European airspace fragmentation assessment model

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MODEL ZA PROCJENU FRAGMENTIRANOSTI EUROPSKOGA ZRAČNOGA PROSTORA

DOKTORSKI RAD

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Zvonimir Rezo

ABSTRACT

Since the establishment of the Single European Sky (SES) initiative in 2004, “fragmentation” has been a key reference point and policy driver of strategic planning and development of the Air Traffic Management (ATM) system in Europe. However, even though the issue of the European airspace fragmentation has been recognized back in the 1990s, yet terminological, conceptual and methodological determinants and frameworks by which the notion of the European airspace fragmentation could be unambiguously defined and measured have not yet been set. Therefore, even nowadays it frequently remains unclear when airspace can be considered as “fragmented” or “defragmented”. Accordingly, as there are many unanswered questions and assumptions associated with the issue of the European airspace fragmentation, this paper presents findings that increase knowledge and understanding in the field of research. The main objective of this research is development of the European airspace fragmentation assessment model. The purpose of its development is to enable determination of the performance-based airspace fragmentation (one of several European airspace fragmentation types). In that regard, this paper presents the conceptual and methodological frameworks of a novel model that can be used to obtain answers to hypothetical questions of where, when, how, and whether it is possible to achieve performance-based airspace defragmentation. After its development, the model was validated through its application. Model applicability was validated based on the applicability of the case study carried out for the purpose of obtaining simple answers to complex questions of how European airspace is fragmented and where and whether it is possible to achieve airspace defragmentation from the aspect of airspace capacity. As such, this paper contributes to a more inclusive, smart, environmentally-friendly and spatially oriented strategic planning and development of the ATM system in Europe.

KEY WORDS

Air Traffic Management system; strategic planning and development; airspace fragmentation; performance-based airspace model; capacity-based assessment

PROŠIRENI SAŽETAK

Fragmentiranost zračnoga prostora predstavlja problem koji se u okviru domene upravljanja zračnim prometom počeo učestalije spominjati tijekom posljednja dva desetljeća. Štoviše, od uspostave inicijative „Jedinstveno europsko nebo“ 2004. godine, „fragmentiranost“ predstavlja ključnu referentnu točku i odrednicu u okviru strateškog planiranja i razvoja sustava upravljanja zračnim prometom (engl. Air Traffic Management - ATM) u Europi. Prvenstveno se često spominje kao jedan od glavnih uzroka koji pridonose neučinkovitosti ATM sustava u Europi. Međutim, iako je problem fragmentiranosti europskoga zračnoga prostora prepoznat još 1990-ih, taj problem nije često niti adekvatno proučavan tijekom posljednjih desetljeća. Sukladno tome, postignut je manji napredak u detaljnijem opisivanju ovog problema. Povrh toga, danas se fragmentiranost zračnoga prostora često uzima „zdravo za gotovo.“ Slijedom toga, tipovi fragmentiranosti zračnoga prostora, njihove implikacije i reperkusije nikada nisu u potpunosti istraženi. Stoga danas često ostaje nejasno kada se zračni prostor može smatrati „fragmentiranim“ odnosno „defragmentiranim.“ Budući da postoji mnogo neodgovornih pitanja i pretpostavki povezanih s pitanjem fragmentiranosti europskoga zračnoga prostora, ovaj rad predstavlja rezultate istraživanja koja povećavaju razinu znanja i razumijevanja u području istraživanja. Glavni cilj istraživanja jest razvoj modela za procjenu fragmentiranosti europskoga zračnoga prostora. Svrha njegovog razvoja jest odrediti fragmentarnost zračnoga prostora na temelju performansi sustava upravljanja zračnim prometom (jednim od više tipova fragmentiranosti europskoga zračnoga prostora). U skladu s tim, ovaj rad predstavlja konceptualni i metodološki okvir novog modela koji se može koristiti za dobivanje odgovora na hipotetska pitanja gdje, kada, kako i je li moguće postići defragmentaciju zračnoga prostora temeljenu na performansi sustava upravljanja zračnim prometom. Nakon razvoja, model je provjeren kroz njegovu primjenu. Primjenjivost modela validirana je na temelju aplikabilnosti studije slučaja provedene u svrhu dobivanja jednostavnih odgovora na kompleksna pitanja; kako je europski zračni prostor fragmentiran, te gdje i je li moguće ostvariti defragmentaciju zračnoga prostora s aspekta kapaciteta zračnoga prostora. Na taj način ovaj rad doprinosi inkluzivnom, pametnom, ekološki prihvatljivijem i prostorno orijentiranom strateškom planiranju i razvoju sustava upravljanja zračnim prometom u Europi.

Rad se zasniva na hipotezi da model temeljen na analizi prostorne distribucije vrijednosti pokazatelja performansi sustava upravljanja zračnim prometom utječe na unaprijeđenu procjenu fragmentiranosti europskoga zračnoga prostora. Argumenti koji podupiru hipotezu istraživanja:

- Pojam fragmentiranost zračnoga prostora često ima kontekstualno značenje, pa ga je potrebno jasnije terminološki definirati.
- Iako je od 2004. godine smanjenje razine fragmentiranosti zračnoga prostora jedna od strateških odrednica planiranja i razvoja sustava upravljanja zračnim prometom u Europi, još uvijek ne postoji konceptualni niti metodološki okvir kojim bi se pratilo navedeno.
- Sustav upravljanja zračnim prometom u Europi utječe na fragmentiranost zračnoga prostora.
- Trenutno primjenjivi regulatorni okvir ne pridonosi smanjenju razine fragmentiranosti zračnoga prostora s aspekta performansi sustava upravljanja zračnim prometom jer se prostorna značajka podataka o izvedbi, kao i međuovisnost pružatelja usluga u zračnoj plovidbi, ne uzimaju u obzir prilikom valorizacije stanja sustava upravljanja zračnim prometom u Europi.
- Regulatorni okvir performansi sustava upravljanja zračnim prometom te pripadajući strateški ciljevi za ključno područje kapaciteta ne doprinose defragmentaciji europskoga zračnoga prostora.
- Utvrđivanje prostornog obrasca fragmentiranosti zračnoga prostora s gledišta utjecaja na kapacitet zračnog prostora važan je kriterij u postuliranju smjernica gdje i kako ostvariti defragmentaciju i povećanje kapaciteta zračnog prostora.
- Razvijeni model bolje odražava sustav upravljanja zračnim prometom u Europi u odnosu na često primjenjive metode i modele jer uvažava metodološku pretpostavku prostorno zavisnih promatranja.

S ciljem potvrđivanja postavljene znanstvene hipoteze, istraživanje će biti provedeno kroz šest temeljnih faza istraživanja. U prvoj fazi istraživanja obrazlaže se motivacija za istraživanje fragmentiranosti europskoga zračnoga prostora, utvrditi ciljevi i istraživačke hipoteze te se daje pregled relevantne znanstvene literature u području istraživanja s kritičkim osvrtom. Nadalje slijedi pregled usvojenog metodološkog pristupa istraživanju te se navode i obrazlažu očekivane koristi istraživanja.

Konvencija o međunarodnom civilnom zrakoplovstvu (tzv. Čikaška konvencija) iz 1944. godine navodi da svaka država ima potpunu i isključivu suverenost nad zračnim prostorom iznad svog teritorija. Stoga u Europi, na relativnom malom geografskom području, posluje relativno velik broj pružatelja usluga u zračnoj plovidbi. Međutim, važno je razumjeti da fragmentiranost zračnoga prostora ne podrazumijeva samo podjelu zračnoga prostora na temelju nacionalnih granica. Stoga se druga faza istraživanja bavi tipizacijom fragmentiranosti europskoga zračnoga prostora. Rezultat je ove faze istraživanja pregled tipova fragmentiranosti europskoga zračnoga prostora te utvrđivanje njihovih međusobnih sličnosti, različitosti i uzroka njihova nastanka.

Pregledom i analizom znanstvene literature u području istraživanja utvrđeno je da ne postoji konceptualni niti metodološki okvir odnosno model koji je moguće primijeniti u svrhu određivanja i praćenja razine fragmentiranosti zračnog prostora na temelju performansi sustava upravljanja zračnim prometom u Europi. Stoga se treća faza istraživanja bavi konceptualizacijom i razvojem modela za procjenu fragmentiranosti europskoga zračnoga prostora. Prvo se opisuje pozadina razvoja modela. Navedeno uključuje kratak pregled regulatornog okvira na koji se oslanja strateško planiranje i razvoj sustava upravljanja zračnim prometom u Europi. Potom slijedi opis metode za obradu podataka koja se često koristi u svrhu prikaza stanja i učinka sustava upravljanja zračnim prometom u Europi. Svrha tih dvaju pregleda jest ukazati na nedostatke koji doprinose postojanju problema fragmentiranosti europskoga zračnog prostora na temelju performansi sustava upravljanja zračnim prometom. Nadalje, u trećoj fazi istraživanja, obrazlaže se novi pokazatelj performansi koji se temelji na uvažavanju metodološke pretpostavke prostorne ovisnosti pružatelja usluga u zračnoj plovidbi na temelju susjedstva prvog reda. Potom se uspostavlja metodološki okvir modela. U ovoj fazi istraživanja razvijen je model koji istovremeno analizira atributivne, prostorne i vremenske značajke ulaznih podataka. Navedeno je omogućeno primjenom interdisciplinarnog istraživačkog pristupa. Tako se primjerice model, umjesto na uvažavanju tradicionalne statističke teorije koja temelji analize na pretpostavci neovisnih promatranja, zasniva na metodološkoj pretpostavci prostorne ovisnosti. Drugim riječima, metodološki okvir modela temelji se na uvažavanju prvog Toblerovog zakona – „Sve je međusobno povezano, ali su bliži objekti međusobno povezaniji nego udaljeniji". Interdisciplinarnost istraživačkog pristupa potvrđuje i činjenica da upravo Toblerov zakon zapravo proizlazi iz Newtonovog općeg zakona gravitacije. Nadalje, razvijeni model bazira se na primjeni eksplorativne analize prostornih podataka iz razloga što omogućuje istovremenu analizu atributivnih, prostornih i vremenskih značajki podataka. Polazna motivacija za takvim istraživačko-metodološkim pristupom proizlazi iz činjenice da jedinice analize (područja odgovornosti pružatelja usluga u zračnoj plovidbi koja su zapravo nepravilni poligoni) imaju međuovisan odnos sa susjednim jedinicama analize. Uz to, u okviru treće faze istraživanja specificirana su metodološka ograničenja razvijenog modela. Pregled konceptualnog okvira za korištenje modela te pregled aplikativnosti razvijenog modela zaključuju treću fazu istraživanja.

U četvrtoj fazi istraživanja razvijeni model je primijenjen na studiji slučaja. Ukratko je dat pregled glavnih značajki vezanih uz upravljanje kapacitetom zračnog prostora. Također, definiraju se istraživačke odrednice u smislu područja i vremena istraživanja te referentnog skupa podataka. Provedbom analize s gledišta utjecaja na kapacitet zračnog prostora utvrđen je prostorni uzorak fragmentarnosti, tj. raspodjela uzorka te jačina i smjer veza između susjednih prostornih jedinica. Također, rezultati istraživanja otkrivaju je li fragmentiranost zračnoga prostora s gledišta utjecaja na kapacitet zračnog prostora rezultat slučajnog prostornog procesa, grupirane distribucije prostornih jedinica ili je rezultat raspršene distribucije prostornih jedinica.

Peta faza bavi se istraživanjem gdje i kako je moguće smanjiti razinu fragmentiranosti te povećati kapacitet zračnog prostora. Pri tome je u svrhu mjerenja fragmentiranosti primijenjen novi prostorni pokazatelj performansi koji je neovisan o mjernoj skali, tj. mjernoj jedinici.

Glavna svrha šeste faze jest prikazati kako rezultati istraživačko-razvojnih aktivnosti mogu unaprijediti razumijevanje tematike u području istraživanja te podržati funkciju strateškog planiranja i razvoja sustava upravljanja zračnim prometom u Europi.

KLJUČNE RIJEČI

Sustav upravljanja zračnim prometom; strateško planiranje i razvoj; fragmentiranost zračnoga prostora; model zasnovan na performansama zračnoga prostora; procjena na temelju kapaciteta

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1. INTRODUCTION

As any other system, the ATM system can be more or less efficient. To maximize its efficiency, strategic planning and development at national, local and regional level is continuously being carried out. That includes creation of various development plans, knowledge management, identification of improvement areas, organisation of research workshops etc. In principle, the main purpose of strategic planning and development is to create or to obtain relevant information required for the purposes of decision-making processes. However, due to the complexity of the ATM system in Europe, the strategic planning and development of the ATM system in Europe is by no means an easy task. Primarily because of the existence of significant risks associated with the possibility of creation or acceptance of partial or misleading strategies that can, in the long run, result with serious business issues. Additional pressure on strategic planning and development of the ATM system arises from its economic aspect. As it is specified within Aviation Strategy for Europe [1], until 2014 the European Union (EU) aviation industry had directly employed between 1.4 million [2] and 2 million [3] people and had in overall supported between 4.8 million [2] and 5.5 million [3] jobs. The direct contribution of aviation to EU GDP was EUR 110 billion, while the overall impact, including tourism, was EUR 510 billion through the multiplier effect [2]. Hence, considering the significance of contribution of the aviation industry to the EU economy, it is strategically important to have an efficient ATM system that does not represent a limiting factor of further economic growth. Additional pressure on the Air Navigation Service Providers (ANSPs) and strategic planning and development of ATM system in Europe comes from the fact that even small percentage loss means a significant financial amount. For instance, in 2018 ANSPs in Europe have generated a revenue of EUR 9.793.820.000 and cost of EUR 9.091.945.000 [4] from gate-to-gate Air Navigation Services (ANS). Therefore, the need for reliable strategic planning and development function arises. Thereby, it should be outlined that due to the SARS-CoV-2 pandemic, the scale of the mentioned figures has certainly changed. Nonetheless, it is expected that by 2025 traffic volume will reach the 2019 figures and that the ATM system in Europe will recover in the meanwhile [5].

Within the last two decades, one of the major goals of strategic planning and development of the ATM system in Europe was to minimise the level of airspace fragmentation and its repercussions on the ATM system and Airspace Users as it contributes to their inefficiency [6–8].

