference (K_3) - an assessment of how significant the criterion of the ability of the sought-after guidance system or device to withstand external influences and perform its function reliably is, and to what extent this criterion is relevant and important for the expected operation, so that the device can perform this function;
   d. The applicability of the technology (K_4) - an assessment of the importance placed on usable operational minima expressed in terms of approach precision, minimum visibility, and minimum decision height, taking into account the operational use and the expected operational and business model of the airport, and the significance of ensuring the ability to approach and land even under very low visibility conditions;
   e. Flexibility in the use of technology within the airport (K_5) - determining the level of importance of the flexibility of the target system, for example, for approaching and landing on multiple runways, the flexibility of the approach trajectory in both the horizontal and vertical planes, the possibility of multiple touchdown points, or its applicability for area or terminal navigation.
6. Application of the AHP Method. Selected experts (ideally representatives of the airport operator, commercial entities expected to significantly contribute to airport operations, representatives of the air traffic services provider, etc.) should assess, using pairwise comparisons, the relative importance of individual criteria and alternatives. The assessment will reflect previously defined operational, commercial, geographical, environmental, and other relevant requirements and expectations. Based on these assessments, the following steps will be carried out:
   a. Saaty pairwise comparison matrix for the established criteria will be created;
   b. Saaty pairwise comparison matrices for individual alternatives with respect to each evaluation criterion will be created;
   c. Geometric means will be calculated and the weights of individual criteria and the local weights of alternatives with respect to each criterion will be determined through normalization;
   d. The consistency of the pairwise comparison matrices will be verified by calculating the Consistency Index (CI) and the Consistency Ratio (CR);
   e. Global priorities and the overall ranking of the alternatives will be calculated.
7. Decision on the selection of an appropriate approach system. The alternative that received the highest global score when the AHP method was applied S_i, represents an approach system that has been evaluated as the most suitable approach system for the purposes of the airport's modernization, considering the planned and expected operational development of the regional airport in question.

The flowchart in Figure 2 illustrates the proposed methodology algorithmically.

Figure 2 *Flowchart of the methodology based on AHP method for selecting an approach system*

Table 4 *An overview of minimum altitudes for individual approaches at LKMT Airport [12]*

OCA/OCH, Cat. C (ft)	RWY 04	RWY 22
ILS CAT III	N/A	---/50 (DH)
ILS CAT II	N/A	880/72
ILS CAT I	N/A	983/175
RNP (LPV)	1008/200	1008/200
VOR/DME	1210/370	1170/370

4 Case study of modernization - Ostrava/ Mosnov regional airport

Ostrava/Mosnov International Airport (LKMT) is a major regional transportation hub with international traffic. Thanks to its strategic location and advanced infrastructure, it facilitates the efficient operation of both passenger and cargo air transport. Ostrava/Mosnov Airport has a runway 3,511 metres long and 63 metres wide, which allows for takeoffs and landings of all types of aircraft, including wide-body commercial aircraft. The runway is used in both directions and is oriented 044°/224° (designation: RWY 04/22).

In the 1980s, the airport's movement areas were partially reconstructed and are now at the end of their service life. Administrative procedures related to their reconstruction are currently being finalized. In this context, the issue of a potential modernization of the safety equipment, including approach systems, has also been raised. In connection with the planned development of the airport, negotiations took place, followed by the signing of a Memorandum of Cooperation regarding the preparation of the site for the implementation of the "Mosnov Logistics Center of the Czech Army" project, between representatives of the Moravian-Silesian Region and the Ministry of Defense of the Czech Republic [36]. The operation of the military logistics center automatically presupposes mixed civil-military traffic, specifically the operation of military transport aircraft.

4.1 Application of the AHP method to approach-system selection at Ostrava/Mosnov airport

The first step of the proposed methodology involves compiling an overview of the approach systems available at the airport, for each runway direction. The approach equipment and systems currently installed and used at Ostrava Mosnov Airport for aircraft approach and landing are:

- ILS (Instrument Landing System) - at LKMT Airport, an ILS is installed only for RWY 22 and is certified for CAT III operations,
- VOR/DME (VHF Omnidirectional Range / Distance Measuring Equipment) - one VOR/DME unit designated as OTA is installed at LKMT Airport. The OTA VOR unit is located approximately at the centerline of the runway in its immediate vicinity and is usable for non-precision (2D) instrument approaches for both runways 04 and 22,
- RNAV/GNSS (Area Navigation / Global Navigation Satellite System) - the system is usable for both runways 04 and 22, for which RNP approaches utilizing GNSS navigation systems are published.

