DOI: 10.21857/9xn31cop7y
Pregledni članak / Review paper
Prihvaćeno / Accepted: 14. listopada 2021.

THE EUROPEAN AIRSPACE FRAGMENTATION: A COST-EFFICIENCY BASED ASSESSMENT

Sanja Steiner, Zvonimir Rezo, Ružica Škurla Babić, Cristiana Piccioni

Summary

Due to the ANSPs' (Air Navigation Service Providers') unit rates variability in different European airspace areas, the AUs (Airspace Users) pay different financial amounts for the same ANS (Air Navigation Service) provision. The AUs' interest is to achieve the lowest possible operational costs, so it is often the case that the aircraft, if there is an alternative, fly on longer but economically more acceptable routes through cheaper charging zones. Over the time, the application of such practice has led to the creation of different business interests – that is a critical issue hindering further air transport development in Europe. This paper investigates the research question of whether and if so, how the European airspace is fragmented in terms of cost-efficiency features. By the application of the spatial autocorrelation methodology, i.e. by associating every ANSP's unit rate value with its spatial position within the European ATM (Air Traffic Management) system, the research question has been answered. Research findings indicate that the European airspace is fragmented from a cost-efficiency aspect and divided into several different homogeneous areas. Such areas are characterized by a certain similarity level of adjacent unit rates, whereas one charging zone represents a hotspot in terms of its dissimilarity to adjacent spatial units.

Keywords: Air Traffic Management; European airspace; Strategic planning; Fragmentation; Cost-efficiency.

1. INTRODUCTION

Since the 1950s, the European countries have hesitated to impose en-route charges to usually financially subsidized or fully state-owned airlines. However, several factors made governments re-evaluate their standpoints. Greater exploitation of jet aircraft, as well as increased traffic levels, have resulted in significantly increased costs of providing air navigation services. Governing bodies became aware that their systems did not correspond with the ideas of the future air traffic development. Moreover, they realized that further expansion of the civil aviation market would enable the free provision of air navigation services to domestic airlines, foreign airlines and privately-owned airlines. This situation resulted in developing a more comprehensive approach to strategic air traffic planning at regional rather than national level, as it was done in the past.

The current applications of strategic air traffic planning with the "demand-oriented" option within highly fragmented European airspace design has caused an unbalanced air traffic development in Europe. This furthermore had a direct impact on the creation of different unit rate values applicable in various charging zones across the European airspace.

Airspace fragmentation is generally recognized as one of the main causes of the ATM system's inefficiency, especially from the economic point of view. In this context, the paper seeks to provide information that can ease the conduction of strategic planning of the future air transport development in Europe. More precisely, this paper aims at determining whether and how the European airspace is fragmented from the cost-efficiency aspect, thus presenting an overview of research background, in terms of literature review and research motivation, the currently applicable European ANS charging scheme, as well as the methodological framework. Furthermore, the obtained results are presented and briefly described. Lastly, before conclusion, the research findings are discussed in wider context, whereby their relevance is argued in sense of airspace fragmentation' repercussions on day-to-day operations, and in respect to some of the ideas/proposals of the future ATM system's development in Europe.

2. RESEARCH BACKGROUND

2.1 A survey of previous studies

In the domain of air traffic management, the term "fragmentation" began to be frequently used within the last two decades. Even though the problem of airspace fragmentation was recognized in the 1990s [1], little has been done to resolve this issue or to minimize associated negative impacts [2]. Various authors [3-14] are concerned with airspace design and system performances, and highlight the European airspace fragmentation as one of the main causes of the European ATM system's inefficiency and a barrier to its future development. Thereby, a null hypothesis of this research is that the European airspace is also fragmented in terms of cost-efficiency (one of four key performance areas of the future development of the ATM system in Europe). However, although the airspace fragmentation became a commonly applied term, during the past years it was neither frequently studied nor comprehensively addressed, so that a minor progress has been made to describe this issue more in-depth [15]. To this end, this research aims at complementing the existing literature in the field.

Although significant work has been done to study design, characteristics and performances of the European ATM system, most studies do not consider all three correlated features of the ANSPs' performance data. They usually omit the spatial, and define only the temporal and value features of data. As a result of this practice, the spatial component of data set is often underutilized. Since 80% of information requirements posed by policy makers are related to the spatial location, it certainly raises many issues [16,17]. Moreover, the literature review indicates that there are no sources that spatially correlate performances of the ATM system in Europe and airspace fragmentation. Hence, it was necessary to study this issue more in-depth.

By testing the existence and determination of the level of the European airspace fragmentation in terms of cost-efficiency, the ones dealing with the strategic planning and development of the ATM system in Europe can get a clear picture of potential areas requiring improvements, and obtain information about why do the AUs "behave" as they do. Figure 1 shows a simplified view of flight trajectory in respect to spatial process that influenced flight planning in such a way that the AU flew rather through green than through yellow and red areas. Thereby, colour gradation from green to red can be observed from various performance indicators. For instance, red areas can denote areas with capacity shortfall, inadequate horizontal flight efficiency, higher en-route charges or higher airspace complexity – and vice versa for green areas. Additionally, considering that risks existence can compromise the realization of strategic goals, one of the core purposes of strategic planning is to reduce business risks. This is of great importance, because aviation is a financially intensive business environment, within which the ATM system represents a business activity with high financial turnover. Accordingly, better understanding of the European airspace fragmentation level in terms of cost-efficiency leads to a better description of business environment, and consequently reduces business risks.

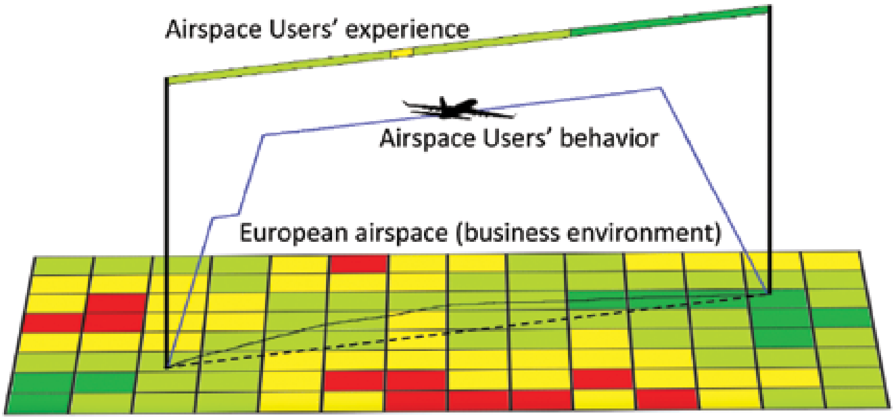

Figure 1. A simplified view of understanding Airspace Users' "behaviour" through the understanding of spatial processes [18]

Slika 1. Pojednostavljeni prikaz razumijevanja „ponašanja" korisnika zračnog prostora kroz razumijevanje prostornih procesa [18]

Considering the above-mentioned, the survey of the previous research points out that it has never been defined how to test the existence or how to measure the level of the European airspace fragmentation in terms of the ATM system performances. In order to determine this, the method of the ESDA (Exploratory Spatial Data Analysis) has been applied. It has been composed from a set of techniques aimed at describing and visualizing the spatial distribution of data, identifying "atypical localization" or outliers, detecting patterns of spatial association (e.g. clusters, hotspots, or cold spots), and suggesting spatial regimes [19-22].

2.2 Research motivation

In addition to attempting to fill the shortcomings identified by the literature review, this research is also strongly motivated by the high relevance of the covered topic in the domain of strategic planning of the ATM system development in Europe, particularly because conceptual assumptions of the currently applicable strategic planning framework have many flaws – all of which are associated with the fragmentation issue. One of them arises from the fact that the European ATM system is still mainly organized at national scale. This is problematic, because the ATM system in Europe involves a high number of stakeholders, which may, in different areas, have greater or smaller impact on the ATM system performances [23]. In such circumstances, partial and nationally oriented development plans are not a rare occurrence, which is a critical issue, because regional planning ought not to be conditioned by individual national interests. This is compounded by the fact that there is currently no methodological framework that considers the ANSPs' performance interdependencies, trade-offs, goal conflicts, etc., or that evaluates the coherence of their development plans, performance targets, etc.