Until 1987 national air traffic markets in Europe were protected, regulated, and fragmented with a goal to safeguard national interests [9,10]. Those times were mainly characterized by different state's financial aids and subsidies to the state-owned companies, inconsistent national and regional regulations, and operational constraints. Meanwhile, the prerequisites for future economic development have been made in the sense of air traffic market deregulation and liberalization. However, despite these changes, the ATM system in Europe, i.e., the European airspace, remained fragmented on the basis of national borders. As a result, nowadays, if not otherwise specified, every time an aircraft transits over a national boundary, it is serviced by a different ANSP. That often leads to situations in which aircraft are guided on the basis of different operational requirements and restrictions [11]. In such way, fragmentation limits airspace capacity, adversely affects the environment, increases operational costs, and above all, potentially affects safety [12]. Consequently, it threatens further development of the ATM system in Europe, and as such, further economic growth.

The issue of the European airspace fragmentation has been officially recognized by the European Commission (EC) back in 1996, arguing that the European Union "cannot keep the frontiers in the sky that it has managed to eliminate on the ground" [13]. Although a long time has passed since then, clearly recognizable constraints associated with fragmentation are still seriously impeding sustainable growth of the European air traffic market. Thereby, within last two decades different regulations and projects tried to reduce fragmentation level and its effects. Some of them achieved greater and others minor benefits. For instance, from operational aspect, the Free Route Airspace (FRA) and Flexible Use of Airspace (FUA) concepts can be distinguished as good examples of how it is possible to improve flight efficiency regardless of fragmented airspace design [14]. On the other hand, in September 2020, European Commission published an amended proposal for a regulation of the European Parliament and of the Council on the implementation of the Single European Sky [15]. In case of its acceptance, a significant shift would occur in the sense of the implementation of the long-standing policy of "solving" the fragmentation issue through the concept of Functional Airspace Blocks (FABs). Particularly as FABs have been frequently presented as "key mechanism of" and "a tool to develop" a Single European Sky [16]. Hence, nowadays the issue of the European airspace fragmentation is considered to be one of the hardest issues to overcome. Hence, the study of the European airspace fragmentation simultaneously represents a highly relevant and challenging research topic.

However, despite its significance and the fact that it is a frequently mentioned issue, there are still many assumptions and unanswered questions on the topic of airspace fragmentation. That indicates the need for additional research efforts. In principle, the issue of the European airspace fragmentation can be studied from several aspects. For instance, it can be studied from organisational, operational, technical, functional, performance-based, and many other aspects. This paper deals with the development of a model for assessing the European airspace fragmentation based on the spatial distribution of the values of the performance indicators of the ATM system. Upon its development, and based on its application, it is possible to determine performance-based airspace fragmentation. The further content deals with capacity-based assessment of the performance-based airspace fragmentation – which actually represents one of many types of the performance-based airspace fragmentation. As such, this paper studies the issue of airspace fragmentation in more detail and provides new insights.

1.1. Research motivation

Compared to the situation thirty years ago, nowadays it is much easier to conduct strategic planning and development of the ATM system (regardless of whether that refers to national, local or regional level). Technological advances, clearer definition of performance areas, indicators and their metrics, the promotion and the increasing adoption of open-access frameworks combined with the greater availability of data describing performance of the ATM system in Europe can be cited as the main reasons for the aforementioned. Establishment of the Performance Review Body (PRB) and the Performance Review Unit (PRU) can be also perceived as contributing factors to the aforementioned. PRB is established to support the EC in the implementation of the Performance Scheme, while PRU, as part of the European Organisation for the Safety of Air Navigation (EUROCONTROL), is responsible for data sharing and a public reporting of number of Key Performance Areas (KPAs) and Key Performance Indicators (KPIs) [17]. However, a few crucial things have not changed in the meantime. In order to conduct strategic planning and development in the field of the ATM system, it is crucial to be well informed and understand how the system performs at national, local and regional level. Primarily as strategic planning and development directly shapes the working environment of the Air Traffic Control Officers (ATCOs), affects air traffic flow, complexity, workload level and consequently the throughput, i.e., airspace capacity.

In order to defragment airspace, one needs to understand in which of the performance areas to look for the efficiency increase and implement corrective measures that will lead to airspace defragmentation. Thereby, one firstly needs to acquire objective information about the existing situation and performance deficiencies. Performance management within the ATM system in Europe is a quite complex task as the ANSPs' performance levels are the result of exogenous and endogenous factors. Exogenous factors are those outside the control of ANSPs, while endogenous factors are those entirely under the ANSPs control [18]. For instance, exogenous factors include legal and socio-economic conditions (e.g., taxation policy, exchange rates, cost of living etc.), operational conditions (e.g., traffic patterns, Area of Responsibility (AoR), weather, traffic variability etc.) and governance arrangements such as international requirements imposed by the SES initiative. On the other hand, the endogenous factors include organisational factors, financial aspect and aspects of operational and technical setup.

Studies dealing with the issue of the European airspace fragmentation are of particular importance for strategic planning and development function of the ATM system. As risks existence can compromise the realization of the strategic goals, one of the core purposes of strategic planning is to reduce and mitigate business risks. Accordingly, a better understanding of the performance-based European airspace fragmentation leads to a better description of business environment, which consequently leads to a reduction of business risks. Additional motivation for this research comes from the literature review where a lack of models, conceptual and methodological frameworks, adequate performance indicators developed for the purpose of airspace fragmentation estimation and monitoring has been identified. In addition, literature review indicates lack of clear terminological determination of the term “airspace fragmentation” – resulting with a fact that it frequently has a contextual meaning. Hence, considering the aforementioned, it can be outlined that this research was motivated by the high relevancy and significance of the issue of the European airspace fragmentation within the domain of strategic planning and development of the ATM system in Europe.

1.2. Research objectives and hypothesis

When it comes to the design of the European airspace, one can frequently find that it is characterized as “zigzagging”, “inefficient” or “fragmented” [19]. In order to minimize these characteristics, the Single European Sky ATM Research (SESAR) project was launched in 2004 as the technological pillar of the SES [20]. Its role is to define, develop and deploy much needed solutions required to overcome the aforementioned characteristics. Later on, the SESAR Joint Undertaking (SJU) was established under Council Regulation (EC) 219/2007 of 27 February 2007 [21] (modified by Council Regulation (EC) 1361/2008 (SJU Regulation) [22] and lastly (at the time of writing) amended by Council Regulation (EU) 721/2014 [23]). However, even though SESAR has fostered a common vision, it has in the meantime strayed from its initial schedule and is now an open-ended project. In addition, while there are notable improvements in terms of the first two aforementioned characteristics [24], the third one still poses an insuperable issue [25]. Mainly because in order to defragment the European airspace, there is a need for political, organisational, operational, technological, as well as Research and Development (R&D) interventions.

From the R&D aspect, there is still a lot of work to be done as there are many unanswered questions. Answering these questions is of high importance as they can objectively serve as a basis for further decision-making processes. Thereby, a shift in an interplay between political decision making and R&D funding needs to change in a way that further R&D activities are not conditioned by political decisions and agendas, but vice versa. The main objective of this research is to develop a conceptual and methodological framework of a novel model that can contribute to better understanding of the European airspace fragmentation and its defragmentation potential from performance-based aspect. Accordingly, model development is oriented towards determination of how fragmented the European airspace is from a capacitive aspect and whether airspace fragmentation is the result of a random spatial process, clustered pattern distribution or a scattered patterns distribution. Thereby, the research is based on the hypothesis that a model based on the analysis of the spatial distribution of the values of the performance indicators of the ATM system affects the improved assessment of the European airspace fragmentation. The following arguments can be stated in support of the research hypothesis:

- The term airspace fragmentation often has a contextual meaning, so it needs to be more clearly defined in terms of terminology.
- Although reduction of the level of airspace fragmentation has been one of the strategic determinants of the ATM planning and development in Europe since 2004, there are still no conceptual or methodological frameworks to monitor the aforementioned.
- Air Traffic Management system in Europe affects the airspace fragmentation.
- The currently applicable regulatory framework does not contribute to reduction of the level of airspace fragmentation from the aspect of performance of the ATM system because the spatial feature of performance data, as well as the interdependence of the ANSPs, are not taken into account when valorising the state of the ATM system in Europe.
- The regulatory framework defining performance requirements of the ATM system and the associated strategic targets for the key performance area of capacity do not contribute to the defragmentation of the European airspace.
- Determining the spatial pattern of airspace fragmentation from the viewpoint of the impact on airspace capacity is an important criterion in postulating guidelines on where and how to achieve defragmentation and increase airspace capacity.
- The developed model better reflects the settings of the ATM system in Europe in relation to the often-applicable methods and models because it takes into account the methodological assumption of spatially dependent observations.

1.3. Survey of previous studies

The Chicago Convention on International Civil Aviation states that every Member State has complete and exclusive sovereignty over the airspace above its territory [26]. Hence a high number of ANSPs operates in Europe, a relatively small geographical area. However, it is important to understand that the aforementioned should not be viewed as reason for taking for granted that the European airspace is fragmented. If we adopt such superficial logic, the airspace around the whole world can be considered fragmented – to a greater or lesser extent, depending on the area. Accordingly, airspace fragmentation does not only refer to airspace division based on the national borders. The issue of airspace fragmentation is much bigger than that. For instance, O'Connell and Williams [27] define that airspace fragmentation has its stronghold in the existence of different stakeholders' business models. Van Antwerpen [28] mentions that airspace fragmentation, as a cause of resources duplication, also impacts the costs associated with trainings, administration and R&D costs. Steele [29] claims that duplication of resources is irritating enough to the Airspace Users (AUs) as they are the ones covering these costs. Moreover, EUROCONTROL, headquartered in Brussels, associates the issue of airspace fragmentation with the question of integrated European defence system and argues that it is difficult to overcome the issue of airspace fragmentation due to the existence of different interest groups [30].

In principle, airspace is a limited resource and the way it is managed primarily depends on the efficiency of the ATM system. However, the cost of inefficiency is rather high within the ATM system. Since airspace fragmentation represents quite a significant issue, the size of the inefficiency-related cost is even higher. Thereby, literature review indicates that there is no consensus on the magnitude of the actual cost associated with the issue of the European airspace fragmentation. For instance, Matsoukis and Poulimenakos [31] have estimated that the fragmentation-associated cost is EUR 880–1,400 million per year. Grebenšek and Magister [32] consider it to be around EUR 2–3 billion per year. Furthermore, even the European Commission shows elements of inconsistency as it mentions three different estimations within its publications. One the one hand, it states that the estimated fragmentation-associated cost amounts to EUR 4 billion a year [33]. On the other hand, according to its Aviation Strategy for Europe [1], the fragmentation-associated cost was estimated to be at least EUR 5 billion per year, whereas in the

Aviation: Open and Connected Europe document [34], it was approximated to at least EUR 3 billion per year. Such cursory approximations also indicate that this issue should be studied in more detail.

By reviewing bibliographic sources, it was recognized that significant work has been done so far to study the performances of the ATM system in Europe. However, most of the sources do not consider all three correlated features of performance data. Most frequently, data manipulation is usually based on the analysis of attribute and temporal features of the performance data. Figure 1 shows an example of the aforementioned. It depicts only variability of attributive and temporal features of average system-wide annual en-route unit rate value, en-route Air Traffic Flow Management (ATFM) delay value, airspace complexity score value, and value of horizontal en-route flight inefficiency.

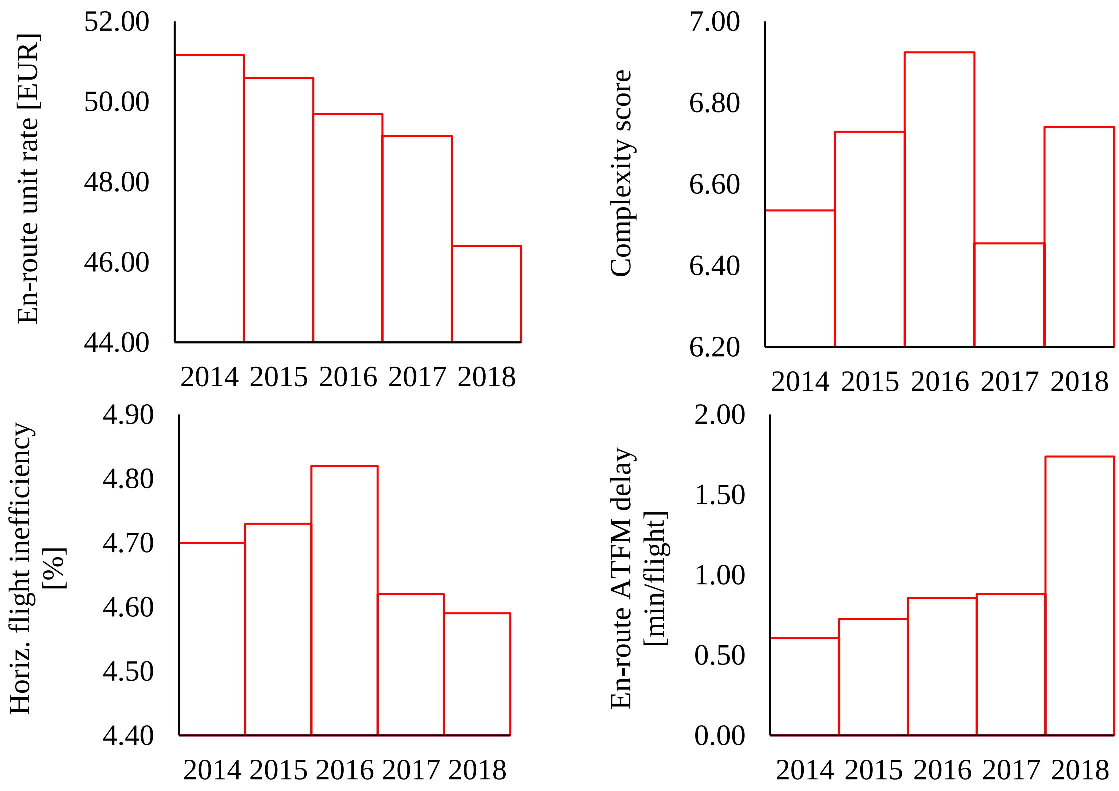


Figure 1. Overview of the ATM-related performance data distribution [35]

As a result, the spatial feature of the data set is frequently underutilized. Since 80% of information requirements stipulated by policy makers are related to spatial location [36,37], that certainly raises many issues. Particularly because performance management is one of the key mechanisms on which strategic planning and development of the ATM system in Europe relies.

