AVIATION TRANSPORT

UDC 656.7.071.1:629.05(045)
DOI:10.18372/1990-5548.85.20436

[1]**D. O. Marshalok,**
[2]**O. Y. Luppo**

AIR TRAFFIC CONTROLLER WORKLOAD AS A FACTOR IN MULTI-CRITERIA ARRIVAL SEQUENCING WITHIN THE POINT MERGE SYSTEM

Faculty of Air Navigation, Electronics and Telecommunications,
State University Kyiv Aviation Institute, Kyiv, Ukraine
E-mails: [1]4646212@stud.kai.edu.ua ORCID 0000-0001-5706-5794,
[2]oleksandr.luppo@npp.kai.edu.ua ORCID 0000-0001-9063-985X

Abstract*—Gate-release strategy in the Point Merge System is crucial for reliable arrival sequencing and separation assurance in terminal areas. In this study, we examine three aggregation policies for the exit decision from the radius-to-fix arc conjunctive (AND), disjunctive (OR), and majority (MAJORITY) implemented with a non-compensatory safety barrier and S* speed-control variants. The objective is to assess each policy's ability to regulate headways, maintain time-based separation, limit low-altitude level-offs, manage advisory demand, and mitigate environmental impact under varying weather conditions, and to identify their strengths and weaknesses. As an example, we conduct an experimental evaluation on the published geometry of Dublin (EIDW) RWY 28L, parameterising arrivals with realistic kinematics and stratifying by METAR; performance metrics include headways at arc/gate/final, spacing error relative to S*, a time-based loss-of-separation proxy, level-off time, and coarse terminal-area fuel / CO_2. Human factors are incorporated through a Human Workload Index combining expected speed-advisory count, level-off time, short-headway alarms, and weather difficulty markers. Alternatives are ranked using TOPSIS with AHP-like weights over Safety, Efficiency, Human, and Environment. The results show that policy choice is the primary driver of headway regularity, advisory load, and low-altitude behaviour; moreover, treating workload as a first-class criterion can overturn rankings obtained from an efficiency-only view. This evaluation helps practitioners select and gate-release policies to site-specific tolerances within an auditable framework.*

Keywords—Navigation; point merge system; air traffic management; controller workload.

I. INTRODUCTION

Arrival flow management in the terminal manoeuvring area (TMA) operates within the International Civil Aviation Organisation (ICAO) regulatory paradigm, whose objective is to ensure a safe, orderly, and expeditious flow of air traffic through the provision of air traffic control service, flight information service, and alerting service [1]. The PANS-ATM procedural framework specifies the application of rules and delineates responsibilities among air traffic control (ATC) units, including requirements for separation minima and arrival sequencing methods [2]. In the current ICAO safety management concept (SMM), the human factor is treated as a structural element of risk-oriented decision-making, requiring the formal accounting of human performance within air traffic planning and control processes [3].

The point merge system (PMS) occupies a special place among structured sequencing procedures. A method for integrating arrival flows via geometrically ordered "waiting arcs" and a single merge point that reduces the need for vectoring and increases trajectory predictability [4]. Recent studies demonstrated PMS's potential to simultaneously decrease delays and environmental burden through coordinated management of spatiotemporal arrival constraints [5]. Extensions such as Parallel-PMS are being developed for high-load TMAs. In these, schedule sensitivity to uncertainties, like wind, increases, complicating the trade-off between performance and safety [6].

The compatibility of PMS with continuous descent operations (CDO) creates room for environmental benefits, provided that airspace/procedure design and controller support are appropriate, as explicitly stated in ICAO Doc 9931 [7]. However, implementing such procedures requires geometrically correct designs and human-algorithm decision-fusion policies in real time. In practice, these policies can be formalised as logical rules for integrating signals/recommendations – AND/OR/MAJORITY – which directly affect radio-communication density, the number of corrective instructions, and controller workload.

