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THE GENESIS OF COST-EFFICIENCY BASED EUROPEAN AIRSPACE FRAGMENTATION

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ABSTRACT

When it comes to discussion about efficiency of Air Traffic Management (ATM) system in Europe, European airspace fragmentation is frequently mentioned as barrier limiting further efficiency improvement of ATM system. Thereby, it should be noted that European airspace fragmentation can be studied from multiple different aspects. It can be analysed from organisational, operational, technical, functional or performance-based aspect. All this fragmentation aspects have their pros and cons. For example, from operational aspect, fragmenting airspace into smaller patterns (sectors) is normal operational practice (performed in order to adjust demand with capacity), while from performance-based aspect highly fragmented airspace is not preferred. In spite of, the European airspace fragmentation is mainly considered as the negative feature. By analysing situation from 1998 till 2020 this paper aims to answer research question whether and how European airspace is fragmented from cost-efficiency aspect. Thereby, the research is based on the examination of the spatiotemporal autocorrelation structures of the European airspace. After their determination, their spatial and temporal variability level was also studied. As research findings indicate that, from performance-based aspect, fragmentation of European airspace is dynamic and heterogeneous in both space and time, they were placed in wider context. Accordingly, the genesis of cost-efficiency based European airspace fragmentation is placed in the context of conceptual framework of currently applicable strategic planning practice whereby their causal relationship was identified.

Keywords: Air traffic management; strategic planning; airspace fragmentation; cost-efficiency; genesis

1 INTRODUCTION

Airspace fragmentation is generally recognized as one of causes of ATM system's inefficiency, especially from the economic viewpoint. In such circumstances, Airspace Users (AUs) seek to utilise every opportunity to reduce their operational costs. One method of making savings is through utilisation of the cheapest flight route. Due to occurrence of different national en-route unit rate values along the flight route, AUs for the same Air Navigation Service pay different route charges. In such circumstances, it's often the case that the aircraft, if there is an alternative, fly on longer but economically more acceptable routes – as it goes through cheaper charging zones. As a result of such practice, different business interests occur. While one can strive for utilisation of the shortest route (e.g. in order to achieve timetable punctuality), others will as much possibly go for cheaper route option (especially when slot isn't allocated), while most of AUs will try to balance between those two options. Thereby, most of AUs make such decisions within tactical planning phase, i.e. after receiving more precise information (e.g. about weather, airspace capacity availability, aircraft type selected, payload etc.).

The thing that is problematic in application of such a business practice is that it's environmentally harmful. In other words, making financial savings have higher priority over adverse effects on the environment. Thereby, one thing needs to be clear. AUs aren't the ones who should be criticised – as such circumstances are result of airspace fragmentation. Moreover, AUs should

be seen as gear wheels that function in the way that the system is designed. The better system design, the less irregularities will occur. In other words, the less fragmented airspace it is in terms of cost-efficiency, there is less chance of occurrence of adverse effects.

Although airspace fragmentation became a frequently mentioned issue, during the past decades it hasn't been frequently studied neither comprehensively addressed. Accordingly, a minor progress has been made to describe this issue more in-depth [1]. Hence, this research paper studies the genesis of cost-efficiency based European airspace fragmentation. It provides answer on the research question whether the European airspace is fragmented from cost-efficiency aspect. Also, spatiotemporal variability level and fragmentation repercussions were studied as well.

2 METHODOLOGICAL FRAMEWORK

This research answers the research question of whether and how European airspace was fragmented from cost-efficiency aspect during the period from 1998 till 2020. Thereby, as an input data national en-route unit rate values published by EUROCONTROL [2] were used. National en-route unit rate values are calculated by dividing charging zone's forecasted en-route facility cost-base by the forecasted number of service units generated in the same charging zone. As so, they represent a final cost-related product of every ANSP and are used within calculation of AUs route charges. For the purpose of answering posed research question, the research is based on application of spatial autocorrelation method. Accordingly, to examine spatial autocorrelation, methodological framework includes computation of the local and global Moran's I index. Fotheringham et al. [3] denote local Moran's I index by following equation:

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

where x_i denotes the value of observed area, $\bar{x}$ average value of observed dataset, w_{ij} spatial weight matrix (Figure 1), x_j the value of the adjacent area and n indicates the number of observed values. After local Moran's indexes estimation, global Moran's I can be obtained as an average value of all local Moran's indexes. The results of spatial autocorrelation measurement are further interpreted within the context of the null hypothesis - which states that the national en-route unit rate values are randomly distributed over studied area. In other words, it states that the European airspace is fragmented from cost-efficiency aspect. Thereby, the significance testing of the local and global Moran's I index is based on z-score computation. After estimation of the expected value and the variance, z-score can be obtained as follows:

$$z - score = \frac{I - E(I)}{\sqrt{Var(I)}} \quad (2)$$

Thereby, within significance testing, the confidence level (α) was set at 95%. As the global Moran's I index doesn't indicate local grouping tendencies, methodological framework was complemented with additional analysis that places a focus on the local level. Hence, with a goal to determine resemblance between neighbouring spatial units, the method of Moran's scatter plot was also applied.

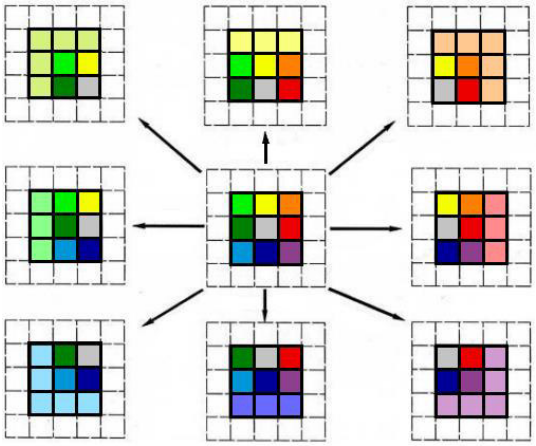


Figure 1: Conceptual framework of spatial weight matrix computation

3 MAIN RESEARCH FINDINGS

Spatial autocorrelation can be defined as the relationship among values that comes from the geographic arrangement of spatial units in which these values occur. Obtained research findings indicate that the null hypothesis cannot be rejected (as it is shown by Figure 2). That means that European airspace is fragmented from cost-efficiency aspect since 1998 (as within studied period at no point z-score and p-value aren't significant). Thereby, within studied period spatial autocorrelation is continuously positive. That indicates that spatial units of similar values continuously tend to group. Also, it could be defined that, as from 2011, national en-route unit rate values tend to be more spatially similar.