One of the most important parameters for individual approach aids, and their corresponding approach procedures, is the published minimum obstacle clearance altitude. The decision height, or minimum descent altitude, is derived from this. The lower this altitude is, the higher the probability that the pilot will establish a visual reference and complete the approach with a landing. When considering the modernization of an approach system, it is therefore important to include this criterion in the decision-making process and to assess how important the selected system's ability to enable the aircraft to approach and land in low visibility is for the final choice. An overview of the minimum altitudes for individual approach procedures at LKMT Airport is clearly presented in Table 4. The individual approaches are listed in ascending order from the most precise (ILS, RNP, VOR/DME). The data provided apply to Category C aircraft, which are commonly used for commercial flights at LKMT Airport.

The second step involves determining the time horizon for which the assessment and selection are being conducted. Another factor that can influence the determination of the time horizon, and which was also considered in this case-is the expected expansion and further technological development of the existing equipment. Given the dynamic technological development in the field of GNSS, the time horizon within which the selected approach system should, to the greatest extent possible, appropriately complement the existing installed approach systems and best meet the expected operational use of LKMT Airport was set at 15 years.

The third step involves determining the scope and type of operations and the expected aircraft mix. Ostrava/Mosnov Airport is a seasonally oriented airport with a high proportion of passenger charter air traffic during the summer months. The share of year-round scheduled passenger air transport is very small due to the high competition from the nearby Polish airports of Katowice and Krakow, and only slow development of

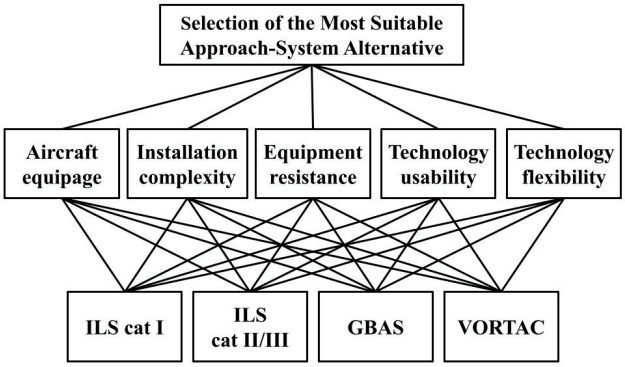

Figure 3 *Hierarchical structure of the problem under consideration*

additional scheduled routes can be expected within the assessed time horizon.

However, long-haul cargo air transport has been developing very dynamically in recent years and is gradually transforming into a year-round scheduled flight schedule. The cargo air transport is expected to play a dominant role in the airport's operational use in the coming period as well. Currently, it is carried out by older cargo aircraft equipped with standard radio navigation equipment used for approach and landing. The pressure on the operating costs of the airlines providing this transport does not allow for massive investment in modern approach technologies.

The planned military logistics center, which will be linked to military aircraft operations, is to be primarily focused on servicing and supplying international missions of the Czech Army and allied forces, or on providing rapid assistance in the distribution of humanitarian aid in the event of natural disasters and other humanitarian situations anywhere in the world. This purpose assumes the use of military transport aircraft, which are typically equipped with standard approach systems used in civil aviation. The operation of the logistics center does not involve the presence or deployment of military combat aircraft.

In addition to general aviation, the remaining existing air traffic consists of aircraft bound for the maintenance facilities located in the northern part of the airport. An area has been reserved at this location for the future expansion of aircraft painting capacity. However, all these activities are expected to involve predominantly older aircraft with conventional avionics and a relatively low level of adoption of the most advanced GNSS-based technologies.