Air traffic control officers (ATCO) workload is a critical variable of system safety: validated psychophysiological instruments such as NASA-TLX provide standardised measurement of subjective workload and enable comparison of traffic-management modes across scenarios [8]. Existing empirical data in the ATC context indicate that excessive mental workload is statistically associated with reduced task performance and thus, indirectly, with the risk of error in a high-stakes operational environment [9]. Additionally, functional safety indicators at the tactical control level are traditionally assessed via trajectory conflict metrics and loss-of-separation / closest-point-of-approach (LoS/CPA) indicators, for which consolidated approaches to conflict detection and resolution in air traffic have been established [10].

Accordingly, choosing and tuning PMS modes in a TMA becomes a multi-criteria problem with conflicting objectives: safety, efficiency, environment, and human performance. A consistent MCDM apparatus provides formal means to weight criteria and rank alternatives (PMS configurations and merge policies), allowing explicit integration of human-factor indicators alongside classical safety and efficiency metrics [11]. At the same time, the literature review reveals a methodological gap: comparative studies of AND/OR/MAJORITY policies in the PMS context rarely treat controller workload as a full-fledged criterion within a multi-criteria model, and the sensitivity of rankings to the weight of the human factor is usually not analysed systematically.

The paper aims to develop-and test on TMA scenarios-a formal MCDM scheme for comparing PMS configuration under different AND/OR/MAJORITY decision-fusion policies with the explicit inclusion of the "Human Performance (workload/SA)" criterion alongside safety, efficiency, and environmental effects. The proposed approach entails safety metrics (LoS, min-CPA, etc.) and arrival performance; environmental indicators consistent with the possibility of CDO; validated indicators of workload/situational awareness; and (iv) subsequent sensitivity analysis of rankings to the weight of the human factor. This design strengthens practical ATC decision-making in mixed human-algorithm control loops for conflict-free air traffic under variable demand.

II. Literature Review

The foundational studies on the PMS established the geometry of arcs and the sequencing logic, demonstrating that standardised "waiting arcs" make it possible to dispense with broad vectoring without sacrificing runway throughput [4]. Subsequent research focused on integrating PMS with arrival optimisation and controlled minimisation of delay and environmental footprint, confirming the procedure's potential in complex TMAs [5]. For high-load terminal areas, Parallel-PMS and related formulations have been proposed, in which schedule robustness depends on wind uncertainties and additional separation requirements at shared merge points, thereby complicating the trade-off among fuel, time, and delay [6]. In parallel, modifications such as Multi-Arrival PMS have evolved, where multiple approaches to sequencing legs can shorten duration and path length while preserving management predictability [12].

Analyses of ADS-B datasets for major European airports show that tromboning / holding produces higher excess emissions than Point Merge trajectories and continuous descents, strengthening the case for procedural standardisation of arrivals [13]. Optimisation models in multi-runway environments with P-PMS confirm the possibility of jointly minimising fuel, flight time, and aggregate delay provided that separation constraints are properly arranged [14]. New experimental approaches to rapid detection of ATCO mental workload (including EEG indicators combined with validated questionnaires) demonstrate the reliability of certain spectral features and the suitability of integrating such assessments into decision-support systems [15]. Independent studies corroborate the value of extended workload/SA assessment protocols for operational changes to the control environment [16].

A review of aviation applications of multi-criteria decision making for 2000–2018 records the leading role of AHP/FAHP and a high share of fuzzy extensions, with Air Traffic Management standing out as an area needing transparent weighting of conflicting objectives [17]. For ATCO workload problems specifically, hybrid DEMATEL-ANP and PROMETHEE II approaches effectively structure causal links among stressors and build a robust outranking of mitigation measures [18]. The classical PROMETHEE method provides a transparent apparatus for ranking alternatives without full compensability of criteria, which is particularly appropriate when combining safety metrics, environmental impacts, and human workload [19]. In parallel, applied MCDM models in adjacent aviation sub-tasks illustrate the maturity of the AHP/TOPSIS toolset and confirm its suitability for operational decision-making [20].