Furthermore, summarization of the most recent literature [38-46] on the topic of the European airspace fragmentation presented during the research workshop titled “Fragmentation in Air Traffic Management” in 2018 indicates that there are currently no unambiguous answers to questions on how to define, and more importantly, how to measure airspace fragmentation. In addition, the literature review indicates that there are no sources that simultaneously correlate attribute, temporal and spatial features of the performance data of the ATM system in Europe in respect to airspace fragmentation assessment. Therefore, since performance-based airspace fragmentation has not been comprehensively addressed so far, through a development of a model for assessing the European airspace fragmentation based on the spatial distribution of the values of performance indicators of the ATM system, this paper complements the existing literature in the domain of strategic planning and development of the ATM system in Europe.

1.4. Methodological approach

Air Traffic Management is a safety-critical system. Therefore, within its strategic planning and development, as well as within change management, previous validation of anticipated changes in simulated conditions is sought. In that respect, it can be outlined that this research is based on laboratory (demonstration) research activities conducted in controlled conditions with the use of various technical and technological equipment and solutions. In addition, conducted research activities are carried out based on input data capturing performance of the ATM system in Europe that were collected and disseminated by EUROCONTROL/PRU. Furthermore, since the research involves measurements of the same phenomenon on several occasions, it can be said that it is based on longitudinal research. Lastly, it can be stated that the research is based on adoption of an interdisciplinary research approach. For instance, methodological framework applied within model development is based on Tobler's first law of geography ("everything is related to everything else, but near things are more related than distant things"), the origin of which actually derives from Newton's law of universal gravitation. Furthermore, the obtained estimations are consolidated and presented in form of a report by adopting means of Information Technology. These reports can be further used within the domain of the strategic planning and development (representing one of the organisation and management functions of economics). A simplified view of the aforementioned is shown in Figure 2.

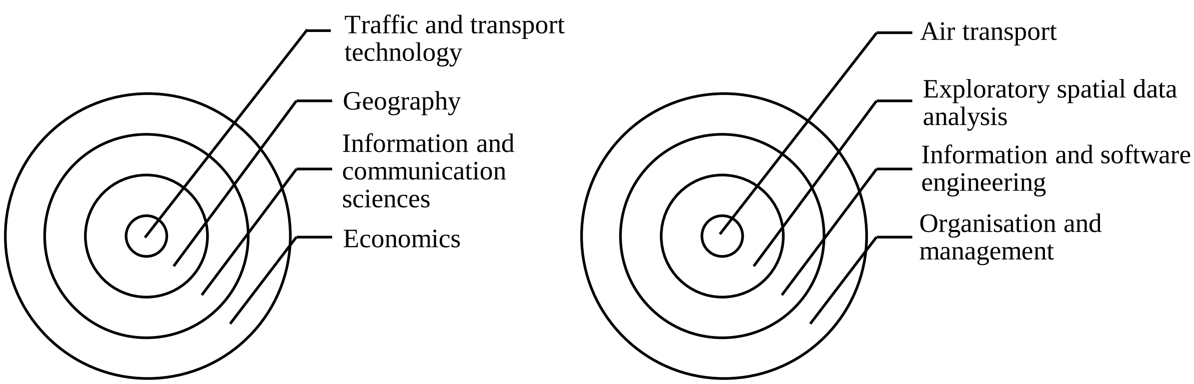


Figure 2. Overview of the applied interdisciplinary research approach

1.5. Expected contribution

After the establishment of the SES initiative, data describing performances of the ATM system in Europe have become highly available. Whereas a few decades ago the major problem was data unavailability, nowadays the most frequent shortcoming is the lack of time and knowledge required to turn large sets of data into useful information. Hence, the scarcity of information on the issue of the European airspace fragmentation might be seen nowadays as one of the causes for the lack of focus of collaborative initiatives on fragmentation issues. In that respect, in order to ease the conduction of strategic planning and development of the ATM system in Europe, a development of the European airspace fragmentation assessment model that simultaneously adopts scientific and professional settings has been initiated.

From professional aspect it can be stated that the developed model goes hand in hand with the aspirations of the European Commission to achieve the European airspace defragmentation. Primarily because the developed model supports evidence-based decision-making processes and enables data-driven argumentations. Moreover, by taking advantage of various performance modelling techniques and approaches, the model derives understandable insights from massive, dynamic and often ambiguous performance data sets and synthesizes business information. Its utilisation brings several benefits – ranging from business processes automation, better understanding of complex relationships of endogenous and exogenous factors and opportunity to evaluate effects of various decisions and projects in the field of strategic planning and development of the ATM system.

Development of the European airspace fragmentation assessment model, i.e., development of a model for assessing the European airspace fragmentation based on the spatial distribution of the values of performance indicators of the ATM system, represents a contribution from the scientific viewpoint. It was recognized in the literature review that there are no sources addressing the issue of performance-based European airspace (de)fragmentation. In addition, there are no studies which correlate all three features of performance data in relation to airspace fragmentation. Furthermore, the subsequent application of the developed model on a case study can also be outlined as the contribution of this paper. It presents insights on how fragmented it is, and where and how it is possible to defragment European airspace from capacitive aspect. These insights are followed by change impact analysis so that this paper also approximates the effects (operational, economic, environmental, i.e., social benefits) that would be enabled by capacity-based airspace defragmentation. Also, one of the main contributions of this paper is that it provides a clear terminological meaning to the term "airspace fragmentation". Determination of the flaws of methodological and conceptual assumptions of currently applicative framework of strategic planning and development of the ATM system in Europe can be also outlined as contribution of conducted research. Thereby, the shortcomings identification is followed by the presentation of findings resolving the identified shortcomings. Furthermore, the development of a new, theoretical and scale-independent spatial indicator introduced with a goal to facilitate estimation and monitoring of the airspace fragmentation based on the performance of the ATM system also represents one of the main research outcomes. In addition, determination of causal relationships that are directly and indirectly associated with the existence of performance-based airspace fragmentation can also be listed as a contribution of the conducted research. In such a way, through combination of scientific and professional settings, by complementing existing scientific literature in the field of research, by developing an innovative model that is based on application of novel conceptual and methodological frameworks, through application of the developed model and presentation of research findings, this paper contributes to a more inclusive, smart, environmentally-friendly and spatially oriented development of the ATM system in Europe.

1.6. Dissertation outline

Dissertation outline consists of six main chapters. The first chapter covers the introductory part. It provides an overview of research motivation, research objectives, and hypothesis. In continuation of an introductory part a survey of previous studies is presented. Literature review is followed by an overview of the adopted methodological approach, while the expected contributions are listed prior to the dissertation outline.

The second chapter provides an overview of the European airspace fragmentation typology. Its first subchapter addresses the organisational airspace fragmentation. It is followed by a description of operational airspace fragmentation. The next subchapter provides an overview of the technical airspace fragmentation. The subchapter to come provides an insight on functional airspace fragmentation, while the last one deals with performance-based airspace fragmentation.

The third chapter presents a review of conceptualization and model development. Its content describes the model development background including a review of regulatory framework on which strategic planning and development of the ATM system in Europe relies. In addition, it presents a review of the frequently used data manipulation method within the ATM domain. Both reviews are presented as they can be correlated with the issue of airspace fragmentation. The next subchapter presents methodological assumptions adopted within the process of conceptualisation and model development. The content of third chapter also presents a data manipulation framework that is followed by a review of methodological limitations. In continuation, an overview of the model utilisation framework is provided. The third chapter is concluded with a comprehensive overview of model applicability.

The fourth chapter presents utilisation of a developed model on a case study of capacity-based assessment. After a brief introductory overview of the airspace capacity management function, research determinants adopted within a case study are presented. The main research findings in the sense of capacity-based airspace (de)fragmentation are presented in continuation.

The fourth chapter is followed by the chapter Discussion within which the main research findings have been placed in wider research context.

Last but not least, the sixth chapter provides an overview of an overall R&D efforts and outlines the main outcomes and conclusions.

2. EUROPEAN AIRSPACE FRAGMENTATION TYPOLOGY

In principle, the issue of airspace fragmentation did not come out of the blue. On the contrary, it is a result of the decision-making processes conducted at national, local, and regional levels over the past few decades. Nonetheless, the term "airspace fragmentation" nowadays frequently has a contextual meaning. Considering that the adoption of such a practice is not scientifically acceptable, the term "airspace fragmentation" requires more precise terminological and typological determination. Particularly as the issue of the European airspace fragmentation can be observed from many different viewpoints. Therefore, in order to facilitate further study of the issue of airspace fragmentation as a research topic, it was firstly required to determine more precisely the following:

- Which airspace fragmentation types exist?
- What are the differences between them?
- How can they be displayed?
- Which types are more apparent than others?
- How much do they spatially and temporally vary?
- When did some types begin to appear?
- Which airspace fragmentation types have been studied the most so far?
- Which airspace fragmentation types require further research?

By providing answers to these questions, i.e., through determination of the European airspace fragmentation typology, a more comprehensive view of the issue of airspace fragmentation can be obtained. Therefore, based on the literature review, this chapter provides an overview on the European airspace fragmentation typology. Accordingly, five airspace fragmentation types were identified, studied, described, and presented in the continuation of this chapter. As such, through supplementation of the literature in the field of research, this chapter makes terminological meaning of "airspace fragmentation" much clearer – so that it should no longer have contextual meaning.

2.1. Organisational airspace fragmentation

Reviewed subject literature on the issue of fragmented design of the European airspace indicates that the term “airspace fragmentation” to a great extent refers to its organizational division. Therefore, organisational airspace fragmentation can be listed as the first type of airspace fragmentation. In addition, it is listed first because the understanding of organizational fragmentation is important for the understanding of other fragmentation types.

Usually when the issue of airspace fragmentation is mentioned, it refers to the issue of the European airspace division based on the national borders. However, airspace division based on national borders represents just one aspect of organizational airspace fragmentation. For instance, from the organizational aspect, European airspace can be divided into different volumes. The appropriate way of defining it can be obtained by placing it in the context of horizontal and vertical airspace division. Horizontally it is divided into controlled airspace volume, airspace volume in which flights are specially regulated, and uncontrolled airspace volume. On the other hand, vertical airspace division refers to the division of the controlled airspace into multiple sectors such as lower, upper, high or top sector. Figure 3 shows an example of the vertical and horizontal view of organizational airspace fragmentation. Also, organizational airspace fragmentation is primarily a result of the application of different airspace organizationally-related policies, strategies, and rules established to ensure safe and coordinated flight operations. Lastly, this fragmentation type represents quite an apparent and consistent airspace fragmentation type which does not significantly vary temporally or spatially.

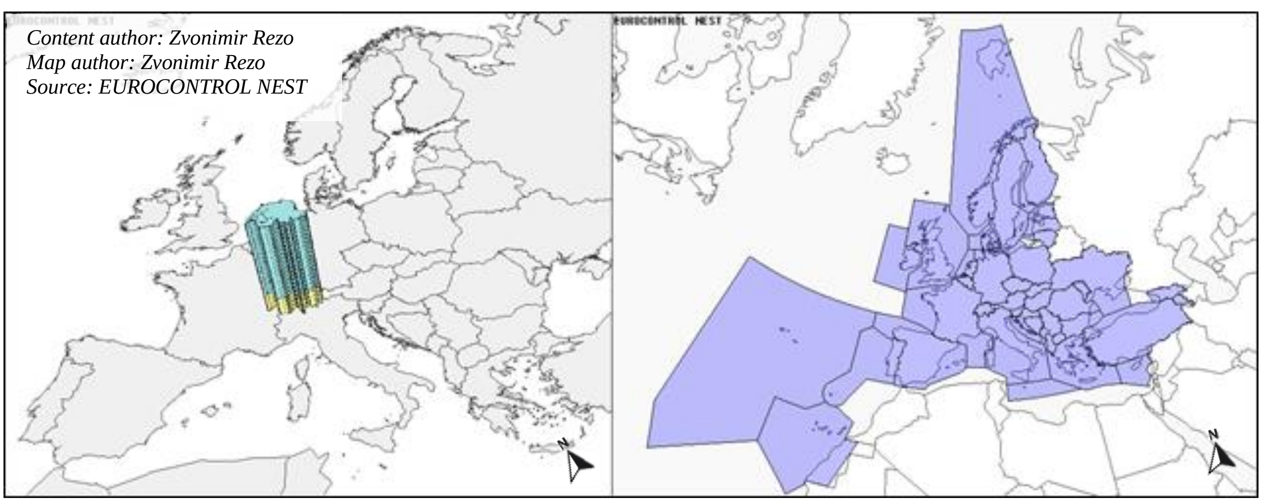


Figure 3. Spatial overview of organizational European airspace fragmentation

2.2. Operational airspace fragmentation

Operational airspace fragmentation is closely related to organizational airspace fragmentation. As the term suggests, it is derived from the operational domain of the ATM system, i.e., its airspace management function. More precisely, it refers to horizontal airspace division and controlled airspace volume in which flights are specially regulated. It coincides with the sovereignty right of every State to prohibit or restrict flights in parts of airspace volume [47]. Therefore, it can be depicted by seceding airspace areas which are categorized as Prohibited (*P*), Restricted (*R*), Dangerous (*D*), Temporary Segregated/Reserved Areas (*TSA*, *TRA*) etc. [48]. Figure 4 show an example of the outlook of the operational airspace fragmentation over the Europe.