Based on the preceding analysis and the available sources, the following modernization alternatives were identified for selecting an appropriate approach system capable of meeting the objective of modernizing the existing facilities at LKMT Airport:

- ILS CAT I RWY 04 - equipping Runway 04 with an ILS precision approach system enabling approaches and landings under CAT I conditions;
- ILS CAT II/III RWY 04 - equipping runway 04 with an ILS precision approach system enabling approaches and landings under CAT II/III conditions, including operations under low visibility conditions (LVO - Low Visibility Operation);
- GBAS - equipping the airport with a GBAS system, which will enable precision approaches and landings for both runways (RWY22 and RWY04), designated as GLS;
- VORTAC - equipping the airport with VORTAC equipment, which, when properly located, will enable non-precision instrument approaches for both runways (RWY22 and RWY04), with civilian aircraft using the VOR/DME portion of the equipment and military aircraft using the TACAN portion, both of which are included in the VORTAC system.

The next step is to establish the criteria for evaluating the most suitable option. The modernization options under consideration must be evaluated based on the significance of the identified criteria, which were proposed and described in the previous section. In combination with the established preference indices for the proposed approach systems at Ostrava/Mosnov Airport, the most suitable solution will then be identified.

The next step is application of the AHP method. The hierarchical structure of the decision-making problem is shown in Figure 3.

To evaluate the individual criteria and alternatives, an expert panel from the air transport sector was consulted. The experts were selected intentionally, based on their practical knowledge of airport operations, approach and landing procedures, aircraft equipage, operational limitations of regional airports, and the potential implications of mixed civil-military traffic. The expert group consisted of specialists familiar with the operational environment of LKMT Airport, including airport operations, aircraft operations, air traffic services, military aircraft operations, and aviation education and research. The composition of the expert panel is summarized in Table 5.

The expert evaluation was carried out in two steps. First, the experts assessed the relative importance of the proposed evaluation criteria using pairwise comparisons based on Saaty's scale. Second, they evaluated the local preferences of the approach-system alternatives with respect to each individual criterion. The assessed

Table 5 *Composition of the expert panel used for the AHP evaluation*

Expert	Professional background	Practical experience	Role in the AHP evaluation
E1	Airport operations / airport management	27 years	Airport infrastructure, operational impacts and implementation constraints
E2	Aircraft operations / pilot	35 years	Aircraft equipage and operational applicability of alternatives
E3	Air traffic services / ATC	26 years	ATC procedures, operational usability and impacts on airport operations
E4	Aviation education and research	21 years	Methodological structure, criteria formulation and consistency check
E5	Military aircraft operations / pilot	28 years	Military aircraft equipage, mixed civil-military usability and operational requirements

alternatives were ILS CAT I for RWY 04, ILS CAT II/III for RWY 04, GBAS and VORTAC. The expert evaluation was carried out as a consensus-based group assessment. The experts jointly discussed the relative importance of the criteria and the local preferences of the alternatives and agreed on the final values entered into the pairwise comparison matrices. This procedure was used to reflect a shared expert judgment rather than a statistical aggregation of independent individual assessments. The consistency of each matrix was verified using the Consistency Ratio (CR). Where the initial consistency ratio exceeded the recommended threshold, the relevant comparisons were reviewed by the expert group and revised only based on the professional judgment, without changing the calculation procedure or forcing a predetermined ranking of alternatives.

Based on the consolidated expert judgments, a Saaty pairwise comparison matrix was first compiled for the evaluation criteria. The criteria considered in the analysis were as follows: aircraft equipage with the given technology, complexity of locating and installing the technology at the airport, resistance of the equipment to interference, usability of the technology, and flexibility of the technology within the airport environment.

Before applying the AHP method to determine the final ranking of the proposed approach-system alternatives, the consistency of the original pairwise comparison matrix of the evaluation criteria was verified. The initial matrix did not meet Saaty's consistency requirement, as the calculated Consistency Ratio (CR) exceeded the generally accepted threshold value of 0.10 [33-34]. For this reason, the original expert assessment of the relative importance of the criteria was reviewed and revised by the expert group. The revision process was focused only on those pairwise comparisons that contributed most significantly to the inconsistency of the criteria matrix. The experts were therefore asked to reconsider these selected judgments while preserving the original decision-making logic and the operational meaning of the criteria. No changes were made to the AHP calculation procedure itself, and the revision was limited exclusively to the expert judgments expressed in the pairwise comparison matrix.

The revised pairwise comparison matrix preserved the original logic of the expert evaluation but adjusted selected pairwise comparisons so that the matrix would meet the required level of consistency. This procedure ensured that the final criteria weights were not obtained by arbitrary mathematical adjustment, but by a controlled revision of the expert assessment. The resulting criterion weights are presented in Table 6.