III. Methodology and Conceptual Framework

This work treats the selection of point merge system (PMS) settings as a multi-criteria problem, in which airspace configurations and control modes are combined with decision-fusion policies in the loop

"ATCO – algorithmic advisor – independent conflict check," and ranked by the criteria Safety, Efficiency, Environment, Human Performance [21]. The regulatory requirements for separation minima, sequencing procedures, and tactical control are taken from ICAO Doc 4444 (PANS-ATM), ensuring the model's consistency with TMA operational norms [21].

We consider: A = {a_1, …, a_m} as pairs "PMS configuration × decision-fusion policy," e.g., "arc radius/angle geometry/speed-control mode × {AND, OR, MAJORITY}." The criteria vector C = {Safety, Efficiency, Environment, Human Performance} With sub-criteria, it is defined as follows

– *Safety:* loss-of-separation (LoS) rate, minimum closest-point-of-approach (CPA), and conflict indicators consistent with Doc 4444 norms [21].

– *Efficiency:* mean arrival delay, in-trail spacing error on arcs, landing rate.

– *Environment:* share (and duration) of level segments within a CDO profile; fuel / CO_2 estimate.

– *Human Performance:* NASA-TLX subjective workload and objective proxies (radio-communication density, number of corrective commands, reaction time). For weights $w=(w_1,\dots,w_n)$ AHP with consistency checking is applied, and if there are dependencies / feedback between subcriteria, ANP with a priority supermatrix is used [22], [23]. Construct the matrix $\mathrm{P}=p_{ij}$, where p_{ij} is the relative preference of criterion i over j. The weight vector is the eigenvector of the largest value $\lambda_{\max}$:

$$Pw=\lambda_{\max}w, \tag{1}$$

$$\sum_{I} w=1,\quad w_i>0, \tag{2}$$

$$CI=\frac{\lambda_{\max}-n}{n-1}, \tag{3}$$

$$CR=\frac{RI}{CI}\le 0.10, \tag{4}$$

To model interactions, a weighted supermatrix *W* is constructed with local priority vectors for clusters; global weights are obtained by raising *W* to the power *k* to convergence $\lim_{k\to\infty}W^k=W^*$ [22]. Two coordinated ranking methods reflect compensatory and "hard" advantages: TOPSIS and PROMETHEE II [24].

$$r_{ij}=\frac{x_{ij}}{\sqrt{\sum_{i=1}^{m}x_{ij}^2}}, \tag{5}$$

where x_{ij} are normalised values (e.g., vector normalisation).

$$v_{ij}=w_j r_{ij}, \tag{6}$$

where v_{ij} are the weighted normalised values.

Positive / negative ideals are calculated as:

$$A^{+}=\left\{\max v_{ij}\left(benefit\right)/\min v_{ij}\left(lost\right)\right\}, \tag{7}$$

$$A^{-}=\left\{\min v_{ij}\left(benefit\right)/\max v_{ij}\left(lost\right)\right\}, \tag{8}$$

After we measure distances and proximity coefficient:

$$S_j^{\pm}=\sqrt{\sum_j\left(v_{ij}-A_j^{\pm}\right)^2}, \tag{9}$$

$$CC_i=\frac{S_i^-}{S_i^+ + S_i^-}, \tag{10}$$

Let $f_j(a)$ denote the performance of alternative a on criterion *j*. For a pair (a,b), define the difference d in $d_j(a,b)=f_j(a)-f_j(b)$ as "how much a outperforms b" on criterion *j* (for cost criteria, reverse the sign or swap *a*, *b*). Then choose a preference function $P_j(d)$ with indifference and preference thresholds q_j and p_j as a linear form.

$$P_j\left(d\right)=0 \text{ if } d\le q_i, \tag{11}$$

$$P_j\left(d\right)=\frac{d-q_j}{p_j-q_j},\ \text{ if } q_j<d<p_j, \tag{12}$$

$$P_j\left(d\right)=1,\ \text{ if } d\ge p_j, \tag{13}$$

Alternatives are sorted by C_i (higher is better) [24]. For each criterion *j*, a preference function $P_j\left(d\right)$ and thresholds q_j, p_j are specified; positive / negative flows $\phi+(a), \phi-(a)$ and the net flow $\phi(a)=\phi^{+}(a)-\phi^{-}(a)$ ranking by ϕ [19], [25].