Another issue related to the above strategic planning is its individualistic approach to evaluating the achieved performance level. Whether or not an ASNP is successful is purely determined by comparing its performance achievements with those regulatory determined, e.g. Performance Scheme. This is problematic, because the spatial component of the data is completely ignored. For instance, if in the following year the ANSP achieves a reduction of 1.9% of unit rate value, according to performance targets of RP3 (3rd Reference Period) [24], this will be considered a success. However, currently, such success is at no point assessed in respect to the situation and performances achieved at local level. Given that "positions are already taken" and that in the following years, every ANSP will be obliged to respect the RP3 targets, the application of such an approach will result in the fact that future outlook will be proportionally equal to the pre-existing situation. In other words, higher and lower values will remain so, only that, within a certain time lag, their values will be reduced. Thereby, as long as individualistic approach in the evaluation of achieved performances is applicable, this will contribute to the existence of the performance-based European airspace fragmentation.

Considering that such an approach is not sustainable in the long run, strategic planning needs to be conceptually set, so that it is oriented towards achieving performances that will lead to spatial cohesion [25]. Accordingly, the first step in closing potential performance gaps is to acquire objective information about the current situation. This means the determination of whether, and if so, how fragmented the European airspace is from the cost-efficiency aspect. Hence, it can be concluded that the identification of the European airspace fragmentation in terms of cost-efficiency, by scientifically acceptable methods, is of high significance as such. Particularly, since the obtained information can later be placed in the context of the valorisation of on-going changes, ideas, discussions and regulation proposals seeking to modify, improve, optimize, etc. the performance and outlook of the European ATM system.

3. THE EUROPEAN AIR NAVIGATION SERVICES CHARGING SCHEME

The provision of air navigation services requires certain financial resources. To this end, the European Commission has established a charging system aimed at covering the ANSPs' costs. Nowadays, the ANSPs' costs are directly covered by the AUs. This includes the coverage of terminal and en-route charges charged within en-route and terminal charging zones. Thereby, the ANSPs' costs of en-route services are financed by means of en-route charges imposed to the ANS' users, while the costs of terminal services are financed by means of terminal charges. Both charges are estimated based on unit rate, so that it represents a crucial element of the European ANS charging scheme. For instance, the terminal charge for a specific flight in a specific terminal charging zone equals the product of the unit rate established for this terminal charging zone and the terminal service units for this flight. Thereby, this research deals with the en-route part of charging scheme. Accordingly, a greater emphasis is given to this aspect of the European ANS charging scheme. The value of the en-route charge is established on the yearly basis for each charging zone, and it consists of two parts – the unit rate, and the administrative unit rate. It is calculated by dividing the charging zone's forecasted en-route facility cost-base by the forecasted number of service units generated in the same charging zone. The purpose of administrative unit rate is to recover the costs of collecting route charges, and it is identical for all charging zones [26]. The ANSPs' remuneration is managed by EUROCONTROL's CRCO (Central Route Charging Office). The CRCO was established in 1971, when seven Member States of EUROCONTROL decided to adopt a common charging policy, thus creating a framework of the presently applicable charging scheme. As Figure 2 shows, 40 Member States participate in the charging scheme, thus covering an area of 18,970,200 km^2.

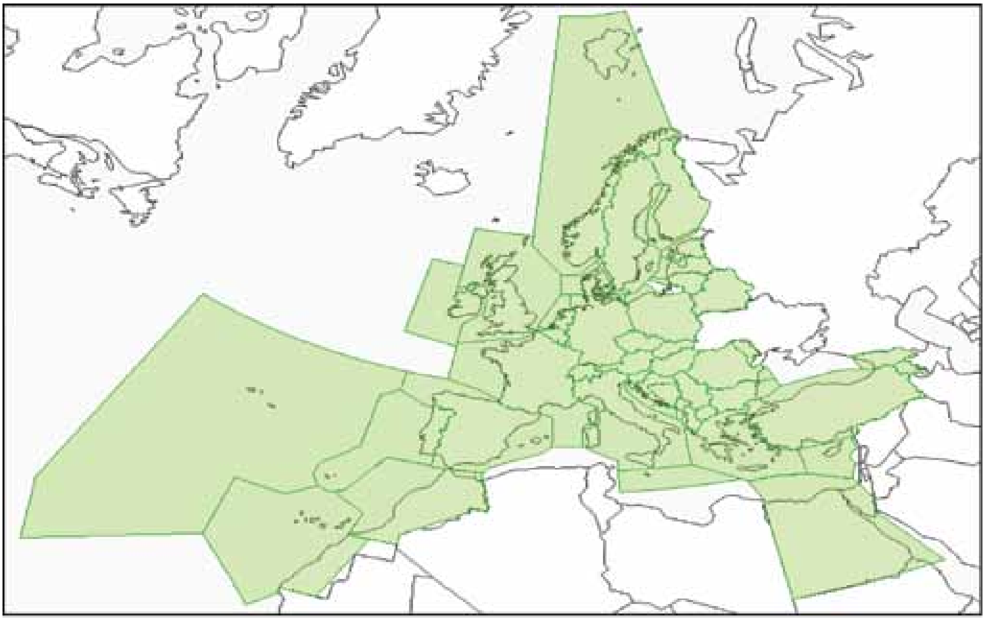

Figure 2. The spatial overview of the charging zones of the European airspace
Slika 2. Prostorni pregled naplatnih zona europskog zračnog prostora

As defined in the Commission's implementing Regulation (EC) 2019/317 [27], when an aircraft enters the charging zones of the Member States, a single *charge for en-route service* (R) is applied. It equals the total amount of the *individual charging zones* (r_i), which the aircraft was flying through:

$$R = \sum_{n} r_i \quad \text{[EUR]} \tag{1}$$

The fee for each individual charging zone is given by the product of the *unit rate* (t_i) and the *number of service units* (N) corresponding to the flight in the specific charging zone:

$$r_i = t_i \cdot N \ \text{[EUR]} \tag{2}$$

The number of service units is calculated as the *flight length factor* (d_i) multiplied by the *weight factor* (p) for the observed flight:

$$N = d_i \cdot p \tag{3}$$

The flight length factor is calculated by dividing by 100 the orthogonal distance between the departing aerodrome (if within the zone) or charging zone's entry point and the first landing airport (if within the zone), or the exit point from the observed charging zone. It is worth noting that the cost calculation process also includes 20 NM (Nautical Miles) deducted for each take-off and landing within the territories of the Member States. The final element required for the cost estimation – *weight factor* (*p*) – depends on the aircraft MTOW (Maximum Take-Off Weight) as follows:

$$p = \sqrt{\frac{MTOW}{50}} \quad [t] \tag{4}$$

Finally, Figure 3 shows an example from practice that best summarises the outlook of the European ANS charging scheme. More precisely, two route options between Cardiff International Airport and Corfu International Airport are given: the blue route indicates the cheapest option, while the green one represents the shortest route option between these two airports.

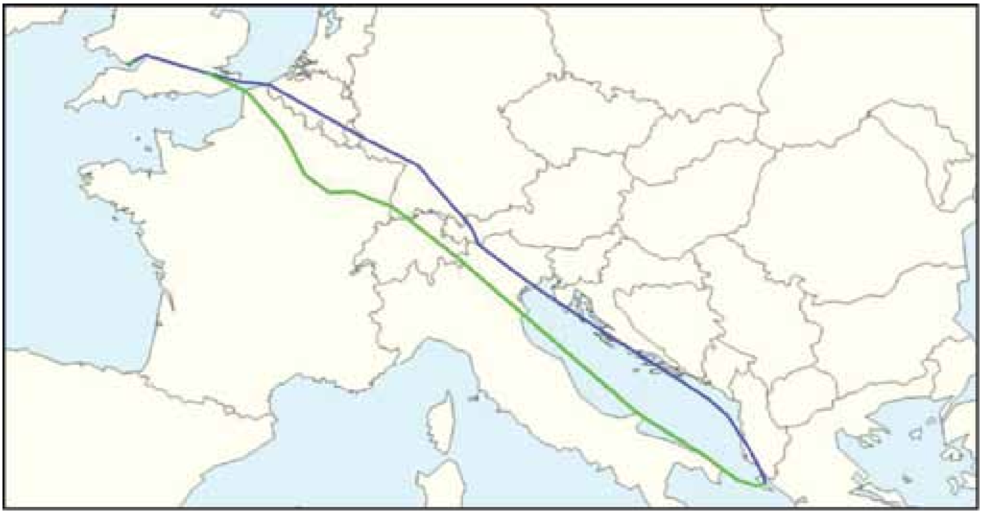

Figure 3. The repercussion of the existing charging scheme' framework on flight planning

Slika 3. Reperkusije postojećeg okvira sustava obračuna naknada na planiranje leta

As already mentioned, the AUs can choose which option suits them best. Considering that aviation is a commercial activity with thin profit margins, it is not surprising that the AUs may, if an alternative exists, prefer the cheaper (but potentially longer) to the shorter (but more expensive) route option. In this context, if the AU uses the blue route option (cheaper, but longer route), its route charges will be approximately 21.90% lower in comparison with the green route option. Moreover, if an AU uses this route/practice two times a day for return flights, by the end of the year, it can reduce its direct operating costs by EUR 543,850. Thus, it is evident that every ANSP's unit rate value in combination with the ANSPs' spatial position within the European ATM network has great importance in relation to the execution of the day-to-day operations of both the ANSPs and the AUs.