The consistency check of the revised criteria matrix confirmed its acceptability. The calculated values were λ_{max} = 5.4099; CI = 0.1025; RI = 1.12; CR = 0.0915. Since the resulting CR value is lower than 0.10, the revised matrix can be considered sufficiently consistent according to Saaty's recommended threshold. In addition to the revised criteria matrix, the local pairwise comparison matrices of the alternatives with respect to the individual criteria were also checked for consistency before calculating the final global preference scores.

The results show that, for the LKMT Airport, the most important criterion is the usability of the technology (K_4), with a weight of 0.4242. In the context of this study, this criterion primarily reflects the operational usability of the approach system with respect to the achievable approach and landing minima. The second most important criterion is the aircraft equipage with the given technology K_1, with a weight of 0.2769. This result indicates that the practical applicability of the selected approach system strongly depends on whether it can be used by a sufficiently broad range of aircraft expected to operate at LKMT Airport, including both civil aircraft and military transport aircraft in the case of possible future mixed civil-military operations.

In the next step, the expert group applied the AHP method to evaluate the proposed alternatives separately with respect to each criterion. The assessed alternatives were ILS CAT I for RWY 04, ILS CAT II/III for RWY 04, GBAS, and VORTAC. For each evaluation criterion, a separate local Saaty pairwise comparison matrix was created, and the local weights of the alternatives were calculated.

For illustrative purposes, the local Saaty matrix for the first criterion, the aircraft equipage with the given technology K_1 is presented in Table 7. This criterion

reflects the extent to which aircraft expected to operate at LKMT Airport are equipped to use the respective approach system. The results show that, with respect to this criterion, ILS CAT I and VORTAC achieved the highest local weights, both reaching 0.3478. ILS CAT II/III reached a local weight of 0.2068, while GBAS achieved the lowest local weight of 0.0975. This result reflects the current differences in aircraft equipage and operational readiness for the use of individual technologies.

The consistency of each local Saaty matrix was verified using the Consistency Ratio (CR). All the local matrices met Saaty's recommended consistency threshold, as the calculated CR values were lower than 0.10. The local weights of the alternatives obtained for the individual criteria are summarized in Table 8.

The global weights of the alternatives were subsequently calculated by multiplying the local weight of each alternative under each criterion by the corresponding criterion weight and summing these partial values across all criteria. This procedure expresses the overall preference for each alternative while considering both the importance of the criteria and the local performance of the alternatives under each criterion. The results of the global evaluation are listed in Table 9.

The final step was to evaluate the results obtained using the AHP method. The global evaluation showed that the most suitable alternative for the modernization and extension of radio navigation equipment at LKMT Airport is the installation of an ILS CAT II/III system for RWY 04, with a global weight of 0.2998. This result is mainly influenced by the high importance of criterion K_4 - usability of the approach system with respect to approach and landing minima, which achieved the highest criterion weight. Under this criterion, ILS CAT II/III obtained the highest local preference, confirming its operational advantage in low-visibility conditions and its ability to significantly increase the probability of completing an approach and landing under adverse meteorological conditions.

The second-ranked alternative was GBAS, with a global weight of 0.2390. Expanding the airport's equipment and utilizing GNSS through the implementation of GBAS technology would increase the redundancy and efficiency of navigation available for both runway directions, particularly for precision instrument approaches under CAT I conditions. The GBAS also offers important advantages in terms of lower requirements for critical and sensitive areas compared with ILS, as well as the potential to support multiple runway approach directions from a single ground-based station. These characteristics may contribute to greater operational flexibility and, in some cases, to increased airport capacity. However, the overall result of GBAS is limited by the lower aircraft equipage and by the fact that its current operational usability is primarily associated with CAT I minima. In the context of the present evaluation, this reduced its competitiveness compared with ILS CAT II/III, especially because criterion K_4 had the highest weight in the overall assessment.

The third-ranked alternative was ILS CAT I for RWY 04, with a global weight of 0.2366. This option would improve the availability of RWY 04 for instrument approaches and would provide a widely used, technically proven, and broadly compatible approach system. However, compared with ILS CAT II/III, it would not provide the same level of operational benefit in low-visibility conditions. Therefore, although ILS CAT I represents a feasible and operationally useful alternative, its contribution to reducing the approach and landing minima would be more limited.