Decision merging policies in the ATC algorithm loop are modelled as logical rules at the level of system recommendations and execution permissions.

AND: manoeuvre execution is permitted if all subsystems (ATCO decision, algorithmic advisor, conflict check) confirm safety.

OR: execution is permitted if at least one subsystem confirms safety.

MAJORITY (2/3): execution is permitted with the support of most subsystems.

Figure 1 depicts the empirical distribution of gate headways by alternative, illustrating the dispersion that the adopted geometry and intercept design must accommodate. The actual impact of the policy is reflected in the change in the values of the sub-criteria Safety (LoS/CPA), Efficiency (delay, landing rate), and Human Performance (workload, radio communication density), after which the alternatives are compared in the MCDM core.

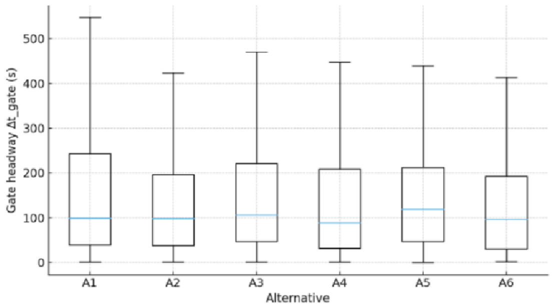

Fig. 1. Distribution of gate headway (Δt_gate) by alternatives ($A1$–$A6$)

IV. Simulation Setup

As a representative airport we take Dublin (EIDW), where Point Merge has been implemented and documented in peer-reviewed studies; the sample covers a continuous span of 4 weeks of a typical "summer" schedule, with peak windows and LT isolated for the analysis of arrival sequencing. This duration provides statistical stability of frequency-based indicators and a sufficient spectrum of weather conditions without mixing seasonal effects. The complete input data is stored in Appendix *A*.

Entry times onto the arc are generated as a stochastic process with target spacing S^* and Gaussian fluctuation ($\sigma \approx 0.22S^*$). A minimum release interval is imposed for the policies:

AND: 1.00 × S^*;

MAJORITY: 0.90 × S^*;

OR: 0.75 × S^*.

On the arc – 210 kt IAS, on final – 160 kt IAS. For each flight, the arc sweep sector is random within 55–95° (determines arc length and time to gate). Firm mode reduces interval dispersion (approximately −30% σ) compared with Moderate.

The probability of "level-off" depends on the policy (AND: 10%, MAJORITY: 20%, OR: 32%); duration follows a triangular distribution 60–240 s (mode 120 s). This adds a low-level horizontal segment and a minor fuel penalty. A time-based LoS proxy is evaluated at the gate: if Δt gate < 30 s, an LoS event is recorded (simplified indicative metric). Simplified TMA model: burn on the arc (22 kg/min), on final (18 kg/min) + 50% penalty from level-off; CO_2 = 3.16 fuel. This yields comparable effect estimates. Each flight is matched to the nearest-in-time EIDW METAR (wind, visibility, precipitation, QNH), which allow key performance indicators (KPI) to be stratified by weather regimes.

Historical ADS-B trajectories (OpenSky) for EIDW are used as seeds: we extract time, latitude, longitude, height, speed, and track series $t, \phi, \lambda, h, v_g, \chi$, filter within the TMA, reconstruct arrivals to final, label waiting arcs and sequencing legs, and identify the merge/gate. Each flight is joined to the temporally nearest METAR (wind, visibility, precipitation, QNH) to enable weather-stratified KPIs. No geometric edits are applied to the empirical trajectories themselves – they provide initial states and profiles only. Given the PMS geometry and the decision-fusion policies (AND/OR/MAJORITY), we set a target spacing S^* and a speed-control regime (Moderate / Firm). We then generate inputs; minimum release intervals depend on policy; we model the probability and duration of level-off (triangular distribution), compute a gate-level loss-of-separation proxy, and estimate fuel / CO_2 using BADA with CORSIA factors. These synthetic components define the experimental scenarios on which KPIs are computed and subsequently evaluated by the MCDM procedures. On the resulting trajectories, we label the segments "waiting arc" and "sequencing leg" according to PMS geometry, identify the merge point, and also the decision points (arc entry/exit, speed-control commands, vectoring to the merge point)-these are precisely where the AND/OR/MAJORITY policies are applied (see Methodology). Figure 2 presents the loss-of-separation (LoS) rate for all six alternatives; values are reported in percent, where lower is better.