4. THE MODELLING APPROACH

In order to answer the well-defined research question, a mathematical model was developed. Such a model performed a data geo-referencing by placing unit rate values in a spatial context. Then the data processing followed, i.e. the conduction of three data analyses involving the European airspace: (1) clustering analysis; (2) spatial outliers' analysis; and (3) critical area analysis. The applied data analysis techniques are further explained in detail in the following paragraphs.

It is worth mentioning that, within the applied model, unit rate values presented in MAUR (Monthly Adjusted Unit Rates) reports have been used as input data. Since EUROCONTROL/CRCO publishes MAUR reports on the monthly basis, all unit rate values were standardized in the form of an average annual value. Thus, unified data have enabled research conduction and the presentation of main findings corresponding to the fragmentation status during 2018. This is important to emphasise because of the variability of the unit rate values both on the annual and on the monthly basis. In this respect, variability on the monthly basis is significantly lower compared to the annual variability. Figure 4 shows the comparison unit rate values in 2012 and 2018. Additionally, the forecasted unit rate values for 2023 have been included in the comparison. In this context, a comparative analysis of the CRCO's and EUROCONTROL's STATFOR (Statistic and Forecast Service) reports [28-33] clearly indicates charging zones, in which unit rate values in 2023 will vary from the given values in 2018. Furthermore, as Egypt, Belarus and Morocco are not EUROCONTROL's Member States, their unit rate values for 2023 were not accounted.

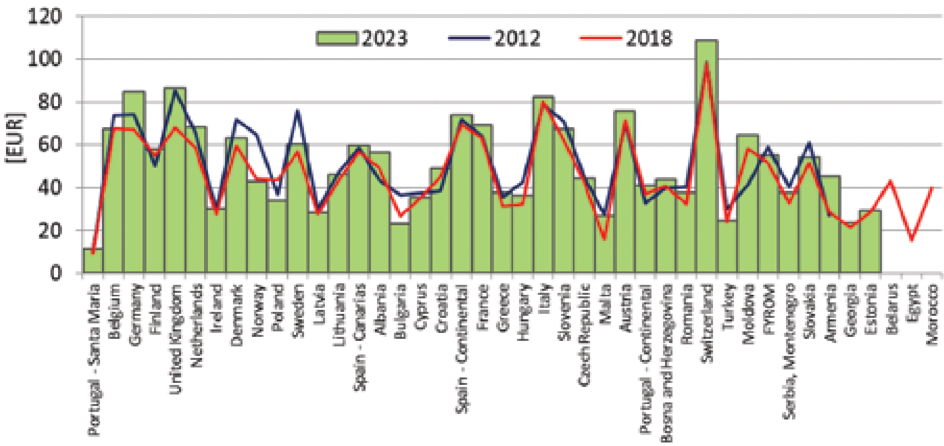

Figure 4. The value and temporal comparison of unit rate values [28-33]

Slika 4. *Vrijednosna i vremenska usporedba vrijednosti jediničnih cijena [28-33]*

4.1 The European airspace clustering analysis overview

A spatial autocorrelation method was used in the analysis of the European airspace clustering. The use of such a method in modelling spatial relations dates back to the late 1940s and 1950s. Schabenberger and Gotway defined it as a relationship among values of a single variable that comes from the geographic arrangement of the areas, in which these values occur [34]. It also corresponds to the Tobler's first law of geography that reads: "Everything is related to everything else, but near things are more related than distant things", thus spatially identifying similarities and differences between adjacent spatial units.

Spatial autocorrelation can be counted both locally (in parts of an observed area) and globally (across the whole observed area). Local spatial autocorrelation analyses are considered more accurate, because the variations are identified by focusing on close neighbourhoods. According to Fotheringham et al. [35], local Moran's indexes I_i can be measured by using the following equation:

$$I_i = \frac{(x_i - \bar{x}) \sum_{j=1}^{n} w_{ij} (x_j - \bar{x})}{\sum_{j=1}^{n} (x_j - \bar{x})^2 / n} \tag{5}$$

where the aforementioned elements designate:
x_i – the value of observed area;
$\bar{x}$ – the average value of observed dataset;
w_{ij} – spatial weight matrix;
x_j – the value of the adjacent area;
n – the number of observed values.

Global spatial autocorrelation analysis detects and measures a spatial pattern across the entire area of interest, but it does not reveal local grouping tendencies or the location of significant patterns. It is measured as an average value of all local Moran's indexes:

$$I = \frac{1}{n}\sum_{i=1}^{n} I_i \tag{6}$$

Based on the obtained local Moran's indexes I_i and resulting global Moran's index *I*, it is possible to determine the type of spatial autocorrelation. On the one hand, in case of obtaining a negative result of spatial autocorrelation, geographic units of similar values will be scattered over the map (observed area). On the other hand, a positive result of spatial autocorrelation indicates that geographical units of similar values tend to group on one spot. Furthermore, since spatial autocorrelation is an inferential statistic, it enables the testing of the null hypothesis. Thereby, as defined by the European Commission [36] and recommended by EUROCONTROL [37], when manipulating aeronautical data and drawing conclusions therefrom, the confidence level must be set at 95%. In order to test the null hypothesis, it is necessary to estimate the z-score. It is estimated based on global Moran's index (*I*), its expected value *E(I)*, and its variance *Var(I)* as follows:

$$z - score = \frac{I - E(I)}{\sqrt{Var_{(I)}}} \tag{7}$$

In order to reject the null hypothesis, the value of the z-score needs to be higher that 1.96 or lower than -1.96. Additionally, the p-value needs to be lower than 0.05 in order to reject the null hypothesis. In case that the p-value is not statistically significant, the null hypothesis cannot be rejected. This would indicate that the spatial distribution of the unit rates is the result of random spatial process – meaning that the European airspace is fragmented from the cost-efficiency aspect. However, in case that the p-value is statistically significant, the null hypothesis can be rejected and this would indicate that the European airspace is not fragmented. In such case, the spatial distribution of high values and low values in the dataset is more spatially clustered than would be expected if the underlying spatial process were random.

4.2 The European airspace spatial outliers' analysis overview

The research of the European airspace fragmentation is expanded by tackling the problematics of spatial outliers. Unlike the previous one, this analysis places the focus on the local level. Accordingly, it determines whether the unit rate value of every charging zone differs from the values of its neighbours. To be able to do so, Moran's I scatter plot method was applied. Anselin [38] describes Moran's I scatter plot as a useful visualization tool for conducting research as it allows to estimate the similarity of the observed value to adjacent values. As Figure 5 shows, Moran's I scatter plot is conceptualized so that the horizontal axis denotes the standard score (*z-score*), while the vertical axis marks the spatial lag (Wz_i), which is a product of the sum of the standard scores multiplied with their spatial weights:

$$W_{z_i} = \sum_{j=1}^{n} w_{ij} y_j \qquad (8)$$

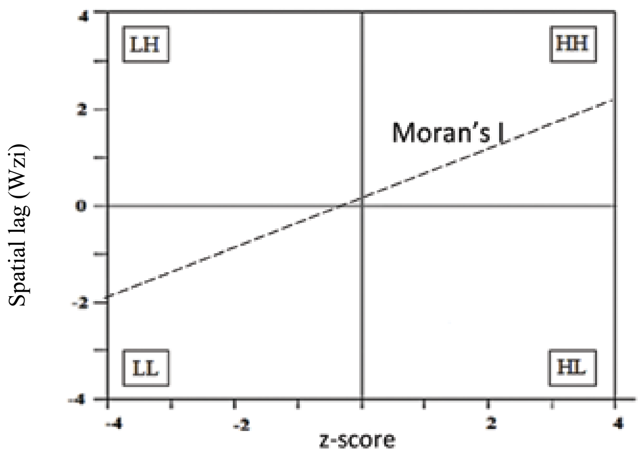

Figure 5. Moran's I scatter plot
Slika 5. Moranov dijagram rasprostiranja

In accordance with Moran's I scatter plot, four indicators have been used:

- HH (High-High) indicator, which defines the area of high neighbouring values;
- HL (High-Low) indicator, which defines a high value area with a low value neighbourhood;
- LH (Low-High) indicator, which defines a low value area with a high value neighbourhood;
- LL (Low-Low) indicator, which defines the area of low neighbouring values.