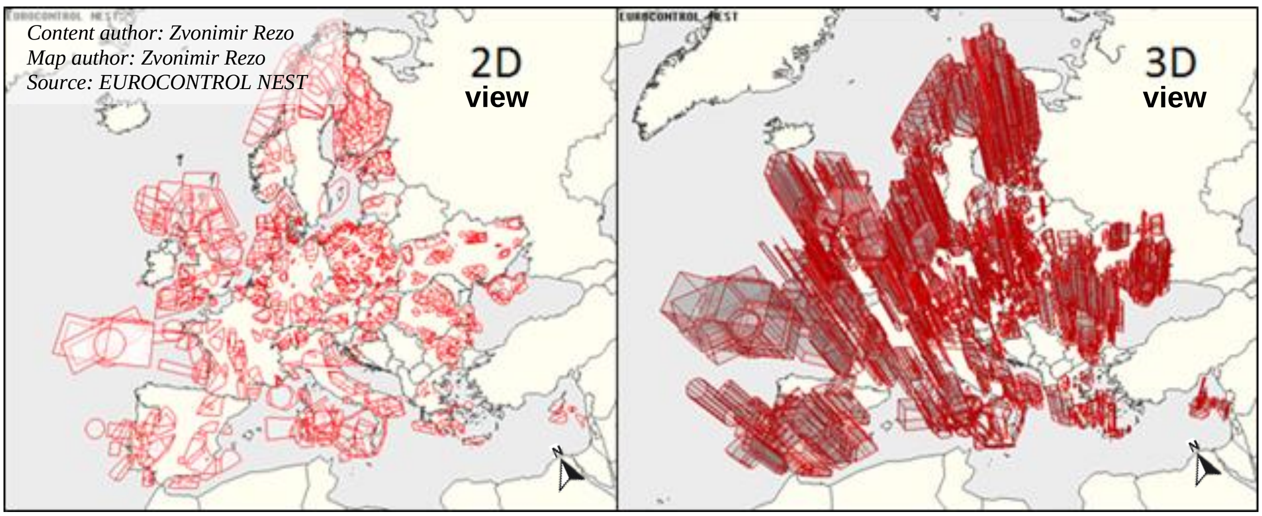


Figure 4. Spatial overview of operational airspace fragmentation

In recent history operational airspace fragmentation had a significant effect on the flight efficiency. Part of the reason were frequent airspace closures and flight routing restrictions imposed as a result of the military activities [49]. Although military airspace structures were closed for commercial flights, frequently they were not H24 operational. During these times such situations made ATFM more complex and civil-military cooperation more difficult [50]. Consequently, the lack of airspace capacity (availability) affected the increase of en-route ATFM delay and increase of operational costs of General Air Traffic (GAT). However, during the last two decades significant efforts were taken to reduce adverse effects associated with the operational airspace fragmentation type.

The tipping point for the operational airspace fragmentation type occurred with the establishment of the SES initiative back in 2004. Primarily because the SES imposed a need for a higher utilization level of military airspace structures – which could no longer be operational H24 and unevenly used. Thereby, the shift from permanent structures into dynamically manageable military airspace structures significantly reduced the level of operational airspace fragmentation. That was primarily enabled by the implementation of the FUA concept initially supported by the Commission Regulation (EC) 2150/2005 [51]. The main idea behind the FUA concept was to create an operationally manageable airspace structure which can be activated and deactivated at certain intervals and in such way subdivide the airspace between different categories of AUs. In addition, it is necessary to emphasize the on-going implementation of the FRA concept which is supported by the Commission implementing Regulation (EU) 2019/123 [52]. Its deployment classifies specified airspace within which "users can freely plan a route between a defined entry point and a defined exit point with the possibility of routeing via intermediate waypoints" [53]. These two concepts are particularly distinguished as good examples of how it is possible to improve flight efficiency regardless of organisational and operational airspace fragmentation. Their implementation reduced the level of operational airspace fragmentation that has consequently enabled multiple benefits, including: minimization of adverse environmental effects, improvements in area of airspace capacity, i.e., its availability, flight efficiency enhancement, and the resulting cost-savings for airspace users.

To sum up, it can be said that operational airspace fragmentation represents quite a familiar and apparent airspace fragmentation type. Compared to other fragmentation types, it can be outlined that during the last two decades the most noticeable effort to overcome the repercussions of airspace fragmentation was achieved in the field of operational airspace defragmentation. Furthermore, the operational airspace fragmentation type is a highly variable airspace fragmentation type. Accordingly, its fragmentation level frequently differs from hour-to-hour or from day-to-day level. Therefore, it can be concluded that this fragmentation type is significantly temporally and spatially variable.

2.3. Technical airspace fragmentation

Technical airspace fragmentation represents a fragmentation type which is rarely placed in the foreground. It is a result of market competitiveness of technical services, equipment and infrastructure provided by different Flight Data Processing (FDP) and Radar Data Processing (RDP) system' suppliers. Accordingly, it is closely related to a highly-technological environment operating under economic pressure with a set of complex links between different parties.

An incontestable right of every ANSP is to choose the best market offer for FDP and RDP systems. On the European level (characterized by market openness), application of such an approach has led to a scattered application of different FDP and RDP technologies, i.e., solutions. In that context, Baumgartner and Finger [54] argue that nowadays FDP and RDP system suppliers are faced with only one market per country. Consequently, that has led to the adoption of business logic of developing tailor-made solutions designed for every ANSP individually. Consequently, there are situations in which sometimes the neighbouring ANSPs have poorly interoperable systems – resulting in a series of handovers between the neighbouring ANSPs as they are working with different technical systems [55]. Therefore, technical airspace fragmentation has an adverse impact on handovers, the ATCOs' workload level, complexity, and airspace capacity and flight efficiency. An example of temporal and spatial variability of the technical airspace fragmentation in Europe is presented by Figure 5.

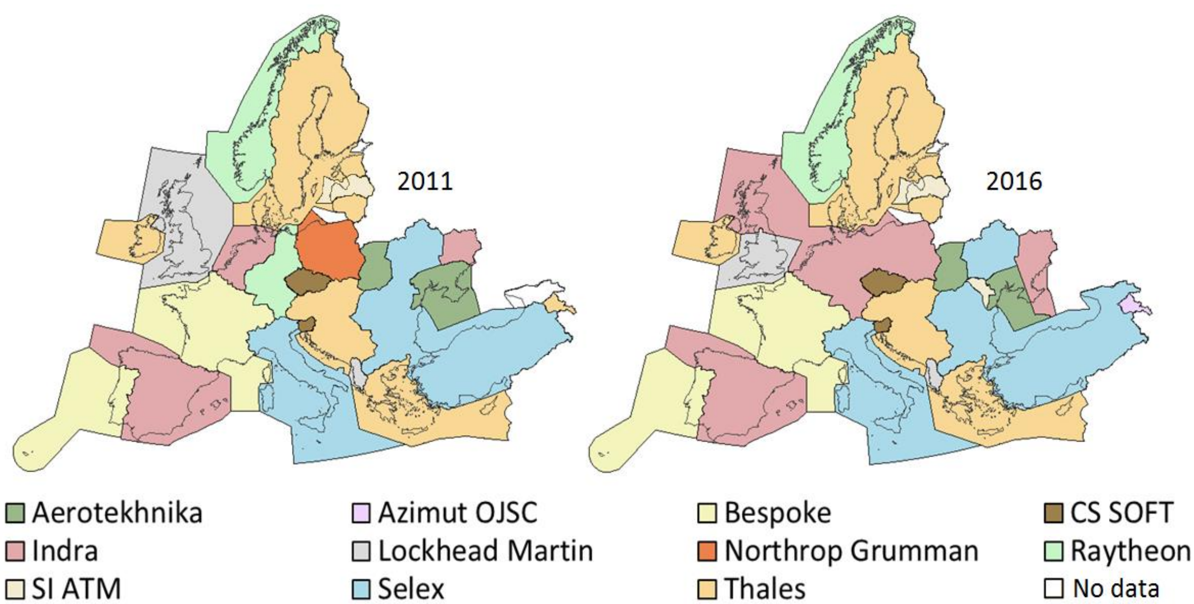


Figure 5. Temporal and spatial variability of the technical airspace fragmentation [56,57]

Furthermore, it can be defined that within previous decades there were none or very few initiatives for collaborative activities with the aim to mitigate technical aspects of airspace fragmentation. However, unlike in the past, during the last decade it is possible to notice different "activities" aiming towards common technical procurements. In addition, compared to previous years, nowadays technical and technological solutions also permit a higher degree of centralised management and maintenance of FDP and RDP systems. The mentioned advances can be seen as a slight improvement contributing to the reduction of this type of airspace fragmentation. However, it must be pointed out that realisation of such initiatives frequently faces opposition due to the existence of different interests, which do not only fall under the domain of the business interests of ANSPs, but also include national interests. Furthermore, it can be outlined that FDP and RDP system suppliers have no interest in the large-scale harmonization of the ATM services, equipment and infrastructure primarily because, if that occurs, most likely some of suppliers would disappear from market. Considering the above, it is expected that technical airspace fragmentation will not significantly change over the years to come. Thereby, previous experiences indicate that slight market differences might only arise with a given time lapse. Hence, it can be defined that this fragmentation type is somewhat variable in space and time.

2.4. Functional airspace fragmentation

Functional airspace fragmentation represents a frequently mentioned and depicted airspace fragmentation type which has experienced a slight spatial and temporal change over the time. It is a conditionally determined and politically supported airspace fragmentation type. That mainly refers to the fact that this airspace division was determined by the European Commission through the introduction of legislative framework – as a support to the realisation of the SES initiative. The idea behind this artificially created fragmentation type was to boost airspace reorganization through the establishment of FABs [58]. A FAB represent an airspace block which is based on operational requirements, reflecting the need to ensure a more integrated management of the airspace regardless of the existing national borders [59]. According to Button and Neiva [60], FABs represent a tool which should simultaneously reduce the airspace fragmentation level and increase the overall efficiency of the ATM system in Europe. Figure 6 shows an approach to the foreseen functional airspace reorganization of the European airspace through the SES initiative.

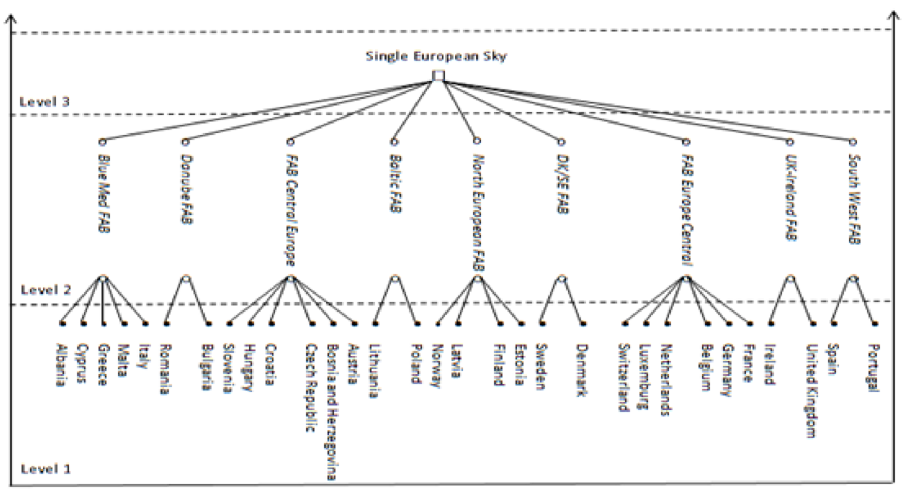


Figure 6. Vertical overview of the functional reorganization of the European airspace

The main goal of creating a functional airspace fragmentation was to defragment the European airspace by reducing its organisational airspace fragmentation. However, as the European Court of Auditors (ECA) had argued in 2017, the establishment of FABs eventually only fostered cooperation forums and did not contribute to airspace defragmentation [11]. Even though it did not meet the expectations of many, the establishment of FABs resulted in additional (administration) cost to be covered by the AUs (i.e., passengers as end-users) of approximately EUR 5 million in total per year, or around EUR 500,000 per year in average per each FAB [49].

By considering the achieved progress in the sense of the establishment of FABs and their significance, it is evident that even though the planning of the SES initiative is based on the implementation of collaborative FABs, the actual implementation is fragmented and based on national levels and interests [61]. Moreover, considering how many years elapsed since the European Commission had launched the SES initiative indicates that the ATM community in Europe too long tries to make a step from functional Level 1 to Level 2. With such a slow progress and partial efforts, it is hard to predict whether and when the transition to the third functional level is even going to happen. Figure 7 shows a spatial overview of the foreseen process of functional airspace reorganization from which it a geographical distribution of FABs and differences between their sizes can be seen.

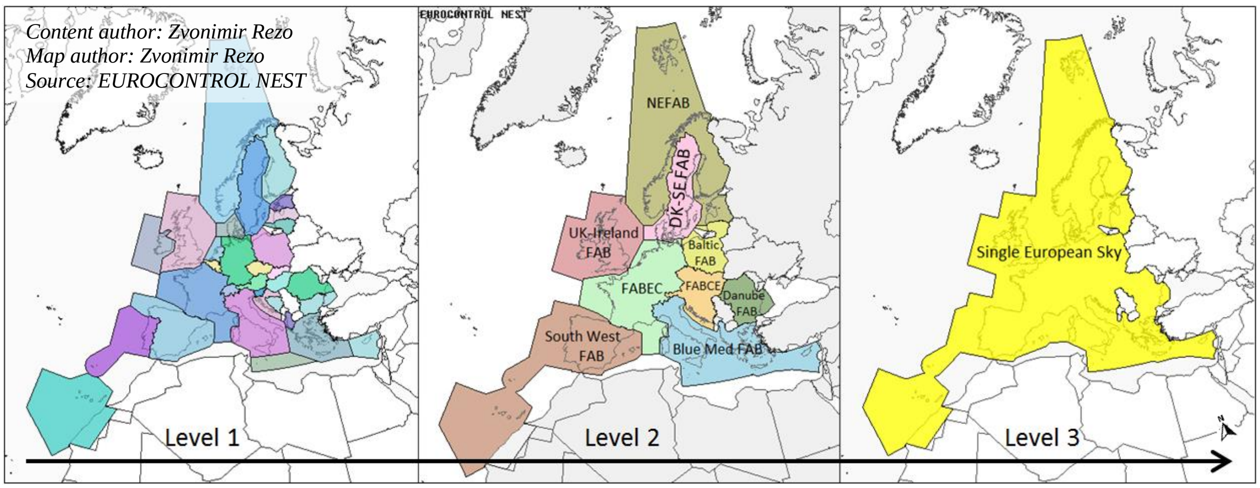


Figure 7. Spatial overview of the functional reorganization of the European airspace

The question of purposefulness of the establishment of functional airspace fragmentation was raised by many ever since idea of the introduction of FABs. For instance, the International Air Transport Association (IATA) argued that the development of FABs is unacceptably slow and passive as well as that FABs did not optimize airspace neither along the air traffic flows nor human or technical resources [62]. On the other hand, in the context of functional reorganization of the European airspace, Franklin [63] argues that the defragmentation process is inconspicuous. Furthermore, Fox [64] argues that the Member States are reluctant to seriously tackle the fragmentation issue. That is also the reason why Jaffe [65] describes Europe as a “jigsaw puzzle of independent national airspaces” and why Steiner et al. [66] argue that the fragmentation problem should be solved by more comprehensive and dynamic harmonization programs.