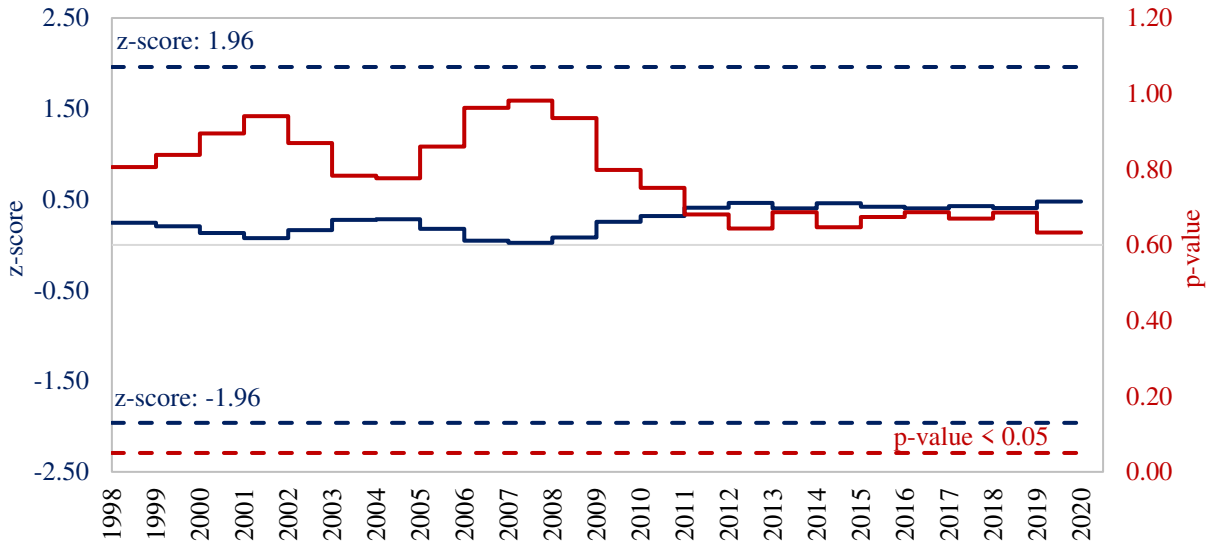
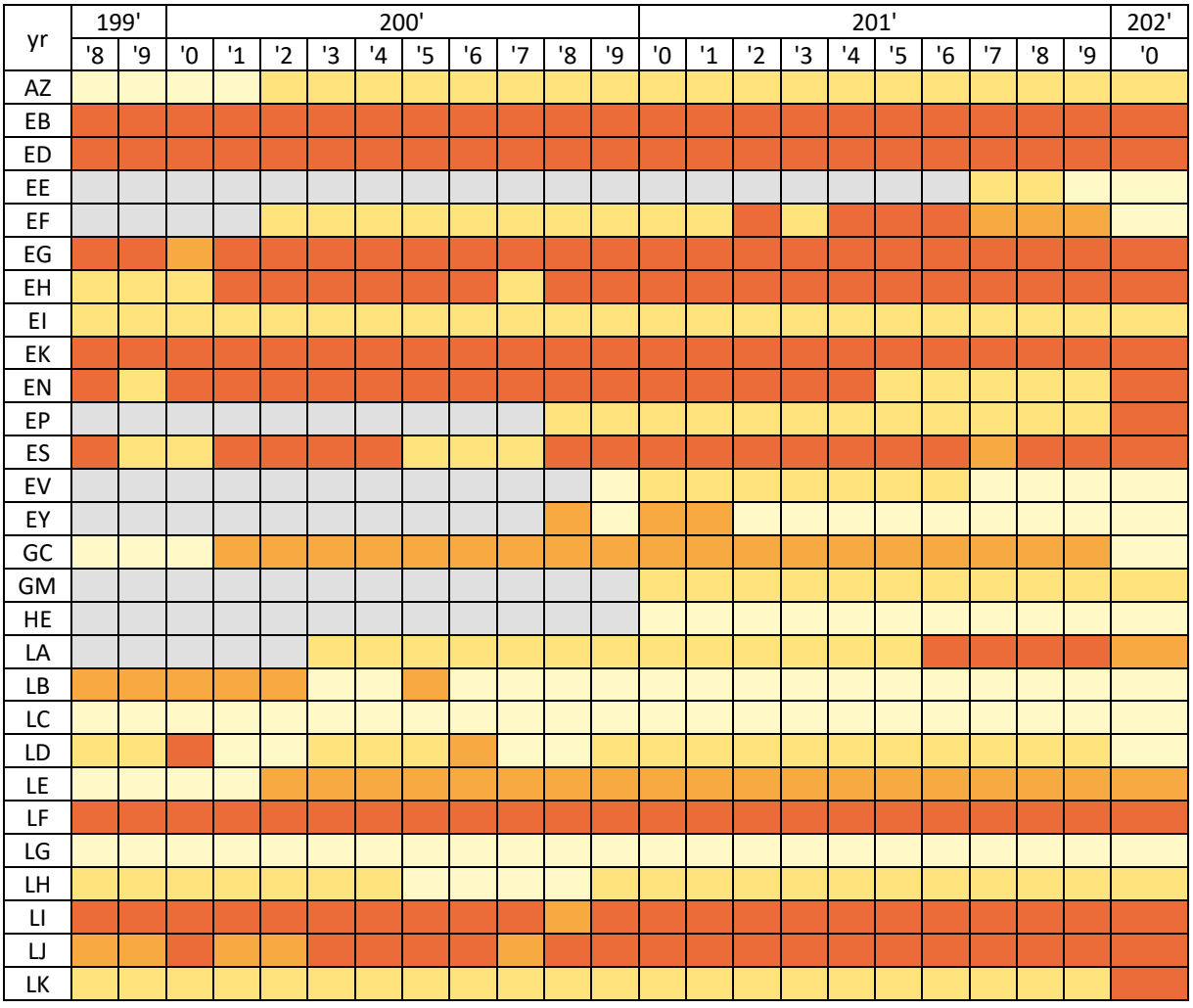


Figure 2: Overview of European airspace fragmentation in terms of cost-efficiency

Resemblance level between neighbouring spatial units is shown by Figure 3. These research findings reveal local grouping tendencies. Accordingly, they indicate patterns of spatial association and spatial outliers. Thereby, in accordance of Moran's scatter plot, four indicator were used: (1) HH indicator denoting spatial units of high neighbouring values, (2) HL indicator marking high value area surrounded with a low value neighbourhood, (3) LH indicator that specifies a low value area surrounded with a high value neighbourhood and (4) LL indicating spatial units of low neighbouring values.