Considering that this analysis is conceptually analogous to the previous analysis, the interpretations of the results are complementary. In this context, Anselin et al. [39] argue that HH and LL areas indicate a positive spatial autocorrelation (a positive spatial association of values that are higher or lower than the samples' average). Accordingly, HL and LH areas indicate a negative spatial autocorrelation – meaning that the observed values bear little resemblance to their neighbours, and hence represent spatial outliers.

4.3 The European airspace critical areas' analysis overview

The last phase of data processing analyses where significant patterns appear. Thus, the European airspace critical areas' analysis places the focus on the national scale. It determines the significance level of every unit rate value by analysing data similarity with the rest of the dataset, as well as the significance of every unit rate value by analysing their spatial similarity with neighbouring values. The interpretation of the significance level is based on the standard score measuring the mathematical deviation of every unit rate value from the mean value of the analysed dataset (*x* axis), and based on the probability density function (*y* axis), which equals:

$$f(x) = \frac{1}{\sqrt{2\pi}} e^{\left(\frac{x^2}{2}\right)} \tag{9}$$

With respect to the aforementioned and as Figure 6 shows, seven indicators were classified and used:

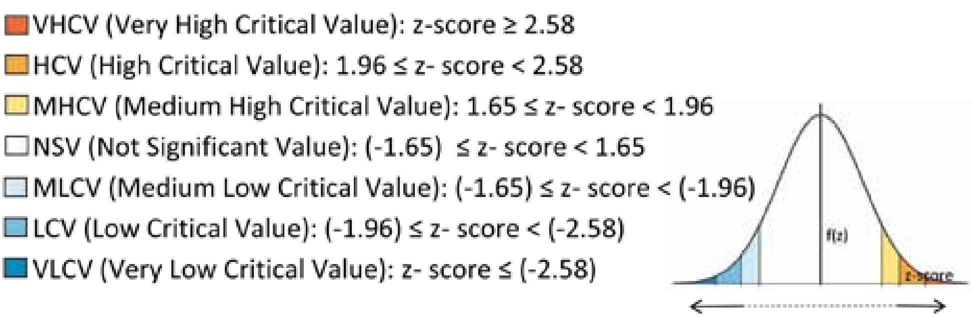

Figure 6. Overview of applied critical values criterion

Slika 6. Pregled primijenjenog kriterija kritičnih vrijednosti

Such an approach (the separation of the spatial from traditional statistics) has allowed the identification of the areas (i.e. charging zones) with significantly higher or lower unit rate values with respect to the analysed dataset, as well as with respect to the values of the adjacent spatial units. Accordingly, extreme unit rate values have been determined. Thereby, extremely high (positive) values, located at the edge of right-tail distribution, have been defined as hotspots. To the contrary, extremely low (negative) values positioned at the edge of the left-tail distribution indicate cold spots.

5. MAIN FINDINGS

5.1 The European airspace clustering analysis' results

The European airspace clustering analysis' outcomes indicate the existence of positive spatial autocorrelation (I=0.32). Keeping in mind that spatial autocorrelation ranges from 0 to 1, it can be argued that a correlation between the spatial units exists, and that geographical units of similar values tend to group on one spot. Accordingly, Figure 7 shows the charging zones composing a spatial pattern that includes 40.48% of all the analysed unit rate values, while from the spatial viewpoint, they cover 33.74% of the total studied area. Additionally, the local Moran's indexes' results show that the Swiss, Belgian, German, Austrian, Turkish, French, Georgian, Armenian and Egyptian unit rate values contribute the most to the positive value of the global Moran's index. Contrary to that, the unit rates of Portugal – Santa Maria, Malta and Ireland deviate in the other direction (areas with negative local Moran's indexes), thus lowering the overall scale of the positive value of the global Moran's index. Moreover, after running the significance test, it has been determined that the depicted spatial pattern does not represent a spatially significant pattern (with the z-score of 0.405, and the p-value of 0.686). In other words, the spatial distribution of high values and low values in the dataset is not spatially clustered. Accordingly, the depicted spatial pattern does not represent a spatial cluster.

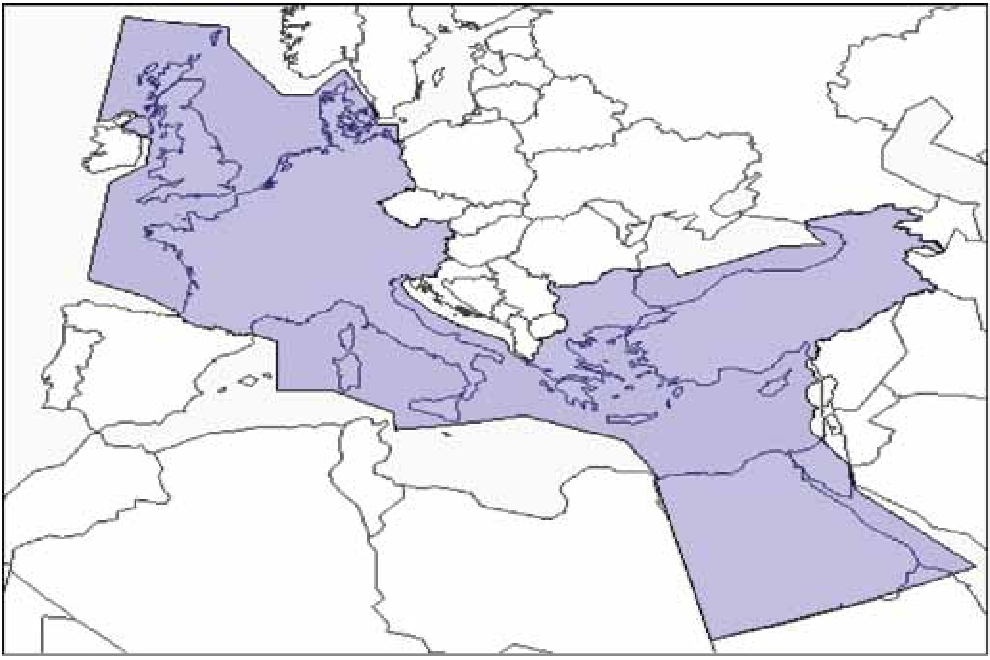

Figure 7. The spatial overview of the obtained spatial pattern

Slika *7*. Prostorni prikaz dobivenog prostornog uzorka

In line with the above, the null hypothesis cannot be rejected. In other words, the spatial distribution of the unit rate values is the outcome of the random spatial process. It can thus be concluded that the European airspace is fragmented in terms of cost-efficiency. Furthermore, considering that there is no significant spatial pattern, the understanding of this outcome can be improved by studying the functional integration of spatial units at the local level. This is also required because the depicted spatial pattern does neither reveal local grouping tendencies nor where significant patterns appear. This has paved the way to further analyses aimed at overcoming the methodological limitations and providing more details about spatial processes occurring locally.

5.2 The European airspace spatial outliers' analysis results

Spatial processes that occur locally and contribute to the existence of the fragmented European airspace in terms of cost-efficiency have been identified by the conduction of the airspace spatial outliers' analysis, i.e. by comparing the unit rate value of every charging zone with their neighbours' values. Accordingly, the research findings indicate that thirteen charging zones (30.95% of overall dataset) can be classified according to the HH indicator, i.e. they are designated as areas of high neighbouring values. Fourteen charging zones are characterized as areas of low neighbouring values, and cover 33.33% of the overall analysed dataset. HL indicator, which characterizes high value areas with low value neighbourhood, includes five charging zones, and covers 11.91% of the whole analysed dataset. All the other charging zones are classified according to the LH indicator, and they constitute 23.81% of the overall analysed dataset. In general, spatial outliers are mainly located in the delimitation areas of high and low adjacent values, and represent 35.72% of the overall analysed dataset. From the spatial viewpoint, in respect to the total area under study, the European airspace is segmented as follows: HH (21.85%); LL (23.46%); HL (14.02%); LH (40.67%). Figure 8 illustrates the European airspace spatial outliers' analysis overview.