2.5. Performance-based airspace fragmentation

Performance-based airspace fragmentation represents an airspace fragmentation type which exists due to different attributive, temporal and spatial features of the performance levels of ANSPs. As Figure 8 shows, it represents a product of partial interactions of several other airspace fragmentation types (but mostly the ones listed earlier). Compared to other airspace fragmentation types, this type does not represent the frequently mentioned fragmentation type primarily as it is “hidden behind” more easily noticeable types of airspace fragmentation.

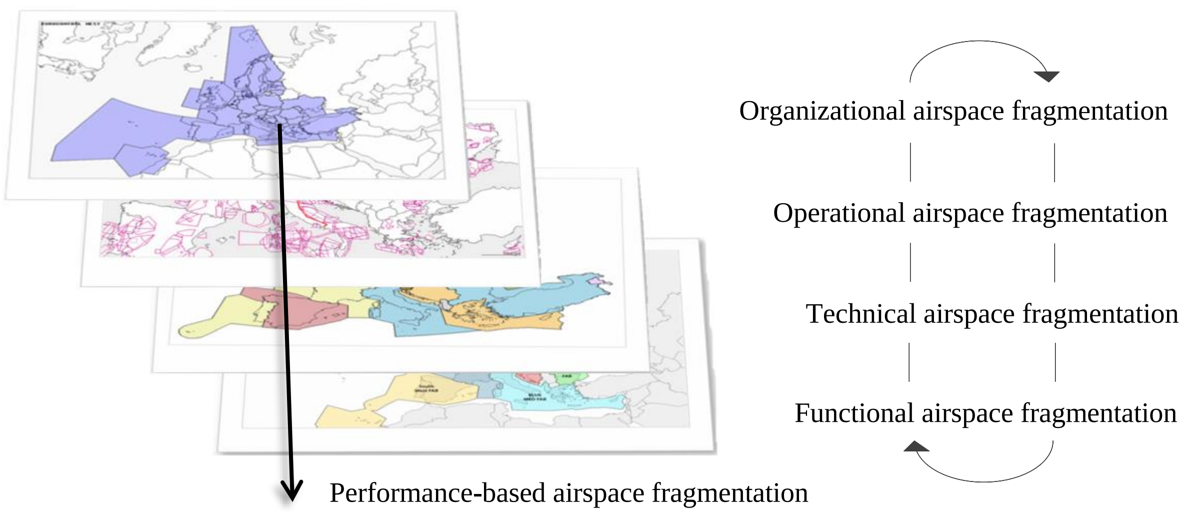


Figure 8. The genesis overview of the performance-based airspace fragmentation

As there are no findings that correlate performance of the ATM system with the performance-based airspace fragmentation, it is expected that this type is highly variable – both in space and time. It is expected that it correlates with the changes of the performance level of the ATM system in Europe. Also, in respect to other fragmentation types which are defined by global, regional or national regulations, acts, standards or treaties, this fragmentation type does not correspond to national borders. In addition, unlike fragmentation types, in order to determine the fragmentation dynamics, defragmentation progress achieved so far etc. of the performance-based airspace fragmentation, empirical research must be conducted. Its outlook and variability differ from one to another performance indicator. Lastly, it can be defined that the need for the development of a model for assessing the European airspace fragmentation based on the spatial distribution of the values of performance indicators of the ATM system originates from the scarcity of information on the issue of the performance-based airspace fragmentation.

3. CONCEPTUALIZATION AND MODEL DEVELOPEMENT

3.1. Model development background

Strategic planning and development of the ATM system in Europe, as well as many other functions within the ATM domain, deal with planning and decisions of a medium to long-term range [67]. From the conceptual aspect, strategic planning and development of the ATM system in Europe is based on adoption of the two-step approach. The first step covers strategy determination through the identification of relevant KPAs and KPIs, while the second step refers to gradual change management. As Figure 9 shows, the second step can be further broken down into three successive phases. The first phase refers to determination of the existing business situation. Determination of the existing business situation represents a crucial step of any decision making as without knowing the starting position, it is hard to know where to strive for improvement. Therefore, this phase should, as much as possible, objectively describe the existing business state. The second phase includes a set of activities that need to be conducted with a goal to identify the desired business situation. The last phase covers activities that are required in order to determine the required performance improvement. This phase should result with determination of how to make a move from the existing to the desired performance level and close the identified performance gap (if it exists) in a few measurable steps. Accordingly, a performance gap represents the difference between the existing and the desired performance level ($|A\Delta E|$).

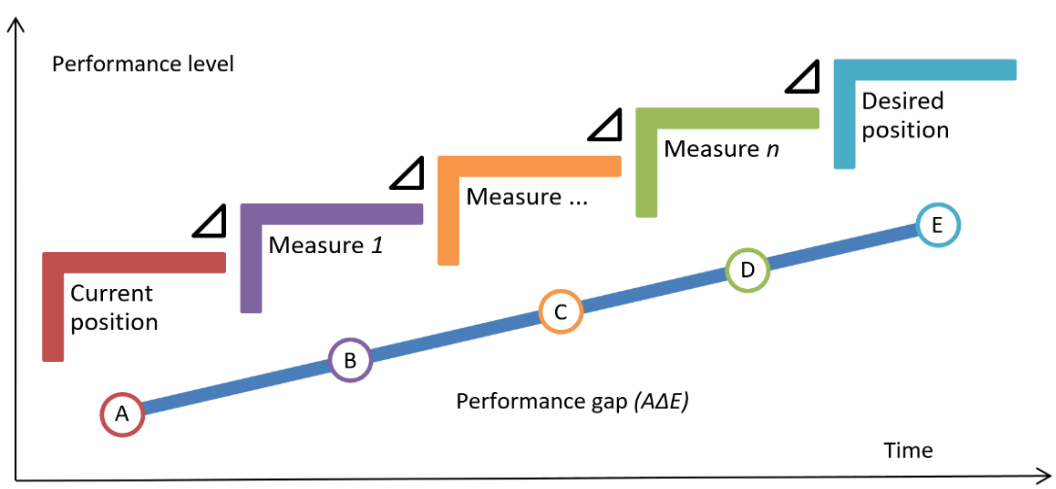


Figure 9. Simplified overview of gradual change management and performance gap reduction

In principle, there are several methods and approaches that can be applied within the domain of strategic planning and development of the ATM system for the purpose of determining the desired business situation. Nowadays, it is most usually perceived that the desired business situation (performance level) corresponds to the value of the performance target set by the Performance Scheme. Briefly, the Performance Scheme represents the regulatory instrument supporting realisation of the SES initiative introduced within the framework of the SES 2 package back in 2009. According to McMillyn and Van Dam [68], the Performance Scheme represents one of the absolute conditions for the very existence of safe and efficient air transport, while Steiner et al. [69] indicate that its aim is to ensure efficiency improvements by providing better service quality at lower cost and to minimize negative impacts arising from performance variability. In addition, it can be defined that it is organised around fixed Reference Periods (RPs) lasting from three up to five years. Thereby, RPs are defined as periods of validity and applicability of the Union-wide performance targets and performance plans. At the time of this study, three RPs were applicative. The first reference period (RP1) ran for three years and it lasted from 2012 to 2014. The second reference period (RP2) lasted from 2015 till 2019. The third reference period (RP3) should have covered the period from 2020 till 2024. However, due to the occurrence of SARS-CoV-2 pandemic, it was amended by the Commission Implementing Regulation (EU) 2020/1627 [70]. Last but not least, it can be outlined that over the years Union-wide performance targets only slightly changed, while the adopted methodological and conceptual assumptions remained the same.

Model development background differs from frequently used conceptual and methodological assumptions of strategic planning and development of the ATM system. More precisely, it differs in conceptual and methodological assumptions applied within the process of determining the desired business position. In addition, it differs in respect to frequently applied data manipulation framework that serves for the purpose of obtaining a sense of performance data distribution (which findings later on serve as basis for decision-making within the domain of strategic planning and development of the ATM system). More detailed overview of the adopted differences within the model development background is presented in the next two subchapters.

3.1.1. Regulatory framework review

The objectives of strategic planning and development are usually evaluated in the sense of their comprehensiveness, applicability and manageability. However, within the ATM domain in Europe they are mainly driven and evaluated with respect to the regulatory framework. With the goal to defragment European airspace, in 2004 the EC initiated an ATM regionalization process. Therefore, nowadays the strategic planning and development of the ATM system in Europe is based around the regulatory framework introduced to support the realisation of the SES initiative. However, there are a few conceptual and methodological flaws within regulatory framework that contribute to the existence of performance-based airspace fragmentation.

In principle, close connection between strategic planning and development of the ATM system with the regulatory framework has on the one hand delivered certain benefits. However, on the other hand, it had irreversibly determined the further direction of the ATM system development. As a result of their close connection, consequently a flaw in regulatory framework reflects also as a flaw of strategic planning and development framework. In that context, the determination of whether an ASNP is efficient is done in Europe by comparing its performance achievements with those determined by the Performance Scheme. Accordingly, from the methodological aspect, performance valorisation framework is based on the adoption of the methodological assumption of statistically independent observations. As a result of adoption of such methodological assumption, the currently applicable regulatory and performance valorisation frameworks do not recognize the causal relationships of performance, performance interdependencies, performance trade-off, goals, conflicting situations etc. between the ANSPs. Also, the spatial feature of the performance data is completely ignored within the regulatory framework, i.e., performance valorisation process. For instance, if by the end of 2018 a certain ANSP achieved an en-route ATFM delay of 0.50 [min/flight], according to the at that time applicable performance targets of the RP2 [71], such ANSP was considered efficient. Within the performance valorisation process, it is irrelevant whether that ANSP represents spatial outliers and as such deviates from the neighbouring ANSPs, or whether it forms a pattern of spatially similar values. As Figure 10 shows, performance valorisation within an existing regulatory framework is performed only in respect to the vertical performance improvement scale and it does not consider the horizontal performance improvement scale.

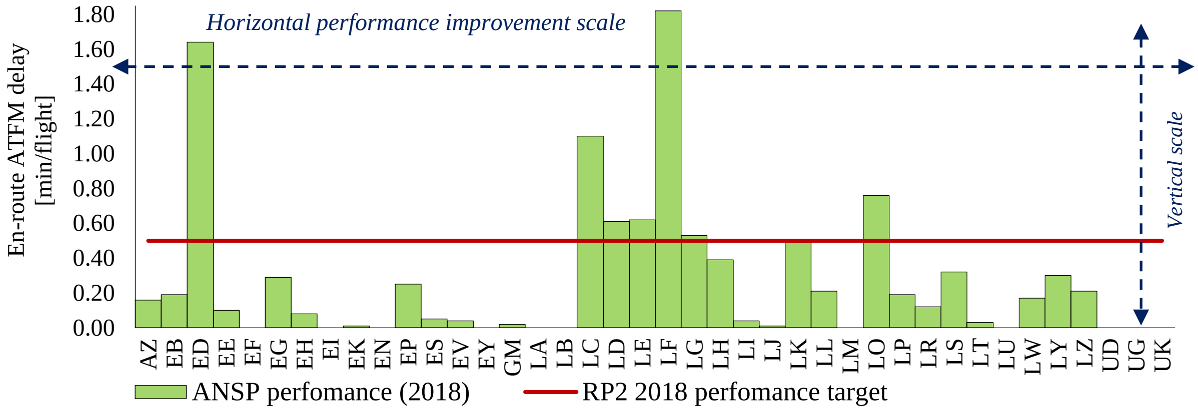


Figure 10. Capacity-related vertical and horizontal performance improvement scales

Considering the above, one can argue that the idea of the horizontal performance improvement scale exists and that it is integrated into the idea of the establishment of FABs. Probably because one may misinterpret the meaning of the FABs in the sense that from organisational and management level they correspond to the “local level”. However, in such an understanding the terminological determination of the term “local level” is frequently omitted. Hence, it raises a rhetorical question of its terminological meaning. Whether it should be perceived within its geographical meaning or whether it should be interpreted as a political formulation – as its meaning is also regulatory (artificially) determined. By considering the horizontal performance improvement scale with respect to the idea of the establishment of FABs, it is evident that the terminological meaning of “local level” does not correspond to its geographical meaning. For instance, a particularly interesting case is the Polish ANSP (PANSA), which is the member of the Baltic FAB, whereas its first-order neighbours are members of the Danish-Swedish FAB (LFV), FABEC (DFS) and FAB CE (ANS CR and LPS). Also, there is an example of the Serbian ANSP (SMATSA) which is not a member of any FAB (even though its geographical position is quite important for the management of the air traffic flow at the South-East Axis).

In continuation, Figure 11 shows the performance gap between the RP-defined performance targets and the achieved performance levels on the system-wide level from a capacitive aspect. As it can be seen, performance targets set by the Performance Scheme were over-promising and they under-delivered for years. In that context, the AUs can be listed as the ones with probably the highest expectations, but simultaneously as the ones highly disappointing in terms of performance achievements. Therefore, one can frequently find public releases with severe allegations (mostly directed to the EC) published by the representative organisations of the AUs.