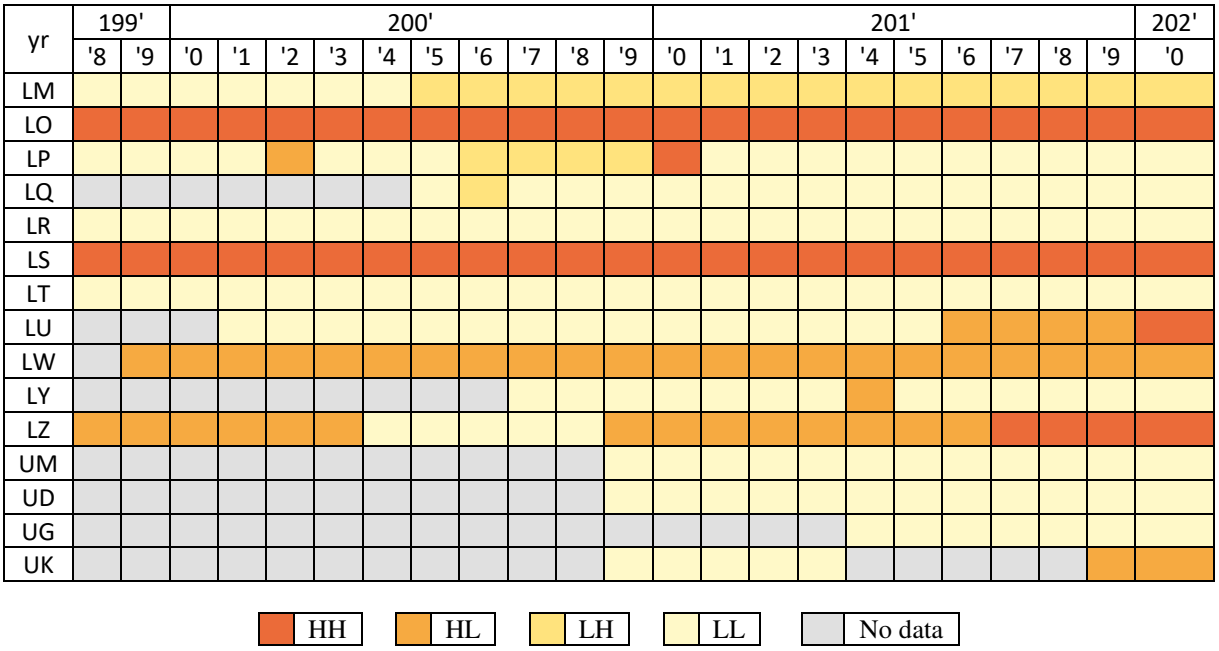


Figure 3: National en-route unit rate values variability overview (ICAO nomenclature)

4 DISCUSION

The genesis of cost-efficiency based airspace fragmentation streams from currently applicable framework of strategic air traffic planning. This is so because it is led by the "demand-oriented" option. The result of such an approach is creation of unbalanced air traffic development. Consequently, through establishment of different national en-route unit rate values that are applicable and scattered within different parts of the European airspace, that contributes to the existence of cost-efficiency based European airspace fragmentation. This is supported by the fact that national en-route charges are determined 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.

As Castelli and Ranieri [4] indicate, in the previous years it was possible to notice a high variability of unit rate values in the different charging zones across the European airspace. As Figure 4 shows, as of 2011, variability of unit rate values began to become more pronounced. That primarily relates to higher unit rate values - which began to deviate even more from the arithmetic mean value of dataset.

This research studied the genesis of the European airspace fragmentation from cost-efficiency aspect by placing unit rate values into their spatial context – thereby measuring their spatial similarity and variability level over time. That was achieved by application of method of spatial autocorrelation, i.e. by correlating every national en-route unit rate value with its application area within the European airspace.