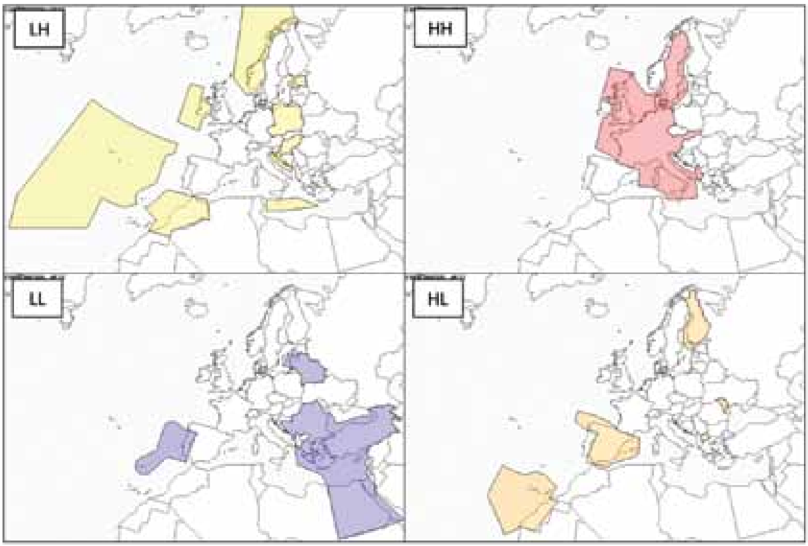

Figure 8. The spatial overview of the European airspace spatial outliers

Slika 8. Prostorni prikaz prostornih netipičnih vrijednosti u okviru europskog zračnog prostora

5.3 The European airspace critical areas' analysis results

The European airspace critical areas' analysis processed data in respect to their (*a*) value-based similarity and (*b*) spatially-based similarity. On the one hand, the value-based similarity of data distribution has been determined by means of traditional statistics, where raw data have been used as an input data. On the other hand, the spatially-based similarity of data distribution has been determined by means of spatial statistics, whereby local Moran's indexes have been used as input data. Accordingly, this approach has led to different data distributions.

Based on the application of Sturges' rule, Figure 9 shows a comparative overview of the resulting data distributions. Thereby, in order to obtain a sense of data distribution, data have been categorized into 6 bins (*x* axis). These bins have been placed in respect to frequency distribution (*y* axis) displaying the number of values in each bin. Their combination makes a histogram that enables the determination of data distribution. By comparing two distributions, it can be viewed that raw data have more uniformed distribution in respect to local Moran's indexes distribution. Furthermore, the figures of frequency distribution that categorises the charging zones according to the observed modality of studied data set indicate that raw data tend to be more dispersed than local Moran's indexes.

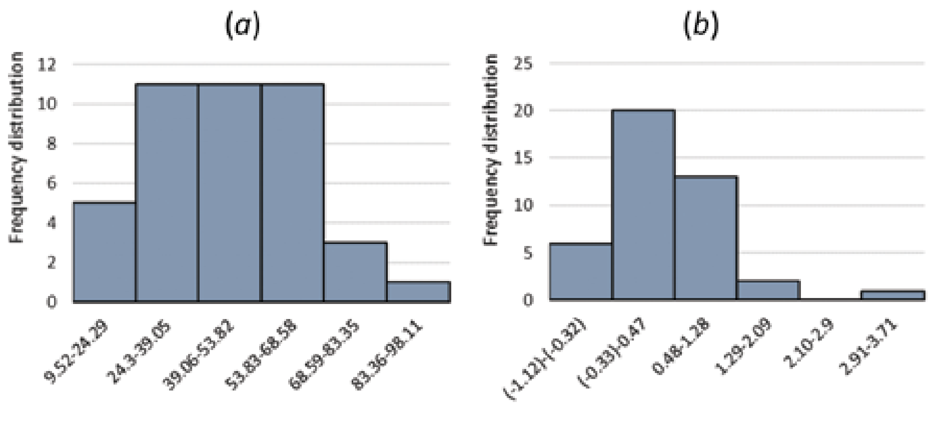

Figure 9. A comparative overview of (a) raw data and (b) local Moran's indexes' distribution

Slika 9. Usporedni pregled distribucije (a) neobrađenih podataka i (b) lokalnih Moranovih indeksa

Furthermore, in terms of the European airspace critical areas' analysis, although the results indicate approximately similar data distributions, different areas were recognized as critical ones. Figure 10 shows the distribution of the identified critical areas. Data distribution within both histograms indicates that only few charging zones can be viewed as outliers. Thereby, the left-hand side histogram and spatial overview under it depict outliers from the attributive aspect. The right-hand side histogram and spatial overview under it denote spatial outliers that differ from the neighbouring charging zones by both the attributive and the spatial aspects. As seen within the spatial overview of the studied area, different charging zones have been identified as critical areas. As such, it was possible to spot differences in the data distribution that are a result of the adoption of the methodological assumption of both independent observations and spatially-dependent observations.

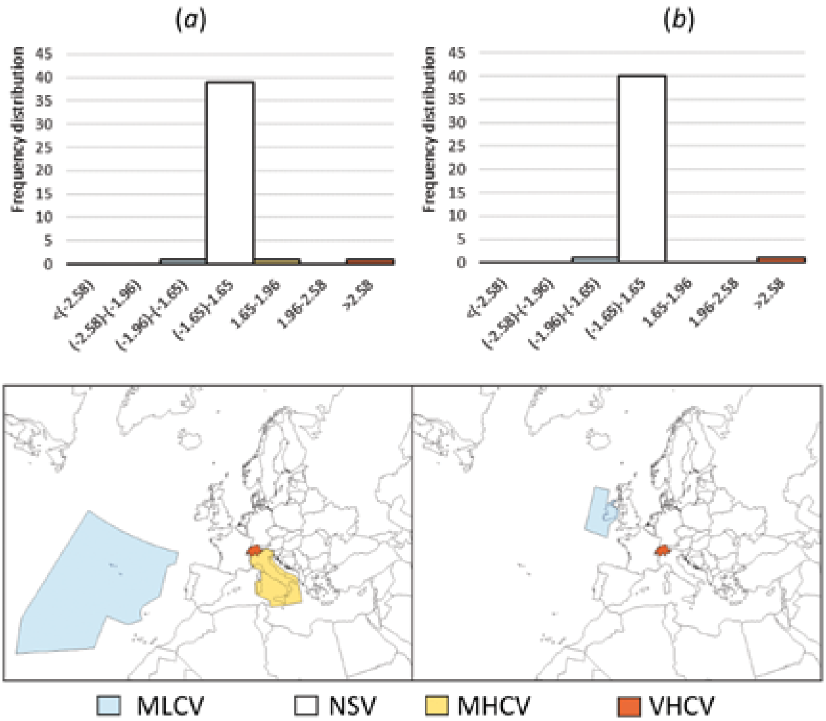

Figure 10. A comparative overview of the critical values' distribution based on the data's (a) value-based similarity and (b) spatially-based similarity

Slika 10. Usporedni pregled distribucije kritičnih vrijednosti na temelju (a) vrijednosne sličnosti i (b) prostorne sličnosti podataka

The results of the value-based data similarity indicate that the unit rate values of Portugal – Santa Maria (z-score of -1.918 indicating MLCV) and Italy (z-score of 1.832 indicating MHCV) significantly differ from the mean value of the analysed dataset, whereby 92.86% share of the dataset, i.e. 68.47% share of the overall studied area, represents an area classified as an "insignificant" one. Compared with the results of the spatially-based data similarity, the unit rate values of these two areas are spatially irrelevant. There are two reasons for this: the first one is due to the fact that the unit rate value of Portugal – Santa Maria charging zone does not significantly differ from unit rate values of neighbouring charging zones; whereas the second reason is that such a charging zone represents a boundary area, thus interacting with both the charging zones of higher and lower unit rate values.