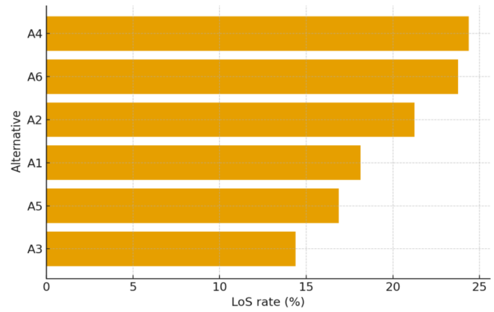

Fig. 2. Loss-of-separation (LoS) rate

NASA-TLX indicators (6 scales with weighting) are collected in a controlled experiment with a simulated ATC environment for the same scenes that reproduce the EIDW geometry and empirical arrival profiles; additional proxies include radio-communication density (messages/min), number of corrective commands per flight, and reaction time from recommendation to acknowledgement [8]. Figure 3 visualises the distribution of spacing error on the arc per alternative, directly tied to the labelled “waiting arc” segment.

Inter-arrival intervals *t* are derived from ADS-B as empirical values (STA-proxy based on time of TMA entry or crossing of the control arc) and, in parallel, we calibrate a Poisson (λt) model for "low / medium / peak" intensity scenarios with subsequent application in the simulation environment.

To interpret deviations and variability of spacing error, scenarios are stratified by weather (wind / visibility / precipitation) based on open meteorological sources; in the analysis, we retain both "averaged" results and slices for the subsamples "calm / moderate / strong wind." On the labelled trajectories we compute in-trail spacing on the arcs (in seconds/NM), landing rate in peak windows, and level-off time and the length of horizontal segments below a specified FL as environmental proxies, (iv) CPA and LoS events by a separation detector compliant with TMA norms [21], [26].

Arrival fuel burn is estimated with BADA for typical fleets (A320/B738/E190, etc.) on the reconstructed vertical profiles, after which the conversion "fuel – CO_2" is performed according to the CORSIA methodology (Annexe 16, vol. IV) [27], [28]. Figure 4 reports the mean terminal-area CO_2 per arrival, enabling a direct environmental comparison between policy/spacing settings.

To compare AND/OR/MAJORITY policies on the "same" flows, we apply an open fast-time simulator BlueSky with conflict-detection and speed-control modules; empirical trajectories serve as "seeds" for reproducing initial states and profiles. In Table I, six alternatives with policies and scenarios are considered.