The fourth-ranked alternative was VORTAC, with a global weight of 0.2246. The addition of VORTAC, or TACAN-based equipment, is currently being discussed in connection with the Czech Army's planned activities at LKMT Airport. This alternative may be beneficial primarily for the military component of the expected mixed civil-military operation. For the civilian segment of air traffic, however, such modernization would bring only limited improvement compared with the current situation, particularly in terms of approach and landing minima. Although the VORTAC achieved relatively strong results in the criteria related to aircraft equipage and resistance to interference, its low local weight under criterion K_4 significantly reduced its final global score. This indicates that from the perspective of improving the airport's usability under adverse meteorological conditions, VORTAC provides a lower operational benefit than the precision approach alternatives considered in the analysis.

The selection of VORTAC could be justified mainly if its implementation were explicitly required by the military component, for example if the establishment of a logistics facility or another form of military presence at LKMT Airport were made conditional upon such equipment. An indirect benefit could consist in synergies and cost-sharing resulting from the shared use of airport infrastructure under mixed civil-military operations. However, if the expected military component consists primarily of military transport aircraft that are generally capable of using standard civil approach systems, and if encrypted or coded approach guidance is not essential for their operation, VORTAC cannot be considered the preferred option for the purposes of airport modernization.

Particularly in view of the high importance assigned to approach-system usability with respect to approach and landing minima, the installation of an ILS CAT II/III system for RWY 04 can be considered the most suitable option for the modernization and extension of LKMT Airport's radio navigation equipment. This solution would increase the airport's operational usability and strengthen its competitiveness in regional and international air transport. Together with the existing ILS CAT II/III system for RWY 22, the proposed

Table 6 *Determination of criterion weights using the Saaty method*

Criterion	K_1	K_2	K_3	K_4	K_5	Geometric mean G_i	Weight of criterion w_i
K_1	1	4	3	$\frac{1}{3}$	4	1.7411	0.2769
K_2	$\frac{1}{4}$	1	1	$\frac{1}{5}$	3	0.6843	0.1088
K_3	$\frac{1}{3}$	1	1	$\frac{1}{3}$	3	0.8027	0.1277
K_4	3	5	3	1	3	2.6673	0.4242
K_5	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	1	0.3920	0.0624

Table 7 *Saaty Pairwise Comparison Matrix of Alternatives with Respect to Criterion K_1*

Approach System	ILS CAT I (RWY04)	ILS CAT II/III (RWY04)	GBAS	VORTAC	Geometric Mean G_i	Local Priority of Alternative p_i
ILS CAT I (RWY04)	1	1	3	1	1.5651	0.3478
ILS CAT II/III (RWY04)	$\frac{1}{2}$	1	3	$\frac{1}{2}$	0.9306	0.2068
GBAS	$\frac{1}{3}$	$\frac{1}{3}$	1	$\frac{1}{3}$	0.4387	0.0975
VORTAC	1	2	3	1	1.5651	0.3478

Table 8 *Summary of Local Weights of Alternatives with Respect to Evaluation Criteria p_{ij}*

Criterion	ILS CAT I (RWY04)	ILS CAT II/III (RWY04)	GBAS	VORTAC
Aircraft equipped with this type of technology	0.3478	0.2068	0.0975	0.3478
The complexity of locating and installing technology at an airport	0.1887	0.1089	0.3512	0.3512
The device's resistance to interference	0.2510	0.2050	0.1219	0.4222
Usability of the technology with respect to the landing minima	0.1901	0.4656	0.2814	0.0629
Flexibility in the use of technology within the airport	0.1125	0.1125	0.6225	0.1525

Table 9 *Global evaluation of alternatives S_i based on the AHP method*

Criterion	Weight w_i	ILS CAT I (RWY04)	ILS CAT II/III (RWY04)	GBAS	VORTAC
Aircraft equipped with this type of technology	0.2769	0.0963	0.0573	0.0270	0.0963
The complexity of locating and installing technology at an airport	0.1088	0.0205	0.0118	0.0382	0.0382
The device's resistance to interference	0.1277	0.0320	0.0262	0.0156	0.0539
Usability of the technology	0.4242	0.0806	0.1975	0.1194	0.0267
Flexibility in the use of technology within the airport	0.0624	0.0070	0.0070	0.0388	0.0095
Global Preference Indices for Alternatives		0.2366	0.2998	0.2390	0.2246
Results		3	1	2	4

ILS CAT II/III system for RWY 04 would provide mutual operational redundancy, particularly in situations where runway selection is affected by wind direction and tailwind limitations.