Moreover, the results of the spatially-based data similarity indicate that the unit rate value of Ireland (with the z-score of -1.691 indicating the MLCV) differs significantly from neighbouring value. This is due to the combination of Ireland's unit rate value and its position within the European ATM network. Accordingly, it deviates from its only neighbouring value (United Kingdom), in relation to which it has a significantly lower unit rate.

Both assessments have identified the Swiss unit rate value as the VHCV (both z-score values are ≥ 2.58), meaning that it represents a hotspot. On the one hand, from a value-based data similarity viewpoint, the Swiss unit rate value differs considerably from the arithmetic mean of the analysed dataset. On the other hand, in terms of the spatially-based data similarity assessment, although it is surrounded by several adjacent charging zones, all of which have above average unit rate values, the Swiss unit rate value differs from them in a relevant manner.

6. DISCUSSION

In Europe, the air transport sector represents a complex yet unique network linking people and playing a vital role in Europe's further integration and development [40]. However, to maintain this function, certain conceptual changes need to be made in the strategic planning domain. For instance, the strategic modelling of the future air transport development should not only be indicated by the transport networks' technical elements or the handled transport volume, but rather in terms of availability or connectivity [41]. Moreover, its aim needs to be oriented towards achieving better performances that will lead to spatial cohesion. In this context, Steiner et al. [42] argue that when considering the strategic modelling of air transport development, it is necessary to bear in mind that it is influenced by different external and internal factors. Hence, when evaluating the current state or determining projections of air traffic development, it is important to take into consideration different factors – ranging from the social to the economic impacts of air transport development [43]. For instance, despite the successful resolution of prerequisites enabling the future economic development in terms of the deregulation and implementation of three packages of market liberalisation measures [44-46], the European airspace has remained fragmented based on national borders. This clearly indicates that such an issue is more complex than it might seem, particularly when considering multiple viewpoints from which the airspace fragmentation can be defined and observed.

The airspace fragmentation problem was officially recognized by the European Commission back in 1996, arguing that the European Union "cannot keep the frontiers in the sky that it has managed to eliminate on the ground" [47]. Although much time has passed since then, recognizable constraints associated with the fragmentation problem are still seriously impeding the ability of the European air traffic market to grow sustainably and compete at the international level [48]. Besides, even though the fragmented design of the European airspace is a rather recognizable problem, there are still many assumptions and unanswered questions requiring comprehensive analyses to provide appropriate feedbacks. In this context, added value to this research is that for the first time, the fragmentation of the European airspace has been determined based on the application of the performance-based assessment. Accordingly, the performance-based fragmentation of the European airspace was studied with respect to cost-efficiency – one of four key performance areas of the further development of the European ATM system. This included fragmentation testing through the application of the top-down approach and analysis conduction at three complementary levels (regional, local and national level). Thereby, on the regional level, it was tested whether the European airspace is fragmented in terms of cost-efficiency. Furthermore, at the local level, spatial processes occurring locally were studied, i.e. the appearance areas of spatially-similar values. Lastly, at the national level, it was studied where value-based and spatially-based critical areas occur.

Besides, this research has shown that the European airspace is fragmented from the cost-efficiency aspect, as well as that homogeneous areas with similar unit rate values do exist, and that they are unevenly sized and distributed across the studied area, and finally, that one charging zone represents a hotspot. Accordingly, since the spatial distribution of unit rate values is a result of a random spatial process, the null hypothesis was rejected. However, the acquired results show that at the local level, it was possible to distinguish homogeneous areas that have equal or highly similar unit rate values. Spatial outliers were identified as well. Thereby, since HL areas bear little resemblance to their neighbours, they can be marked as areas in which improvements are needed in near future. Contrary to this, areas that need to avoid their alignment with the adjacent values have been marked as LH areas. Lastly, it is possible to conclude that Switzerland, based on both data similarity and spatial similarity, represents a hotspot and has the highest critical value within the studied area.

In the previous years, it was possible to notice a high variability of unit rate values in different charging zones across the European airspace [49]. This is important to emphasise, because the way that the airspace has been "arranged" will have an impact on the "behaviour" of the air traffic flows / the AUs. Thus, one of the indirect ways of managing air traffic flows is through the unit rates.

The variability of the unit rate values and the spatial inconsistency of the air transport demand has resulted in the current situation, where the AUs pay different fees for Air Navigation Services across different European airspace's areas. That is problematic, because such situations lead to development based on partial and business-oriented interests. For instance, airspace fragmentation in terms of cost-efficiency results in a fact that the AUs have an option to purposely impair their flight efficiency (with the goal to make some financial savings). However, such practice is environmentally harmful, because it results in an increased fuel consumption and consequently, a higher emission level.

From the practical viewpoint, fragmentation effects from the cost-efficiency aspect can be verified by correlating spatial and economic dimensions of research findings with the two earlier presented route options. In this regard, Figure 11 clearly shows why the AUs would prefer the blue to the green route option. It is evident that the green trajectory – indicating that the shorter route (which is environmentally more acceptable, but more expensive) passes almost along its whole length through the charging zones of high neighbouring values. It additionally passes through the charging zone identified as the hotspot. Opposite to this, the blue trajectory indicating the cheaper, but longer route option, avoids the hotspot, and later enters areas marked as LH and LL – hence additionally making financial saving for the AUs. Moreover, considering the spatial position of the identified hotspot within the European ATM network, probably situations as the one shown in Figure 11 are not so rare. Thus, it can undoubtedly be concluded that the way that the European airspace is fragmented in terms of cost-efficiency will have a significant impact on the flight planning activities performed by Airspace Users.

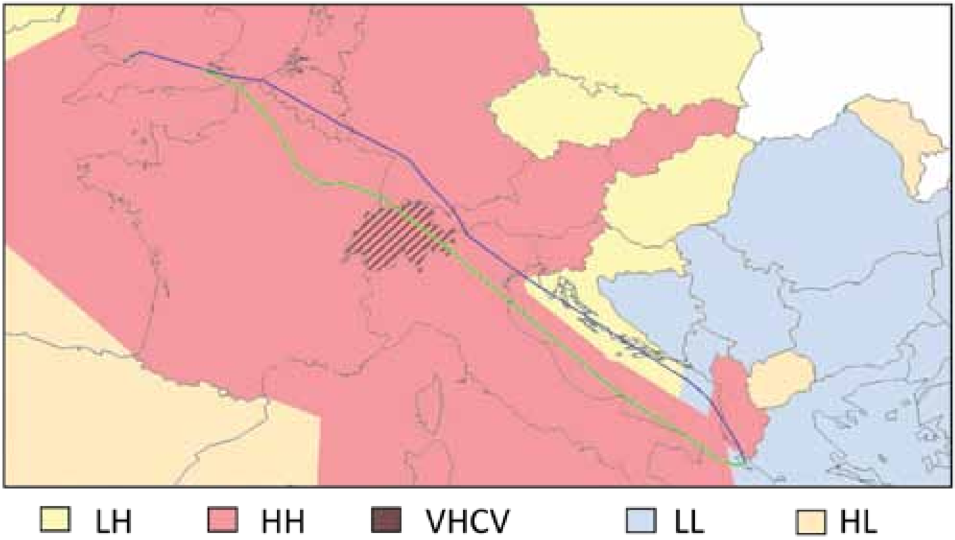

Figure 11. A comparative overview of research findings in relation to two possible flight routes
Slika 11. Usporedni pregled rezultata istraživanja u odnosu na dvije moguće rute leta

The obtained results can be placed in a wider context. For instance, Castelli et al. [50] have concluded that the unit rate values may also be used as a means for preventing further airspace congestion. It is important to note that such an approach should be taken into account with extreme caution. The increase of the unit rate value would not affect the ANSP's annual profitability level significantly, but the same conclusion cannot be drawn in relation to the profitability level of Airspace Users – which directly cover the ANSPs' costs. Profit margins of the AUs are often very low and even a small increase of operational costs will have a major impact on their annual net profit. Hence, one of the strategic goals of the future ATM system development in Europe should be oriented towards (1) the preservation of charging zones marked as LH, so that they do not become identical with their business environment, and (2) the gradual narrowing of the gap between the charging zones marked as LH with their adjacent zones – hence defragmenting the European airspace from the cost-efficiency aspect.