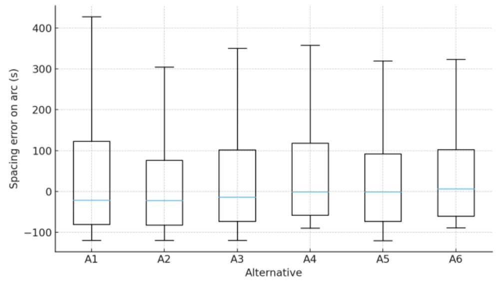

Fig. 3. Spacing error on the arc (seconds) by alternatives

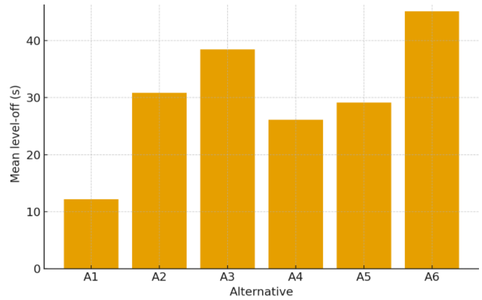

Fig. 4. Mean level-off time at low altitude, by alternative

TABLE I. KPI AGGREGATED RESULTS FOR SIX ALTERNATIVES

alt_code	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**
flights	160	160	160	160	160	160
S_star_s	120	120	120	90	120	90
policy	AND	MAJ	OR	MAJ	MAJ	OR
speed_control	Moderate	Moderate	Moderate	Moderate	Firm	Firm
mean_delta_gate	168.486	175.3767	172.2287	141.1062	180.7488	147.2059
p5_delta_gate	10.0401	6.101651	5.527468	4.685727	6.122269	4.059901
p95_delta_gate	548.4394	558.425	490.9145	407.7723	517.9439	446.7758
spacing_err_arc_mean	48.48599	55.37672	52.22865	51.10621	60.74884	57.20586
los_rate	0.18125	0.2125	0.14375	0.24375	0.16875	0.2375
leveloff_mean_s	12.17269	30.83069	38.48096	26.12854	29.1335	45.14569
co2_mean_kg	40595.32	40768.59	40553.07	40000.78	40653.58	40094.86
fuel_mean_kg	12846.62	12901.45	12833.25	12658.47	12865.06	12688.25

Figure 5 shows the relationship between wind speed and gate headway by policy, illustrating the weather-sensitivity of release regularity.

Each alternative simulates 160 flights on the RWY 28L geometry. For each flight, we compute Δt at arc entry, at the gate, and on final; spacing error relative to S^*; LoS flag; level-off time (s); arc length; fuel and CO_2 estimates; and meteorological parameters are also attached. At the alternative level, we aggregate means/quantiles of Δt, mean spacing error, LoS share, mean level-off time, fuel and CO_2 TOPSIS is used with AHP weights: Safety 0.40, Efficiency 0.25, Human 0.20, Environment 0.15.

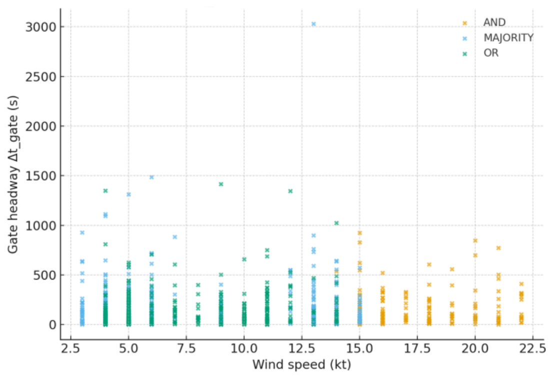

Fig. 5. Gate headway Δt gate versus wind speed (scatter)

V. Conclusions

We modelled Point Merge gate release as a fusion of readiness signals under three aggregation logics AND (conservative), OR (aggressive), and MAJORITY (intermediate), protected by a non-compensatory safety guard. With baseline safety held constant, policy choice primarily shaped headway regularity, radio-communication density, speed-advisory frequency, and low-altitude level-offs. Crucially, air traffic controller workload was treated as a first-class outcome through a human workload index (HWI) combining expected advisory count, level-off time, short-headway alerts, and METAR-based difficulty markers. Incorporating HWI into multi-criteria ranking (Safety, Efficiency, Human, Environment) often reordered preferences: options that look time-efficient alone can impose higher controller workload and more low-level flight, whereas steadier, earlier releases support idle-thrust segments and lower fuel / CO_2.

Practically, the interplay between target spacing and control firmness must be calibrated together with an acceptable ATC workload level. Tighter spacing raises nominal access but narrows the window for speed-based corrections and amplifies sensitivity to stochastic arrivals; firmer pre-gate control can contract input variance and reduce last-moment advisories without altering admissibility logic. The framework is auditable and tunable via a compact parameter set (spacing buffer around S^*, maximum speed change, short-horizon stability look-ahead / variance, short-time separation proxy). Limitations (type-agnostic performance, no controller-in-the-loop trials, coarse fuel estimates, no departures / mixed modes) motivate future work with real-track calibration, type-specific models, parallel-runway scenarios, and outranking schemes that keep Safety and ATC workload non-compensable.