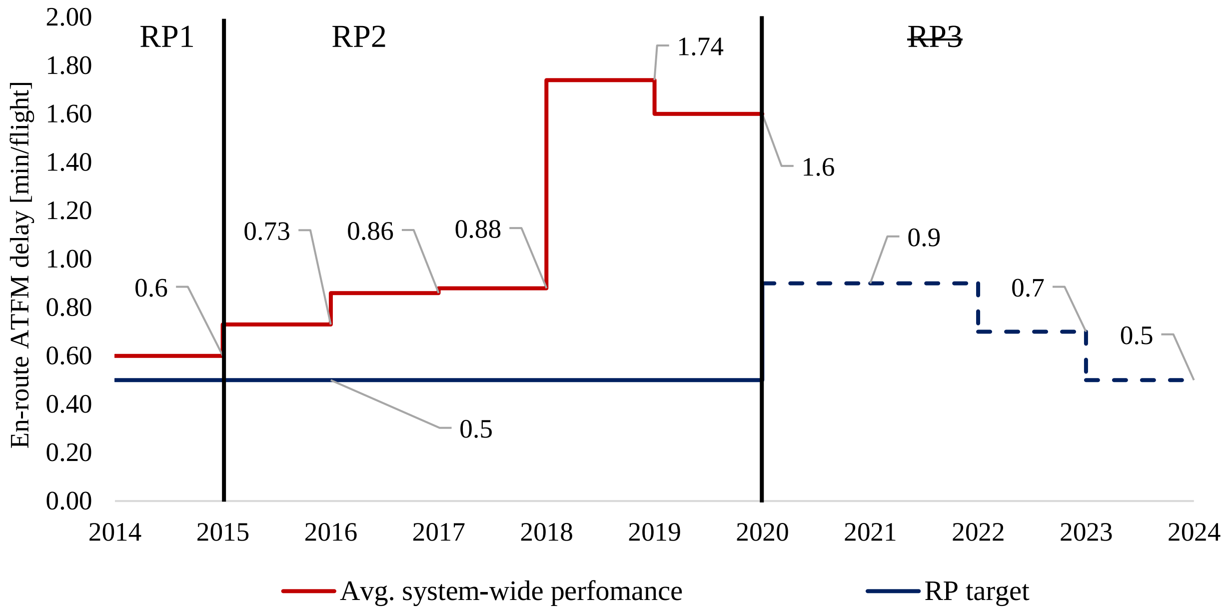


Figure 11. Performance gap between the achieved and the required performance level

Apart from the accuracy of the AUs' allegations, it is interesting that an en-route ATFM delay generated during e.g., RP2, despite its significance, was actually not evaluated negatively from the regulatory standpoint. Primarily during RP2, there was a high share of ANSPs that generated significantly lower figures of the en-route ATFM delay than it was "allowed" by the Commission Implementing Decision 2014 setting the Union-wide performance targets for the air traffic management network and alert thresholds for the second reference period 2015–2019. In other words, in the case of a uniform en-route ATFM delay distribution all up to the marginal level of the regulatory-defined performance target, the generated value would be far more significant. However, even then, when it comes to performance valorisation, the overall conclusion from the regulatory viewpoint would be that from the capacitive aspect all ANSPs were in line with the regulatory-defined requirement. Again, that raises many questions on the applicability of conceptual and methodological assumptions of strategic planning and development of the ATM system in Europe. In order to present the abovementioned effect more clearly, Figure 12 shows the results of the conducted analysis in support thereof. Thereby, for the purpose of the analysis, an assumption of maintaining the same level of traffic demand [number of Instrument Flight Rules (IFR) operations] was adopted, while en-route ATFM delay [min] represented a variable that was manipulated for the purpose of analysis.

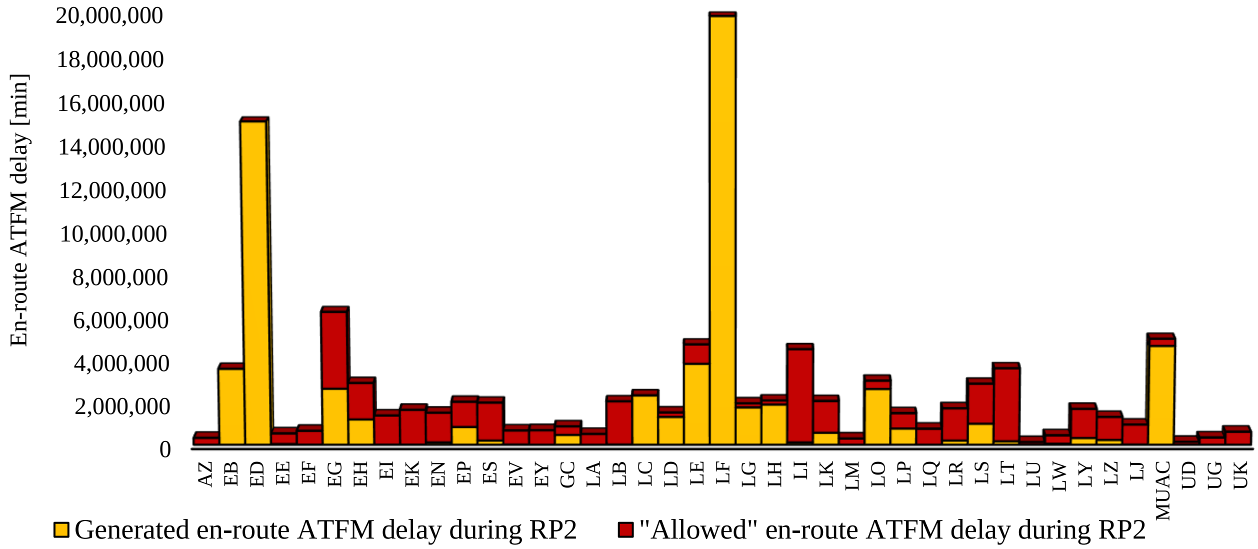


Figure 12. En-route ATFM delay at marginal RP2 performance level

Figure 13 shows a comparison of the achieved effects in respect to approximate effects “allowed” by the RP2. Thereby, the obtained results indicate that the generated ATFM delay and its effects during the RP2 could be 64.05% higher than the actually generated figure, and still be seen as acceptable by the current regulatory framework. These figures are the best demonstration for the need for urgent action. Otherwise, as long as the regulatory framework is based on the performance valorisation framework that does not consider the identified shortcomings, it will contribute to existence of performance-based airspace fragmentation.

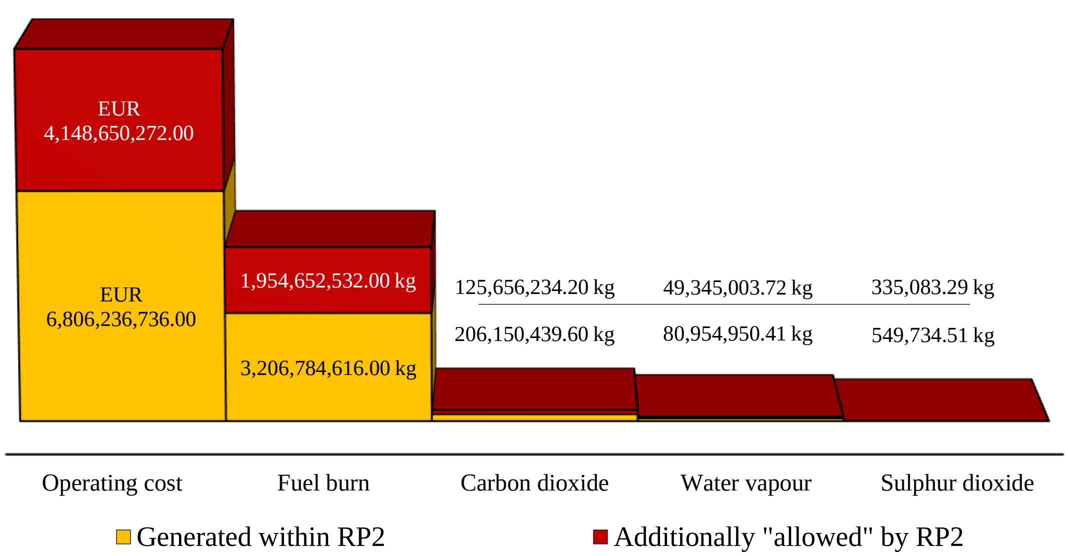


Figure 13. Comparative overview of the achieved effects in respect to “allowed” effects

3.1.2. Data manipulation practice review

In order to depict data distribution, various data visualization methods are often applied. Data visualisation represents part science and part art, where the challenge is to get the art right without getting the science wrong (and vice versa). Within the ATM domain, the most frequently applied method to obtain a sense of data distribution is the data grouping method. Therefore, it can be considered a conventional approach of presenting data distribution.

The data grouping method provides an insight of attribute feature distribution by breaking down a data set n into a certain number of classes k according to the previously established modality x_i. This method is quite useful in cases when n is large enough, but may perform poorly in cases when data is not normally distributed. After breaking down a data set, comparable attributes are identified. Accordingly, data set $x_1, x_2 \cdots x_N$ is grouped so that similar values $x_i, i = 1{,}2 \dots n$ are placed in one class. Thereby, values belonging to the corresponding interval (a_i, b_i) are placed in one class so that $a_i \leq x_i \leq b_i$. In order to determine values a_i and b_i, the number of classes k and their width, i.e., size h need to be determined as follows:

$$h = \frac{x_{max} - x_{min}}{k} \tag{1}$$

where both k and h depend on the size of the data set and the difference between its largest x_{max} and lowest value x_{min}. In addition, the classes must be adjacent and are often of equal size. The number of classes k usually ranges between five and fifteen classes. The most usual k determination is achieved by adopting the the Sturges rule (named after Herbert A. Sturges) [72]. According to the rule, the number of classes k is approximated by the following equation:

$$n = \sum_{i=0}^{k-1} \binom{k-1}{i} \tag{2}$$

where the right-hand side of the equation by the binomial theorem equals to:

$$\sum_{i=0}^{k-1} \binom{k-1}{i} = \sum_{i=0}^{k-1} \binom{k-1}{i} (1)^i (1)^{k-1-i} = (1+1)^{k-1} = 2^{k-1} \tag{3}$$

By taking logarithms with base ten, the Sturges formula is as follows:

$$(k-1)\, log(2) = log(n) \tag{4}$$

$$k = 1 + \frac{1}{log(2)}\log(n) \approx 1 + 3.3log(n) \quad (5)$$

$$k \approx 1 + 3.3\log(n) \approx [1 + 3.321928091 \cdot \log(n)] \approx [1 + 1.442695 \cdot \ln(n)] \quad (6)$$

The next phase of the conventional approach of data manipulation includes counting the number of attributes in each class. The outcome of that process is the identification of frequency distribution. If some class i contains a certain number of f_i elements of the data set, that number represents a relative frequency f_r as follows:

$$f_{r_i} = \frac{f_i}{n} \qquad i = 1, 2 \dots k \quad (7)$$

The last phase of the conventional approach of data manipulation usually includes visualization of the obtained findings. Since they provide an accurate representation of the distribution of numerical data, histograms nowadays represent one of the most frequently applied method of visualization of data distribution. Moreover, histograms have represented a popular visualization method since the 19th century, i.e., after they were introduced by Karl Pearson [73]. In general, a histogram is a convenient graphical object representing the shape of an unknown density function [74]. They can be applied to reveal data distribution, the shape of the distribution, and outlier values [75]. They are constructed so that the bases of the columns are proportional to the sizes of the classes, and if they are not equal, the height of the columns must be proportional to the corrected frequencies. Thereby, for the construction of histograms both absolute frequencies and relative frequencies can be equally used.

Although the presented data manipulation framework is quite frequently applied within the ATM-related publications [76-79], it should be noted that its methodological assumptions do not accurately reflect the real-world, i.e., the settings of the ATM system in Europe. Its application is hazardous as it hinders continuous performance improvement, which can lead to erroneous conclusions and decision-making, primarily due to systematic error in data manipulation and visualisation that occur as the result of applying an inadequate method of observation. In theory, systematic errors should be eliminated immediately after their identification. However, a prerequisite required to identify the existence of such error is to have an adequate level of knowledge in the field of research, i.e., to have an adequate level of understating of the ATM system in Europe.

With a goal to minimise further occurrences of identified systematic errors, the content below presents the methodological shortcomings of the conventional approach of data manipulation. Figure 14 shows an example of the application of the presented method within the ATM domain.

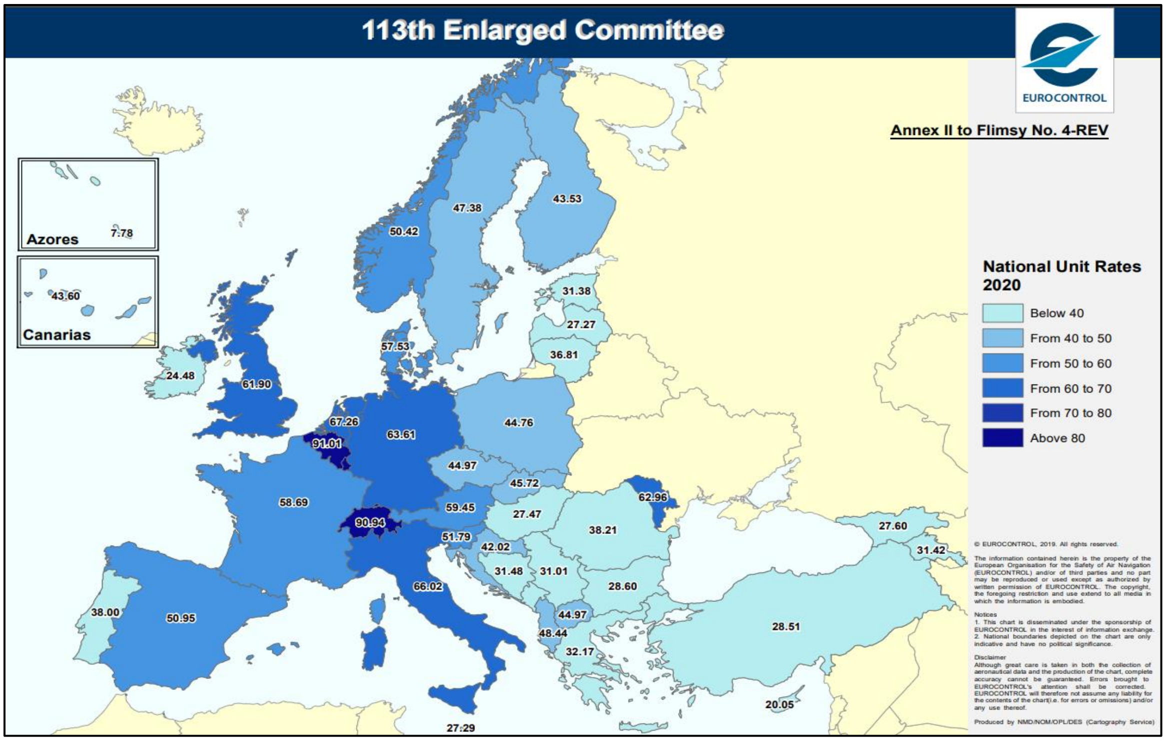
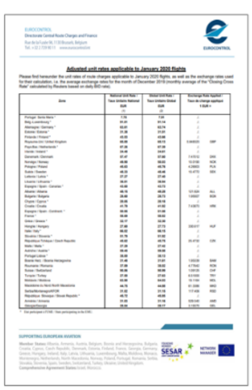
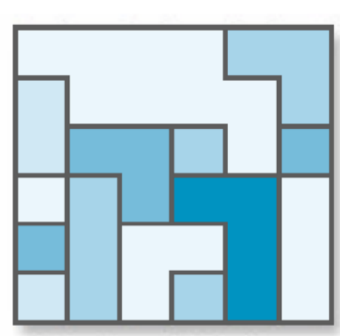


Figure 14. A spatial overview made by applying the data grouping method [80]

Figure 15 shows a conceptual framework of creating Figure 14. Based on the report containing figures of national en-route unit rates, data manipulation was performed. Thereby, instead of being presented in form of histogram, the data were visualized by using a map.