Considering obtained research results it can be defined that European airspace is fragmented from cost-efficiency aspect. Also, the main research findings indicate existence of homogeneous areas, i.e. areas with similar national en-route unit rate values that are unevenly sized and are scattered over the European airspace. Lastly, their variability level was determined. As such results indicate that during studied period from 1998 till 2020, the global Moran's I index is far from being significant. On the other hand, the way how airspace was fragmented during the same period did change over time. In that context Figure 5 shows variability level in-between spatial neighbours recorded from 1998 till 2020.

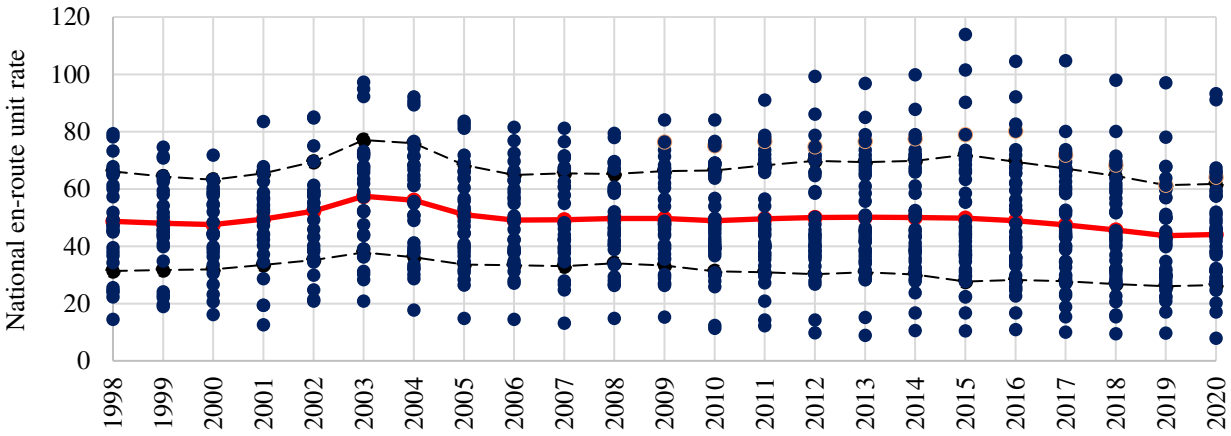


Figure 4: Overview of national en-route unit rate variability

The highest variability level in-between spatial neighbours have been recorded in Area of Responsibility of Croatia Control. In other words, in sense of cost-efficiency based European airspace fragmentation, that area can be singled out as most dynamic. This is so due to variability of Croatia Control's unit rate values, but also due to variability of neighbouring unit rate values. Also, as dynamic areas can be distinguished Finnish, Swedish, Slovenian and Portuguese charging zones. Thereby, it should be noted that size of studied area did change during observed period. As that may have a smaller impact on the results, variability level was also placed in respect to number of spatial units studied (Figure 6).