A disadvantage of this option is the need to establish the protection areas for the LOC and GP components serving RWY 04. However, given the existing experience with similar equipment installed for RWY 22, the implementation of such protection areas should be manageable from both procedural and operational perspectives. It should not create significant difficulties in terms of staff training or airport operating procedures.

The main operational disadvantage of this alternative is the need for regular maintenance, inspections, and flight checks, which will increase the financial costs associated with airport operation. Despite these disadvantages, the AHP results indicate that ILS CAT II/III for RWY 04 provides the most balanced and operationally beneficial solution for the modernization of approach-system infrastructure at LKMT Airport.

4.2 Sensitivity analysis of the AHP results

Since criterion K_4, representing the usability of the approach system with respect to approach and landing minima, obtained the highest criterion weight, a one-way sensitivity analysis was carried out to examine whether the final recommendation was excessively dependent on this dominant criterion. The purpose of the analysis was to verify whether the moderate changes in the weight of K_4 would change the preferred alternative.

The sensitivity analysis was performed by decreasing and increasing the weight of K_4 by ±10% and ±20%, while the weights of the remaining criteria were proportionally normalized so that the total sum of all criteria weights remained equal to 1. The local priorities of the alternatives with respect to individual criteria were kept unchanged.

The results showed that ILS CAT II/III for RWY 04 remained the preferred alternative in all tested scenarios. Although the order of the lower-ranked alternatives changed in some scenarios, the first position remained stable. This indicates that the final recommendation is influenced by the high importance assigned to operational usability, but it is not determined solely by this criterion.

The sensitivity analysis therefore confirmed that the preference for ILS CAT II/III is robust under moderate changes in the weight of K_4. The result follows from the combined effect of the criterion weights and the local priorities of the alternatives, rather than from the dominance of a single criterion alone.

5 Conclusion

In this article was addressed the operational and technical assessment of suitable approach-system alternatives for an international regional airport with anticipated mixed civil-military traffic in the event of future modernization. The theoretical part of the article provided a description of selected approach systems, summarized their basic advantages and disadvantages, and presented a methodological framework for the selection process, using the AHP method.

Within the proposed methodology, it was necessary to evaluate the current range of available approach systems, define the relevant time horizon, specify the scope and type of expected traffic, and determine the anticipated structure of the aircraft fleet, including possible military aircraft. In the article are presented the sample evaluation criteria intended for operational and technical assessment of approach-system alternatives. Those criteria could be modified or expanded according to the specific operational, technical, economic, or strategic conditions of the airport under consideration.

The practical part of the article was devoted to application of the proposed methodology at Ostrava/Mosnov Airport, where the runway reconstruction is expected in the coming years and where the mixed civil-military operations are currently being considered. The AHP result showed that, for the purposes of modernizing and expanding the airport's radio navigation equipment, the installation of a Category II/III ILS system for RWY 04 is the most suitable option. In addition to the basic AHP evaluation, a sensitivity analysis was carried out to verify the stability of the final ranking with respect to changes in the weight of the most influential criterion. The results confirmed that ILS CAT II/III for RWY 04 remains the preferred alternative even under moderate changes in criterion weights. This option increases the airport's operational usability, particularly with respect to approach and landing minima under adverse meteorological conditions. The results also showed that GBAS represents a promising alternative, mainly due to its flexibility and lower requirements for protection areas. However, its current operational limitations and lower aircraft equipage reduce its overall suitability in comparison to ILS CAT II/III. ILS CAT I remains a feasible but less operationally beneficial option, while the VORTAC appears to be the least suitable alternative for modernization focused on improving the airport's usability in low-visibility conditions.

The proposed methodology can be applied to other regional airports facing similar modernization decisions. However, the specific ranking of alternatives cannot be generalized automatically, as it depends on local operational conditions, expected traffic structure, aircraft equipage, meteorological characteristics, infrastructure constraints, and strategic requirements. Therefore, each application of the methodology should be based on airport-specific input data and expert assessment.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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