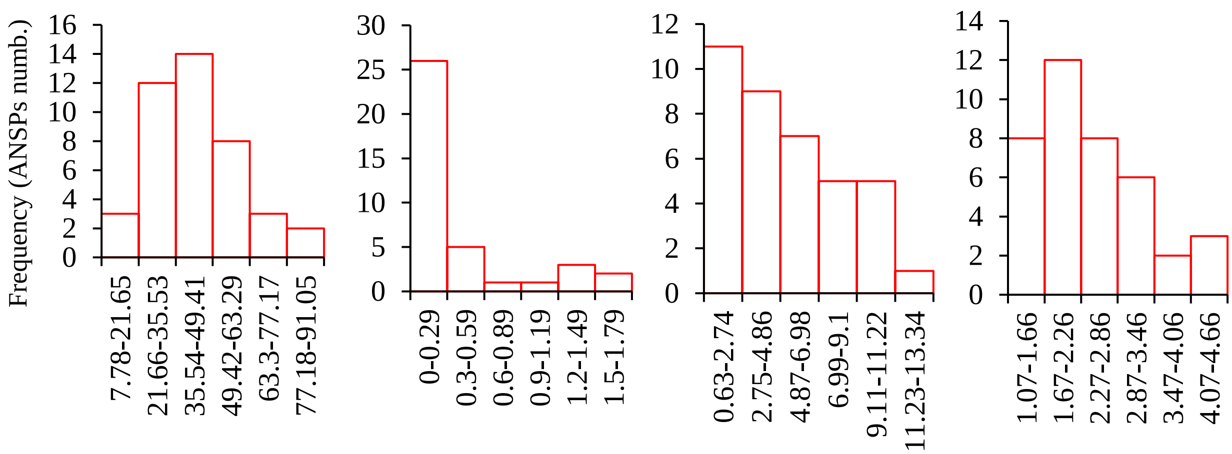
Distribution	f_i
Below 40	16
40 - 50	9
50 - 60	6
60 - 70	5
70 - 80	1
Above 80	2



Report *Data manipulation* *Data visualization*

Figure 15. Conceptual overview of conventional approach of data manipulation

Model development background differs in respect to conceptual and methodological framework of the presented conventional approach of data manipulation from several aspects. Firstly, as a result of applying the conventional approach of data manipulation, the issues of partial understanding of the business environment, improvement areas and scales, performance interdependencies, performance trade-offs, goal conflicting situations etc. may occur. Primarily because it does not capture performance interactions/compliance between the neighbouring ANSPs. This is so because the presented method is based on the adoption of the methodological assumption of independent observations. Secondly, the presented method may perform poorly in events when input data is not normally distributed. More precisely, it may provide misleading results when extremely high or low values exist. Primarily because k depends on the size of the data set n and the difference between the maximum x_{max} and minimum value x_{min}. The example *b)* shown within Figure 16 is one instance that can be found within the ATM domain.



a) National en-route unit rates [EUR] distribution

b) En-route ATFM delays [min/flight] distribution

c) Airspace complexity scores distribution

d) Flight in-efficiency [%] distribution

Figure 16. ATM related performance indicators distribution (2019) [31]

With a goal to obtain a more detail answer to the question of applicability of the data grouping method on the en-route ATFM delay, a case study has been conducted. It included the study of performance levels of 38 ANSPs operating in Europe and covered the period from 2012 to 2020. The obtained research findings on the distribution of en-route ATFM delay over the studied period was presented through the application of histograms. As shown in Figure below, all histograms have a right-skewed, i.e., positively skewed distribution. Such data distribution indicates that there are attributive features that are greater than the mode. Also, as a result of the right-skewed distributions, the mean values are greater than the median values.

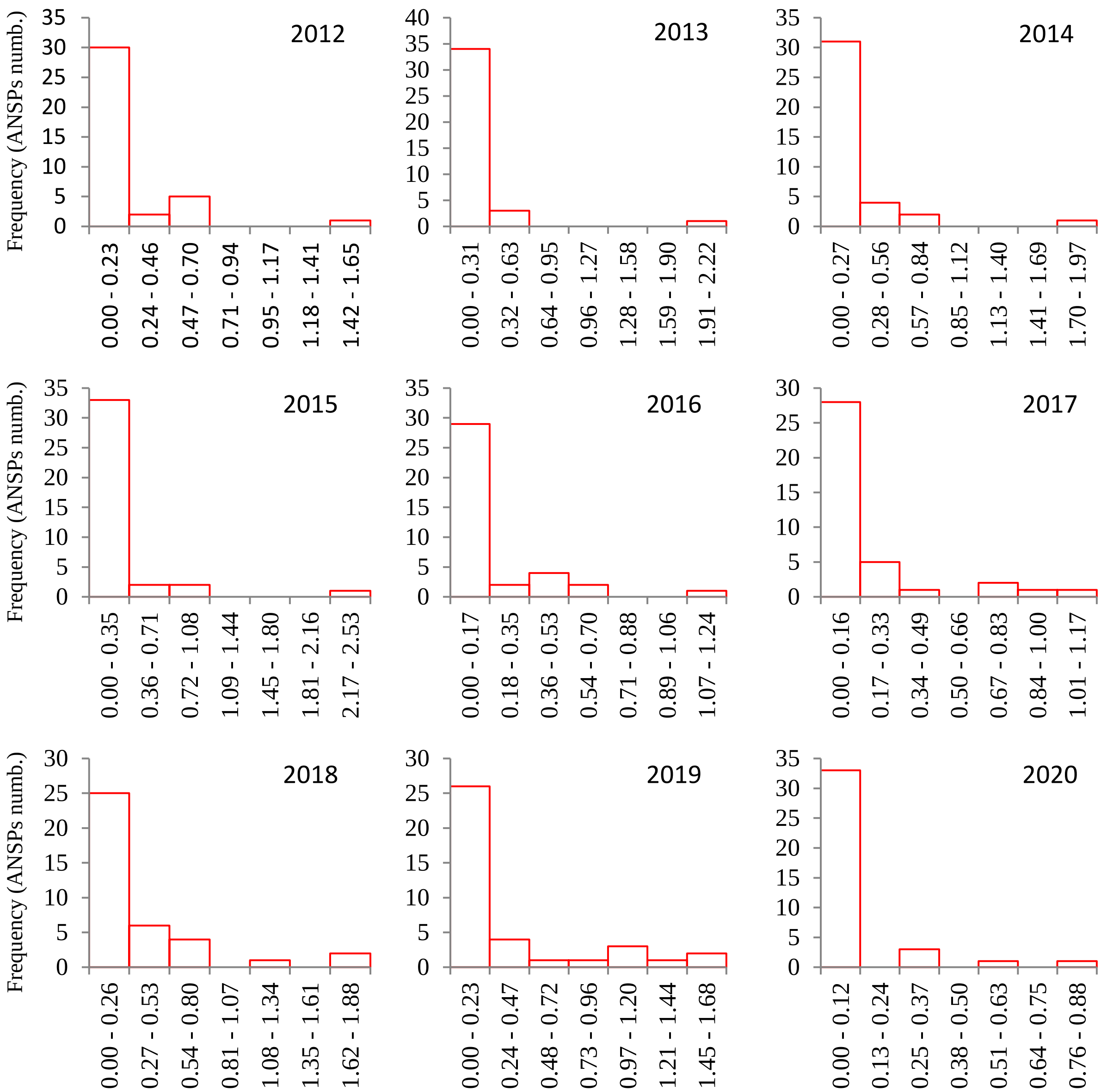


Figure 17. En-route ATFM delay [min/flight] distribution overview the studied period [81]

Even though the presented histograms provide sufficient insight on the normality of data distribution, an additional, more exact validation method was applied for the purpose identifying the systematic error. Accordingly, a normal probability plot developed by Chambers et al. [82] was applied to test the applicability of the earlier presented method. In short, it represents a graphical technique for normality testing, i.e., for assigning whether data set is approximately normally distributed. In cases when data is normally distributed, the points should form an approximate straight line. Thereby, deviations from the straight line represent deviations from normality. In case the line is skewed to the left or right, this indicates that the data is not normally distributed. In such cases a bow-shaped pattern of deviation indicates that the residuals have excessive skewness (as a result of too many large errors in one direction), while an s-shaped pattern of deviations indicates that the residuals have an excessive kurtosis (as there are either too many or two few large errors in both directions). Considering the above, Figure 18 shows the results of plotting the observed en-route ATFM delay against theoretical normal distribution. It can be noticed that the results of coefficient of determination (r^2) and Root-Mean-Square-Error (RMSE) over the studied period range from 0.38 to 0.70, i.e., from 0.53 to 0.76 respectively. Hence, the obtained findings confirm a significant violation of the normal distribution assumption where the condition of normal distribution of error terms is not met.

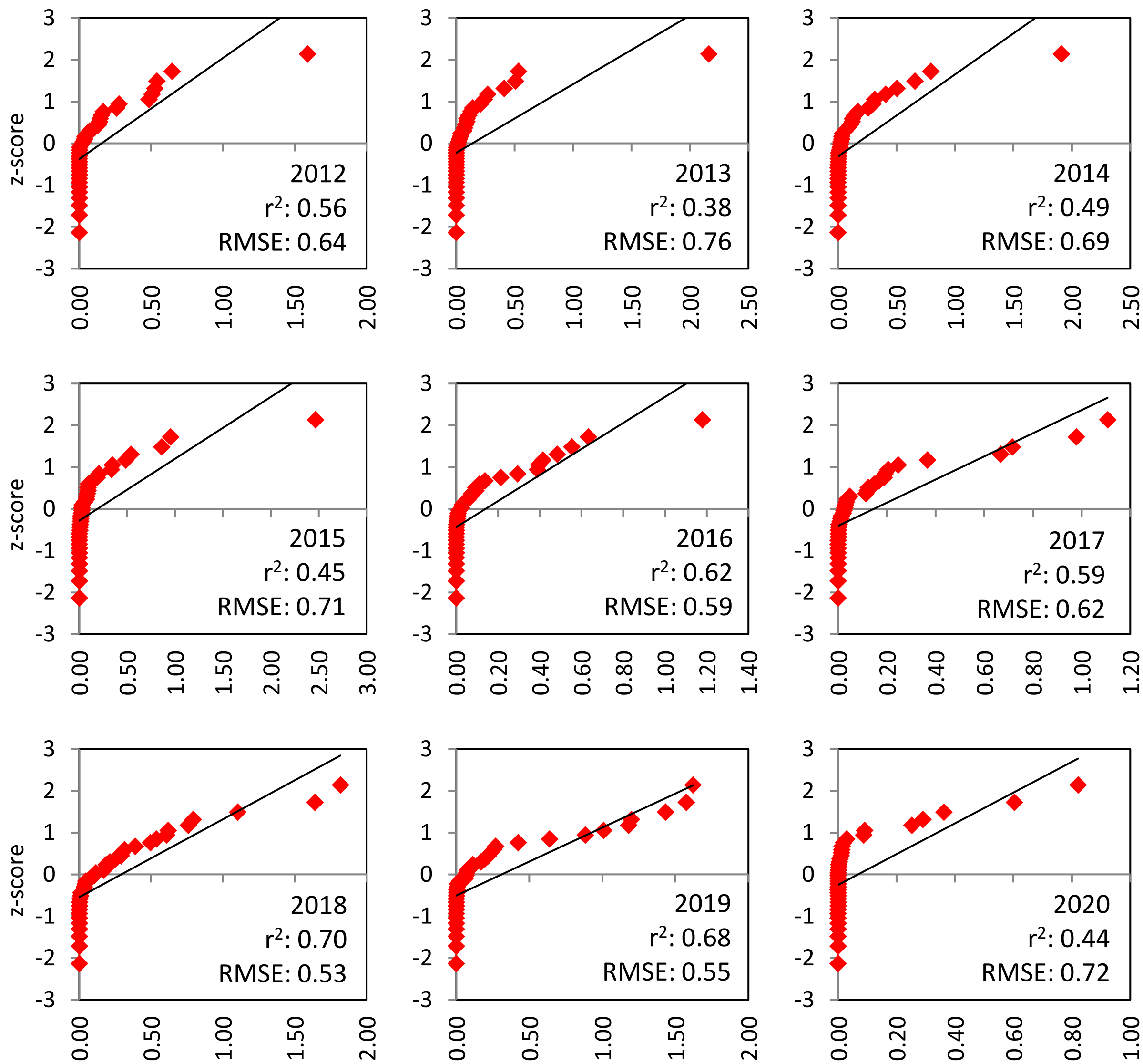


Figure 18. Overview of the normal probability plots

Furthermore, it should be outlined that as some of the values of the en-route ATFM delay continuously significantly deviate from the rest of the data set, the application of the data grouping method results in misleading results. Figure 19 shows that over the years there were several outliers and that their number slightly varies over time.