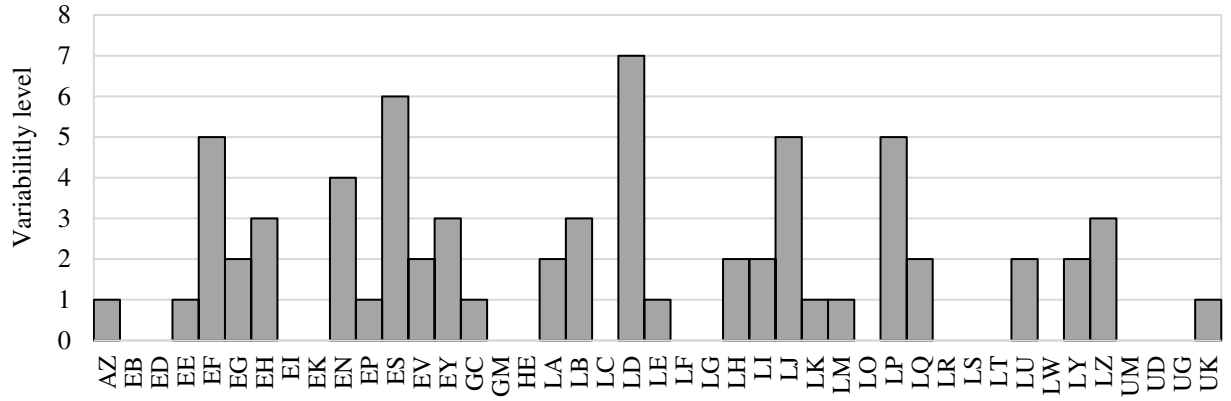


Figure 5: Variability level between spatial neighbours

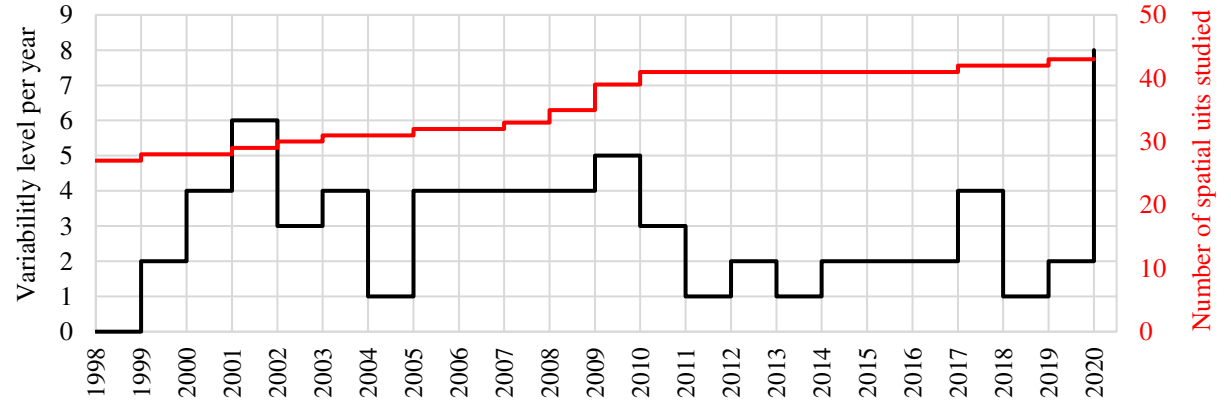


Figure 6: Annual variability level between spatial neighbours in respect to number of studied spatial units

Through determination of cost-efficiency based European airspace fragmentation level, decision makers can get a clear picture of their business environment. Also, they can improve their knowledge and understanding of AUs "behaviour". In that context, the effect of airspace fragmentation in terms of cost-efficiency can be valorised on practical example. Figure 7 shows an example of two route options between Cardiff International Airport and Corfu International Airport. Blue route indicates the cheapest option, while green one represents the shortest route option. Those two routes are also placed in respect to main research findings.

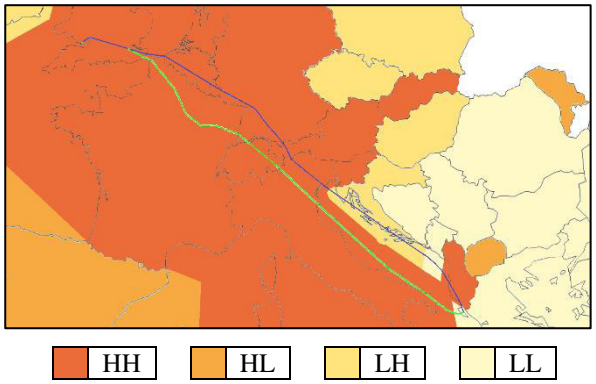


Figure 7: Cost-efficiency based airspace fragmentation effects on flight planning [5]

In order to valorise the effects of such airspace fragmentation, few assumptions need to be made:

- flight will be operated by Airbus A320;
- no en-route capacity constraints;
- assigned optimal flight level;
- summer flight schedule (7 months duration);
- four flight frequencies per weak;
- 2018 national en-route unit rate values [6];
- A320 fuel burn rate: 38.5 (kg/min) [7];
- The cost of fuel: 0.31 (EUR/kg) [8];
- CO_2 emitted: 3.15 kg (per burned fuel kg) [9];
- H_2O emitted: 1.230 kg (per burned fuel kg) [9];
- SO_2 emitted: 0.00084 kg (per burned fuel kg) [9];