The research findings are also valuable to air traffic stakeholders when put in the context of new ideas and proposals for the future development of the European ATM systems. Accordingly, they can be discussed in the context of e.g. the idea of the EUA (European Upper Airspace) area, including a common route charge. In brief, the establishment of the EUA area was recommended in the report of the Wise Persons Group [51,] which was set up by the European Commission to consider recent developments in the European aviation [52]. The expectation of this idea is to achieve a higher utilisation of the shortest route options – consequently delivering benefits for the environment. However, the strategic planning of the future air transport development is influenced by several factors. The EUA idea is problematic because – as argued by Adler et al. [53] – setting a single unit rate across the entire network will result in an average price, likely to cause such a situation in which some AUs will be winning and other losing. Accordingly, over a certain period after the establishment of the EUA idea, some AUs would disappear from the market, while the "stronger ones", after the disappearance of some competitors, would (1) have the option to strengthen their position by entering markets that they have not served before; (2) in case they are already serving some market, have the option to increase their presence; or (3) have the option not to operate non-profitable routes, hence leaving some geographic areas poorly connected or isolated from other parts of Europe. If we consider research findings, we can precisely distinguish the aviation stakeholders (Member States; ANSPs; AUs) that might find the EUA idea acceptable from those that might find it unacceptable. For instance, it would be acceptable for the aviation stakeholders coming from France, Germany, Italy, Netherlands, Belgium (those mainly marked by HH indicator), and especially for Switzerland (since it is marked by the VHCV indicator). To the contrary, as research findings indicate, it is probable that aviation stakeholders coming from the less developed Member States (mainly those marked by the LL indicator) would find this idea unacceptable.

To sum up, it can be determined that the European airspace fragmentation issue, and consequently the issue of its fragmentation in terms of cost-efficiency, represents a complex problem that undoubtedly decreases the efficiency of the ATM system in Europe. Thereby, since this research provides information about every ANSP in respect to their unit rate value and position within the European ATM network, it supports the decision-making process, contributes to better understanding of business environment, and may form a basis for the future argumentative discussions in the context of strategic planning, e.g. in the context of the future development initiatives, plans, etc. Lastly, this research confirms the fact – as argued by Rezo and Steiner [54] – how difficult it is to create and implement a comprehensive and sustain air transport development plan that evenly complies with the interests of all stakeholders.

7. CONCLUSION

The problem of the fragmented design of the European airspace has been known for a long time and addressed in many different ways over the past decades. The primary reason is that airspace fragmentation negatively affects the efficiency of the European ATM system. The problem of the European airspace fragmentation in terms of cost-efficiency arises due to the fact that the ANSPs' unit rate values vary across the European airspace. This is so because they are calculated by dividing the charging zone's forecasted en-route facility cost-based by the estimated number of service units generated in the same charging zone.

The main added value of this paper is the confirmation that the European airspace is fragmented, along with the provision of the interpretation of fragmentation details in terms of cost-efficiency. By emphasising the international dimension of unit rate values impacts, it accurately shows the European airspace fragmentation level in 2018 and represents the ANSPs' competitiveness level on the economic (unit-rate) basis. The main research outcomes confirm that the European airspace is fragmented, and indicate the existence of different homogeneous areas across the European airspace, wherein one charging zone stands out as the hotspot. In addition to this, the European ATM's business environment boundaries have been clearly determined, thus framing the key issues to enhance the air market sector competitiveness. In this context, the main research findings presented within this paper will complement further research activities that will deal with airspace fragmentation from the capacitive aspect. The expected outcome of correlating the cost-efficiency and the capacitive aspect of performance-based airspace fragmentation will be the determination of where it is possible to achieve capacity-based airspace defragmentation.

Furthermore, scarcity of information supporting the European ATM community can be singled out as one of the causes for the lack of focus for collaborative initiatives addressing the European airspace defragmentation from the performance-based aspect. In this context, since it has been recognized that there are currently no unambiguous answers to the question how to test existence and measure the airspace fragmentation level, this research complements the existing literature, additionally presenting a novel approach. Its further added value is that the fragmentation has been studied by placing values of interest (unit rates) in their spatial context – which has not been the practice so far. As a result, the cost-efficiency based boundaries of the European airspace have been clearly identified, thus paving the way to further progress in terms of a performance-based airspace defragmentation.

In principle, strategic planning should provide guidance on how to improve the ATM system, so that it may become more efficient in future. In order to do so, conceptual assumptions of the strategic planning of the ATM system development in Europe need to turn to new perspectives that can contribute to the smart, inclusive and spatially-oriented development. Keeping in mind that the ATM system's most apparent flaw for the last few decades has been decision-making at the national level, this research represents one of the ways of ensuring high-quality information that might address the complex issues. Therefore, the findings shown in this paper could facilitate decision-making, and boost the future strategic air traffic planning activities.

References

[1] European Commission. Air Traffic Management; Freeing Europe's airspace; White Paper. Brussels, Belgium. 1996.

[2] Steiner S, Mihetec T, Rezo Z. Resolution of operational constraints imposed by fragmentation of European airspace. Proceedings of International Conference Science and Traffic Development (ZIRP2019), 9-10 May 2019, Opatija, Croatia

[3] Helios Economics and Policy Services. The impact of fragmentation in European ATM/CNS. EUROCONTROL. Report number: S031D019, 2006.

[4] Hartman N, Boscoianu M. Single European Sky – the transformation of the aviation industry based on the dynamic capabilities. INCAS BULLETIN. 2017;7(1): 97-109.

[5] Matsoukis E, Poulimenakos S. Air traffic management in the South East European countries. Current situation and prospects. European Transport\Trasporti Europei. 2007;37: 16-34.

[6] EUR-LEX. An Aviation Strategy for Europe [Internet]. [cited 2019 Feb 16]. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52015DC0598&from=EN

[7] Van Antwerpen N. Cross-Border Provision of Air Navigation Services with Specific Reference to Europe: Safeguarding Transparent Lines of Responsibility and Liability. Alphen aan den Rijn, The Netherlands: Kluwer Law International; 2008.

[8] Crespo D, Mendes de Leon P. (eds.) Achieving the Single European Sky: Goals and Challenges. Alphen aan den Rijn, The Netherlands: Kluwer Law International; 2011.

[9] O'Connell J, Williams G. Air Transport in the 21st Century: Key Strategic Developments. New York, USA: Routledge; 2016.

[10] Mihetec T, Vidović A, Rezo Z. Assessment of Single European Sky Implementation in the Functional Airspace Block Central Europe. Promet - Traffic & Transportation. 2017;29(6): 643-655.
[11] Grebenšek A, Magister T. Traffic variability in benchmarking of Air Navigation Service Providers cost-effectiveness. International Journal for Traffic and Transport Engineering. 2012;2(3): 185-201.
[12] Fox SJ. Single European Skies: Functional Airspace Blocks - Delays and responses. Air and Space Law. 2016;41(3): 201-227.
[13] Nava-Gaxiola C, Barrado C. Performance measures of the SESAR Southwest functional airspace block. Journal of Air Transport Management. 2016;50: 21-29.
[14] Young D, Pilon N, Brom L. Challenges of Air Transport 2030: Survey of experts' views. EUROCONTROL. Report number: 09/07/15-20, 2009.
[15] Rezo Z, Steiner S. European Airspace Fragmentation Typology. International Journal for Traffic and Transport Engineering. 2020;10(1): 15-30.
[16] Biggs RS, Garson GD. Analytic Mapping and Geographic Databases. Newbury Park, CA: Sage Publications Inc.; 1992.
[17] Franklin C, Hane P. An introduction to GIS: linking maps to databases.Database.1992;15(2):17-22.
[18] Rezo Z, Steiner S, Piccioni C. Potential of Geospatial Business Intelligence Solutions for Air Traffic Management. International Conference on Transport Science, 4-5 June 2020, Portorož, Slovenia
[19] Anselin L. Interactive techniques and exploratory spatial data analysis. In: Longley PA, Goodchild MF, Maguire DJ, Wind DW (eds.) Geographical information systems: principles, techniques, management and applications. Wiley, New York; 1998.
[20] Anselin L. Exploratory spatial data analysis in a geocomputational environment. In: Longley PA, Brooks SM, McDonnell R, Macmillan B (eds.) Geocomputation, a primer. Wiley, New York, 1998.
[21] Bailey T, Gatrell AC. Interactive spatial data analysis. Longman, Harlow; 1995.
[22] Ertur C, Le Gallo J. An Exploratory Spatial Data Analysis of European Regional Disparities, 1980-1995. In: Fingleton B. (ed.) European Regional Growth. Springer, Berlin, Germany. 2003. 55-97.
[23] Rezo Z, Steiner S. European airspace complexity and fragmentation correlation research. Research Workshop: Fragmentation in Air Traffic and its Impact on ATM Performance, 14-15 May 2019, Budapest, Hungary, 2019. p. 31-38
[24] EUR-LEX. Commission Implementing Decision (EU) 2019/903 of 29 May 2019 setting the Union-wide performance targets for the air traffic management network

for the third reference period starting on 1 January 2020 and ending on 31 December 2024 [Internet]. [cited 2020 Feb 20]. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019D0903&from=GA

[25] Steiner S, Feletar P, Šimecki A. Transport and spatial correlation of regional development. In: Vidan P, Twrdy E, Leder N, Mulić R. (Eds.) 6th International Maritime Science Conference. 28-29 April 2014, Solin, Croatia, p. 505-517

[26] Central Route Charges Office. Guidance on the route charges system. Brussels, Belgium: EUROCONTROL; 2012.