References

[1] International Civil Aviation Organization. (n.d.). *Annex 11: Air traffic services* (15th ed.). ICAO.

[2] International Civil Aviation Organization. (n.d.). *Doc 4444: Procedures for Air Navigation Services – Air Traffic Management (PANS-ATM).* ICAO.

[3] International Civil Aviation Organization. (n.d.). *Doc 9859: Safety management manual* (4th ed.). ICAO.

[4] B. Favennec, E. Hoffman, et al., "The point merge arrival flow integration technique," *AIAA Aviation Technology, Integration, and Operations Conference*, 2009. https://doi.org/10.2514/6.2009-6921

[5] H. Hardell, E. Otero, T. Polishchuk, & L. Smetanová, "Optimizing air traffic management through point merge procedures: Minimizing delays and environmental impact in arrival operations," *Journal of Air Transport Management*, 102706, 2025. https://doi.org/10.1016/j.jairtraman.2024.102706

[6] K. Dönmez, C. Çetek, & O. Kaya, "Air traffic management in parallel-point merge systems under wind uncertainties," *Journal of Air Transport Management*, 102268, 2022. https://doi.org/10.1016/j.jairtraman.2022.102268

[7] International Civil Aviation Organization. (n.d.). *Doc 9931: Continuous descent operations (CDO) manual.* ICAO.

[8] S. G. Hart, & L. E. Staveland, "Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research," In *Advances in Psychology*, vol. 52, 1988, pp. 139–183. https://doi.org/10.1016/S0166-4115(08)62386-9

[9] B. Alaydi, et al., "Mitigating the Negative Effect of Air Traffic Controller Mental Workload on Job Performance," *Safety*, 10(1), 20, 2024. https://doi.org/10.3390/safety10010020

[10] J. K. Kuchar, & L. C. Yang, "A review of conflict detection and resolution modeling methods," *IEEE Transactions on Intelligent Transportation Systems*, 2000. https://doi.org/10.1109/6979.898217

[11] H. Taherdoost, "Multi-criteria decision making (MCDM) methods and concepts," *Encyclopedia*, 2023. https://doi.org/10.3390/encyclopedia3010006

[12] A. Oren, & O. Şahin, "The flight efficiency analysis on the multi-arrival route point merge system," *The Aeronautical Journal*, 2022. https://doi.org/10.1017/aer.2021.105

[13] X. Olive, J. Sun, L. Basora, & E. Spinielli, "Environmental inefficiencies for arrival flights at European airports," *PLOS ONE*, 2023. https://doi.org/10.1371/journal.pone.0287612

[14] K. Dönmez, C. Çetek, & O. Kaya, "Aircraft sequencing and scheduling in parallel-point merge systems for multiple parallel runways," *Transportation Research Record*, 2022. https://doi.org/10.1177/03611981211049410

[15] H. Li, F. Wang, R. Yan, et al., "Rapid mental workload detection of air traffic controllers based on EEG power spectrum features, *Sensors*, 2024. https://doi.org/10.3390/s24144577

[16] Q. Shao, Y. Sun, X. Zhang, et al., "Air traffic controller workload detection based on EEG and NASA-TLX," *Sensors*, 2024. https://doi.org/10.3390/s24165301

[17] S. Dožić, "Multi-criteria decision making methods: Application in the aviation industry," *Journal of Air Transport Management*, 2019. https://doi.org/10.1016/j.jairtraman.2019.101683

[18] M. F. Bongo, K. M. S. Alimpangog, J. F. Loar, J. A. Montefalcon, & L. A. Ocampo, "An application of

DEMATEL-ANP and PROMETHEE II approach for air traffic controllers' workload stress problem, *Journal of Air Transport Management*, 2018. https://doi.org/10.1016/j.jairtraman.2017.10.001

[19] J.-P. Brans, & P.-H. Vincke, "Note – A preference ranking organisation method (the PROMETHEE method), *Management Science*, 1985. https://doi.org/10.1287/mnsc.31.6.647

[20] K. Kiracı, B. Yıldız, & M. Bakir, "Aircraft selection by applying AHP and TOPSIS in interval type-2 fuzzy sets environment," *Complex & Intelligent Systems*, 2020. https://doi.org/10.1007/s40747-020-00154-3

[21] International Civil Aviation Organization. (n.d.). *Doc 4444: PANS-ATM.* ICAO.