After running simulation by NEST [10] and SET [11] tools obtained results were consolidated as the differences between cheapest rout option in respect to shortest route option. In respect given assumptions, utilization of cheapest rout option (instead of shortest route option) would result with: (1) 510.72 NM additionally travelled, (2) 41,720 EUR savings in route charges, (3) 2,800 kg of fuel additionally burnt, (4) for 868 EUR higher fuel costs, (5) 8,820 kg higher CO_2 emission, (6) 3,444 kg higher H_2O emission and (7) 2.352 kg higher SO_2 emission. Furthermore, by subtracting the additional costs resulting (due to higher fuel consumption) from the savings achieved by utilization of cheaper route option, a final estimation is obtained. Through utilization of cheapest route options AU would save approximatively 40,852 EUR. On the other hand, the question arises whether the additional environmental pollution is worth that money? The answer could be found in already mentioned fact that AUs should be seen as gear wheels that function in the way that the system is designed. The better system design, the less irregularities will occur. In other words, the less fragmented airspace it is from cost-efficiency aspect, there's less chance of occurrence of adverse effects on the environment. From there it stems that negative effect of ATM system on the environment can be reduced through spatially balancing unit rate values.

As example show, cost-efficiency based airspace fragmentation is problematic as it enables AUs to purposely impairment their flight efficiency (with a goal to make financial savings). In that way this kind of airspace fragmentation have negative effect on the environment (as it leads to higher fuel consumption and consequently higher emissions level). In order to defragment European airspace from cost-efficiency aspect, certain conceptual changes need to be made within the framework of the strategic planning. In that context, the aim of strategic planning should be oriented towards achieving better performances that will lead to spatial cohesion [12]. To achieve that, few conceptual assumptions of currently applicable strategic planning framework needs to be modified. One of the causes contributing to existence of the airspace fragmentation is fact that European ATM system is still mainly organized at national scale [13]. This is problematic because ATM system in Europe involves a high number of stakeholders which may, in different areas, have a greater or smaller impact on the overall efficiency of the ATM system in Europe [14].

Another conceptual assumption that contributes to airspace fragmentation needs to be modified. Performance measurement scheme represents one of strategic planning mechanisms by which it seeks to contribute to ATM system development in Europe. However, it's based on the individualistic approach in evaluation of achieved performance level. Whether or not an ASNP is successful is purely determined by comparing its performance achievements with those regulatory determined. Such practice is problematic as the spatial component of the data is completely ignored. For example, if in following year ANSP achieves reduction of 1.9% of national en-route unit rate value, according to performance targets of 3rd Reference Period (RP3) [15], that will be considered as a success. However, currently that success at no point is assessed in respect to situation and performances achieved at local level. Given that "positions are already taken" and that in following years every ANSP will be obliged to respect RP3 targets, application of such an approach will result with 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 what, with certain time lag, their values may in greater or lower volume variate (as shown earlier). Thereby, as long as individualistic approach in evaluation of achieved performances is applicable, that will contribute to existence of cost-efficiency based European airspace fragmentation.

5 CONCLUSION

Even though the problem of airspace fragmentation has been recognized in the 1990s, obtained research findings indicate that over time a little has been done to resolve this issue or to minimize associated negative impacts. The main contribution of this paper is identification of the genesis of cost-efficiency based airspace fragmentation. Research confirms that, although the way how it was fragmented from 1998 till 2020 did change, European airspace continuously remained fragmented from cost-efficiency aspect. Also, research findings indicate that as of 2011, from spatial aspect, national en-

route unit rate values tend to be more similar, but still that is far away of being characterised as spatially aligned. Furthermore, spatial and temporal variability level was also identified. In addition, repercussions of cost-efficiency based airspace fragmentation have been presented by introduction of example from practice. Lastly, the research topic was placed in wider context. That included identification of causal relationship between the genesis of cost-efficiency based European airspace fragmentation and conceptual framework of currently applicable strategic planning practice. In that context, it was concluded that conceptual assumptions of strategic planning of ATM system development in Europe need to turn to new perspectives that would lead to the smart, inclusive and spatially oriented development. Thereby, as long as individualistic approach in evaluation of achieved performances is applicable, that will contribute to existence of cost-efficiency based European airspace fragmentation.

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