[27] EUR-LEX. Commission implementing regulation (EU) 2019/317 of 11 February 2019 laying down a performance and charging scheme in the single European sky [Internet]. [cited 2019 Jan 20]. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0317&from=EN

[28] CRCO. Monthly Adjusted Unit Rate - March 2012. Brussels: EUROCONTROL; 2012.

[29] CRCO. Monthly Adjusted Unit Rate - March 2018. Brussels: EUROCONTROL; 2018.

[30] STATFOR. Seven-year forecast; Flight Movements and Service Units 2017-2023. EUROCONTROL. Report number: 17/01/02-100

[31] EUROCONTROL. Information circular: Air Navigation charges in the Belarus. Brussels: EUROCONTROL; 2018.

[32] EUROCONTROL. Information circular: Air Navigation charges in the Arab Republic of Egypt. Brussels: EUROCONTROL; 2018.

[33] EUROCONTROL. Information circular: Air Navigation charges in Morocco. Brussels: EUROCONTROL; 2018.

[34] Schabenberger O, Gotway CA. Statistical Methods for Spatial Data Analysis. Boca Raton, FL: Chapman & Hall/CRC Press; 2005.

[35] Fotheringham AS, Brunsdon C, Charlton ME. Quantitative Geography: Perspectives on Spatial Data Analysis. London, England: SAGE Publications Ltd; 2000.

[36] Commission Regulation (EU) No 73/2010 of 26 January 2010 laying down requirements on the quality of aeronautical data and aeronautical information for the single European sky. Brussels, Belgium, 2010.

[37] EUROCONTROL. Guidelines for Supporting the Implementation of Commission Regulation (EU) 73/2010. Brussels, Belgium, 2017.

[38] Anselin L. The Moran Scatterplot as an ESDA Tool to Assess Local Instability in Spatial Association: Spatial Analytical Perspectives on GIS. London, England: Taylor and Francis; 1996.

[39] Anselin L, Syabri I, Kho Y. GeoDa: An Introduction to Spatial Data Analysis. Geographical Analysis. 2006;38(1): 5-22.

[40] Steiner S, Božičević A, Mihetec T. Prospects of Air Traffic Management in South Eastern Europe. Promet - Traffic & Transportation. 2010;22(4): 293-302.

[41] Steiner S, Feletar P, Šimecki A. Transport and spatial correlation of regional development. In: Vidan P, Twrdy E, Leder N, Mulić R. (Eds.) 6th International Maritime Science Conference. Solin, Croatia, 2014, p. 505-517.

[42] Steiner S, Božičević A, Mihetec T. Determinants of European air traffic development. Transport Problems. 2008;3(4): 73-84.

[43] Steiner S, Galović B, Radačić Ž. Strategic Framework of Air Traffic Development. Promet - Traffic & Transportation. 2008;20(3): 157-167.

[44] Janić M. Liberalisation of European aviation: analysis and modelling of the airline behaviour. Journal of Air Transport Management. 1997;3(4): 167-180.

[45] Button K. Deregulation and Liberalization of European Air Transport Markets. Innovation: The European Journal of Social Science Research. 2001;14(3): 255-275.

[46] Ozmec Ban M, Škurla Babić R. European air transport market under influence of cooperative arrangements. Proceedings of the 4th International Conference on Traffic and Transport Engineering. Belgrade, Serbia, 2018, p. 38-43.

[47] European Commission. Air Traffic Management - Freeing Europe's airspace. Brussels, Belgium, 1996.

[48] European Commission. Aviation: Open and Connected Europe. Brussels, Belgium, 2017.

[49] Castelli L, Ranieri A. Air Navigation Service Charges in Europe. Proceedings of the 7th USA - EUROPE ATM R&D Seminar. Barcelona, 2007.

[50] Castelli L, Labbe´ M, Violin A. A network pricing formulation for the revenue maximization of European air navigation service providers. Transportation Research Part C: Emerging Technologies. 2013;33: 214-226.

[51] Wise Persons Group. The Future of the Single European Sky. Brussels, Belgium, 2019.

[52] European Commission. Aviation: European Commission receives high-level recommendations on air traffic management in Europe [Internet]. [cited 2020 Feb 22]. Available from: https://ec.europa.eu/transport/modes/air/news/2019-04-15-recommendations-on-air-traffic-management-in-europe_en

[53] Adler N, Hanany E, Proost S. Managing European Air Traffic Control Provision. 4th SESAR Innovation Days, 25-27 November 2014, Madrid, Spain

[54] Rezo Z, Steiner S. South East Common Sky Initiative Free Route Airspace – implementation aftermath. Transport Research Procedia. 2020;45: 676-683.

FRAGMENTIRANOST EUROPSKOG ZRAČNOG PROSTORA: PROCJENA ZASNOVANA NA TROŠKOVNOJ UČINKOVITOSTI

Sažetak

Zbog varijabilnosti jediničnih cijena Pružatelja usluga u zračnoj plovidbi na različitim područjima europskog zračnog prostora, korisnici zračnog prostora za istu uslugu u zračnoj plovidbi plaćaju različite financijske iznose. Interes korisnika zračnog prostora je ostvariti što niže operativne troškove, pa je čest slučaj da zrakoplov, ukoliko postoji alternativa, leti dužim, ali ekonomski prihvatljivijim rutama kroz jeftinije naplatne zone. Tijekom vremena, primjena takve prakse dovela je do stvaranja različitih poslovnih interesa - što predstavlja kritični problem koji ometa daljnji razvoj zračnog prometa u Europi. Ovaj rad se bavi proučavanjem istraživačkog pitanja je li i ukoliko jest, kako je europski zračni prostor fragmentiran s aspekta troškovne učinkovitosti. Primjenom metodologije prostorne autokorelacije, tj. povezivanjem jediničnih cijena Pružatelja usluga u zračnoj plovidbi s njegovim prostornim položajem u okviru europskog sustava upravljanja zračnim prometom, dobiva se odgovor na postavljeno istraživačko pitanje. Rezultati istraživanja ukazuju da je europski zračni prostor fragmentiran s aspekta troškovne učinkovitosti i da je podijeljen u nekoliko različitih homogenih područja. Pri tom, takva područja karakterizirana su određenom razinom sličnosti susjednih jediničnih cijena, dok jedna naplatna zona predstavlja žarišno područje u smislu svoje neusklađenosti sa susjednim prostornim jedinicama.

Ključne riječi: Upravljanje zračnim prometom; strateško planiranje zračnog prometa; europski zračni prostor; fragmentiranost; troškovna učinkovitost.

Sanja Steiner
Hrvatska akademija znanosti i umjetnosti,
Zavod za promet
Kušlanova 2, 10000 Zagreb,
Croatia
e-mail: ssteiner@hazu.hr

Ružica Škurla Babić
Sveučilište u Zagrebu,
Fakultet prometnih znanosti, Zavod za zračni promet
Vukelićeva 4, 10000 Zagreb,
Croatia
e-mail: rskurla@fpz.hr

Zvonimir Rezo
Hrvatska akademija znanosti i umjetnosti,
Zavod za promet
Kušlanova 2, 10000 Zagreb,
Croatia
e-mail: zvonimir.rezo@gmail.com

Cristiana Piccioni
Sapienza Sveučilište u Rimu,
Faculty of Civil and Industrial Engineering,
Dept. of Civil, Constructional and Environmental Engineering,
Via Eudossiana 18, 00184 Rim, Italija
e-mail: cristiana.piccioni@uniroma1.it