[22] T. L. Saaty, "Fundamentals of the analytic network process," *Journal of Systems Science and Systems Engineering*, 2004. https://doi.org/10.1007/s11518-006-0158-y

[23] T. L. Saaty, "Decision making with the analytic hierarchy process" *International Journal of Services Sciences*, 2008. https://doi.org/10.1504/IJSSCI.2008.017590

[24] M. Behzadian, S. K. Otaghsara, M. Yazdani, & J. Ignatius, "A state-of-the-art survey of TOPSIS applications, *Expert Systems with Applications*, 2012. https://doi.org/10.1016/j.eswa.2012.05.056

Received 14 April 2025

Marshalok Daniil. Postgraduate student.
Faculty of Air Navigation, Electronics and Telecommunications, State University Kyiv Aviation Institute, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine, (2021).
Research area: air navigation.
Publications: 3.
E-mail: 4646212@stud.kai.edu.ua

Luppo Oleksandr. Candidate of Pedagogical Sciences. Associate Professor.
Department of Air Navigation, Faculty of Air Navigation, Electronics and Telecommunications, State University Kyiv Aviation Institute, Kyiv, Ukraine.
Education: Civil Aviation Academy, (1982).
Research area: air navigation.
E-mail: oleksandr.luppo@npp.kai.edu.ua

Д. О. Маршалок, О. Є. Луппо. Робоче навантаження диспетчера як чинник багатокритеріального секвенування прибуттів у системі точкового злиття

У роботі досліджено стратегії випуску з дуг Point Merge у термінальних районах для надійного секвенування прибуттів і забезпечення розділення. Розглянуто три політики агрегації рішень на виході з дуги кон'юнктивну, диз'юнктивну та мажоритарну із неконпенсаційним бар'єром безпеки та варіантами керування швидкістю щодо цілі S*. Метою є оцінка здатності цих політик регулювати інтервали, підтримувати часове розділення, зменшувати політ на ешелоні на малих висотах, керувати попитом на вказівки та обмежувати екологічний вплив за різної погоди. Як приклад виконано експеримент на оприлюдненій геометрії Дубліна (EIDW) RWY 28L із реалістичною кінематикою й стратифікацією за METAR; показники включають інтервали на дузі/воротах/фіналі, помилку від цілі S*, часовий проксі втрати розділення, тривалість польотів на ешелоні та грубі оцінки пального / CO_2. Людський фактор ураховано через індекс робочого навантаження диспетчера, а ранжування альтернатив здійснено методом TOPSIS з AHP-подібними вагами за критеріями Безпека, Ефективність, Людський фактор і Довкілля. Результати показують, що вибір політики є ключовим драйвером регулярності інтервалів, навантаження радіообміну та низьковисотної поведінки, а явне врахування робочого навантаження диспетчера може змінювати пріоритети порівняно з оцінкою лише за ефективністю; отримана рамка є аудиторною та придатною до налаштування під специфіку аеродрому.

Ключові слова: навігація; система точкового злиття; керування повітряним рухом; робоче навантаження диспетчера.

Маршалок Даніїл Олександрович. Аспірант.
Факультет аеронавігації, електроніки та телекомунікацій, Державний університет Київський авіаційний інститут, Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна, (2021).
Напрям наукової діяльності: аеронавігація.
Кількість публікацій: 3.
E-mail: 4646212@stud.kai.edu.ua

Луппо Олександр Євгенійович. Кандидат педагогічних наук. Доцент.
Кафедра аеронавігаційних систем, Факультет аеронавігації, електроніки та телекомунікацій, Державний університет Київський авіаційний інститут, Київ, Україна.
Освіта: Академія цивільної авіації, Київ, Україна, (1982).
Напрям наукової діяльності: аеронавігація.
E-mail: oleksandr.luppo@npp.kai.edu.ua