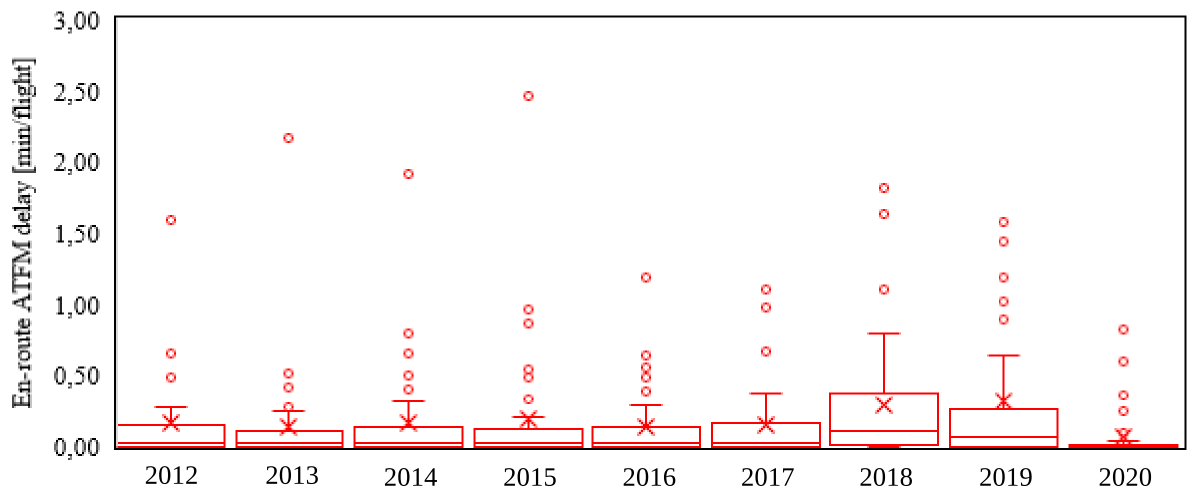


Figure 19. Outliers within data distribution

One more issue arises with the application of the conventional approach of data manipulation. As a result of applying inadequate width of the classes, locally inadequate performance levels become insignificant. Also, there is an issue of applying different observation scales. For instance, by changing the observation scale applied within Figure 19 and by focusing only on first bin distribution, new outliners will arise – as shown in Figure 20.

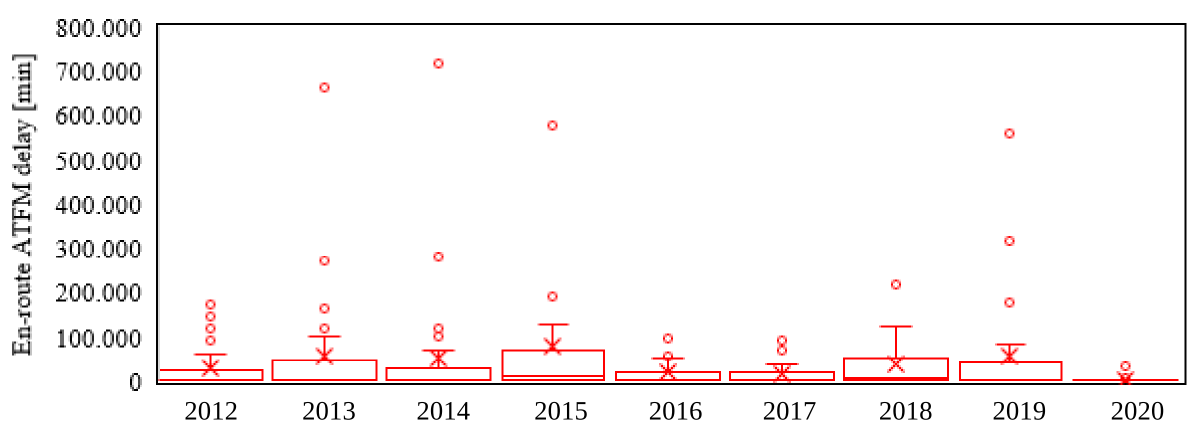


Figure 20. First bin outliers

An additional flaw of applying the data grouping method on the en-route ATFM delay is that, barring a few outliers, most of the data set would be categorised into the same (first) class. That is hazardous as such results may be misinterpreted in the sense that these ANSPs have the same or aligned performance levels. In that regard, a rhetorical question arises on how meaningful it is to place ANSPs without and with a certain level of en-route ATFM delay in the same class which, due to non-normal data distribution, are depicted as the "same" because they are categorized into first class. In that context, Figure 21 presents approximate effects of all performance levels categorized into first class. Accordingly, Figure 21 depicts in the best manner the difference between ANSPs without and with a certain level of en-route ATFM delay.

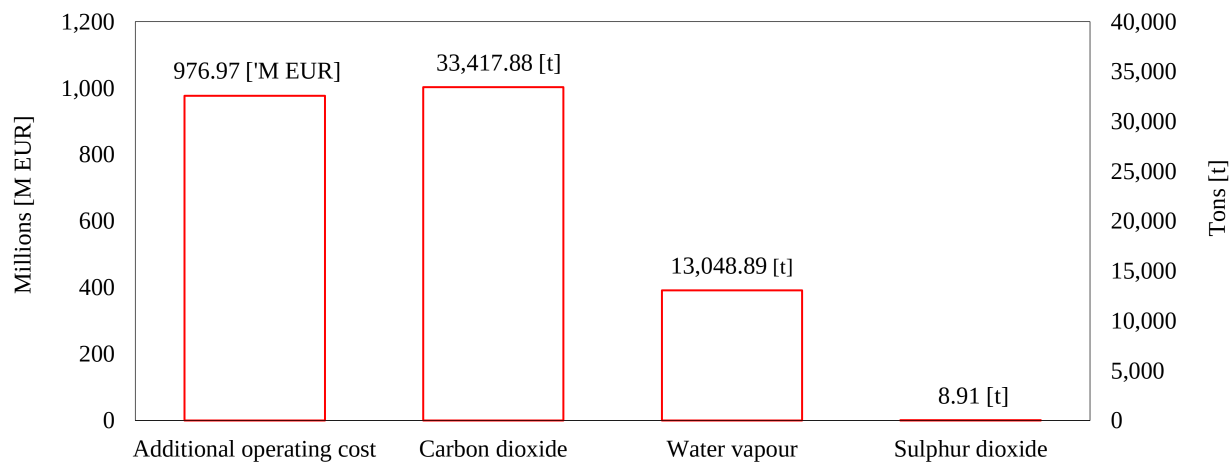


Figure 21. First bin effects

Furthermore, it can be frequently found that performance levels in the ATM context are processed by applying the data grouping method, results of which are later visualized by using maps (instead of using histograms). From methodological aspect, such approach is hazardous as at no point are data georeferenced, which can consequently lead to the misinterpretation of the results. Moreover, this is problematic because a map shows "where something is", whereas a histogram summarizes "how often" measurement occurs – regardless of where it occurs. Last but not least, by applying the presented data grouping method, it can be determined where which value of the performance data occurs within the ATM system (network). Primarily because data distribution is analysed according to the attribute distribution and not spatial distribution. Moreover, by using the conventional data manipulation framework, network design, i.e., network configuration is not being considered at all. As such, even though the same data set was used for all illustrations within Figure 22, the changes made in network configuration did not have any impact on the data manipulation process and consequently on the interpretation of the results – which indicates the methodological limitation, i.e., shortcoming of applying the studied method within the domain of strategic planning and development of the ATM system in Europe.

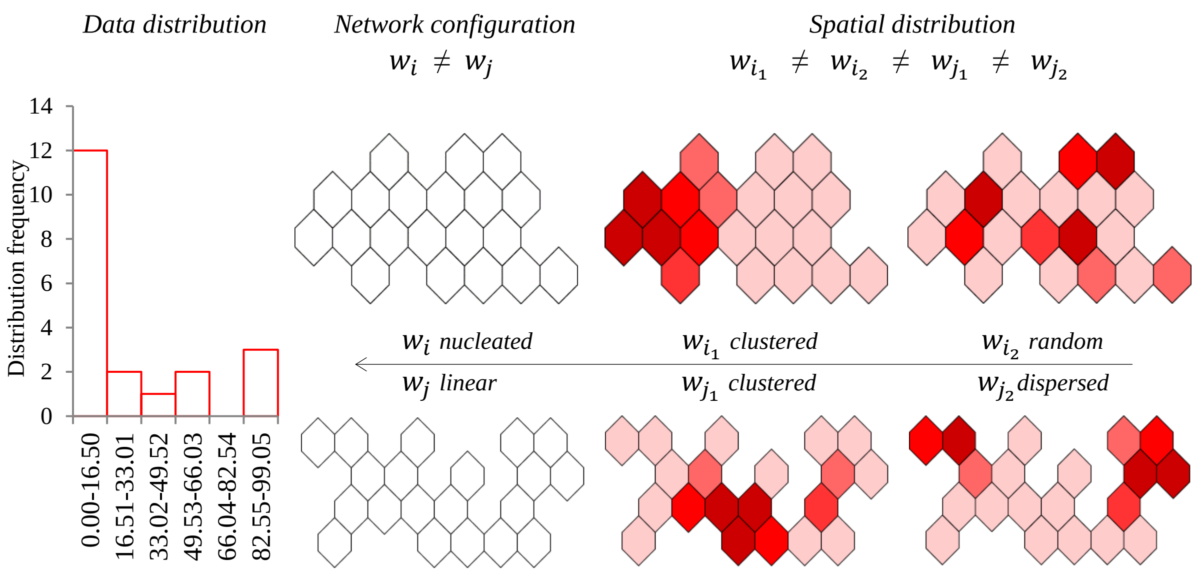


Figure 22. Simplified overview of applying the assumption of independent observations

To sum up, the presented systematic error is mostly not yet recognized. As such, within the ATM domain one can frequently come across scientific and professional publications which, for the purpose of depicting differences in the performance levels of ANSPs, use the conventional data manipulation framework. However, the application of the data grouping method, due its methodological limitations from the viewpoint of its data manipulation framework, should be avoided in the context of strategic planning and development of the ATM system in Europe.

3.2. Methodological assumptions

The contents below present a brief review of the ATM system in Europe. Its aim is to argument the methodological assumption applied within the model development. In principle, if an international commercial flight is subject to ANS in one state, service provision must also be continued in the next state (into which the aircraft intends to enter), and so on until the aircraft reaches its destination. Hence, it can be inferred that the coordination and cross-border cooperation between the neighbouring ANSPs represent a prerequisite that enables the functionality of the ATM system worldwide. In that respect, Figure 23 shows ANS distribution in Europe for 2018. By applying the criterion of whether the service was provided to an international or domestic flight, it can be concluded that 94.05% of the total share of ANS provided in 2018 were delivered in cooperation of at least two neighbouring ANSPs. Among other reasons, but also due to interdependency between the neighbouring ANSPs and the differences in their performance levels, performance interdependencies, trade-offs, goal conflicting situations and spill-over effects occur within the ATM system in Europe. For instance, due to the occurrence of capacity congestion in the AoR of one ANSP, occurrence of such phenomenon will also affect the neighbouring areas (ANSPs). Repercussion of such phenomenon will be that the aircraft will go through one of the neighbouring areas instead through the originally planned (saturated) area. Thereby, the significance of such repercussions depends on the significance of the event occurred. Button and Neiva [83] have also recognized this issue by arguing that since different national ATM systems are not independent from their neighbours, there might be issues of spatial autocorrelation – meaning that the efficiency of one ANSP might depend on the efficiency of the neighbouring ANSPs. Considering the aforementioned, the model developed is based on the adoption of the methodological assumption of spatial dependency. As such, the model goes beyond the methods of traditional statistical theory that base their analyses on the assumption of independent observations.

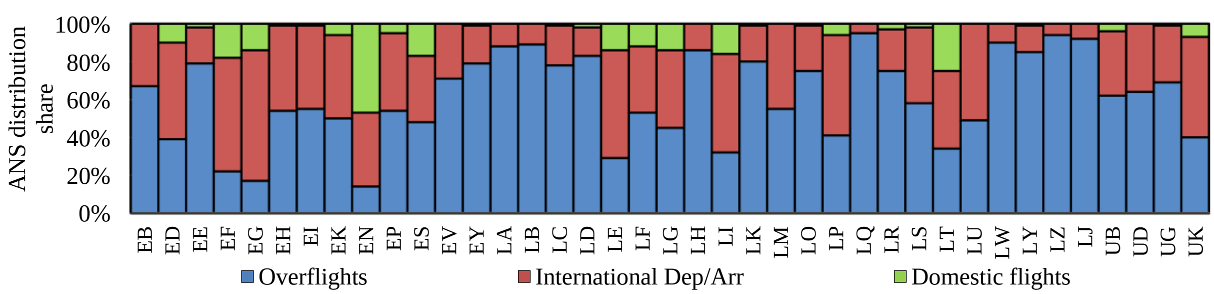


Figure 23. Air Navigation Services' distribution (2018) [84]

Model development has included adoption of additional methodological assumptions and several arguments. Accordingly, within model development process, an additional methodological assumption was adopted postulating that airspace fragmentation is the result of a random spatial process. That assumption is integrated into the developed model and it is tested within the data manipulation framework of the developed model. Accordingly, once the model is used, the aforementioned assumption can be either accepted or rejected.

The argument that the ATM system in Europe affects the airspace fragmentation, which supports the research hypothesis and model development, represents a terminological and thought inversion in respect to literature in the field of research. Primarily within the reviewed literature, national borders are seen as a cause of European airspace fragmentation. In spite of that, this research adopts the aforementioned argument because performance-based airspace fragmentation is not the result of national borders, but rather the interactions and the resulting differences in the exogenous and endogenous factors between the neighbouring ASNPs. For instance, due to capacity shortage (e.g., caused by the ATCOs shortage) in a given airspace volume, that area becomes detached from the neighbouring areas that are not faced with the issue of capacity shortage. In such way, AoR, i.e., spatial object, with the capacity shortage becomes a spatial outlier and thus contributes to the occurrence of performance-based airspace fragmentation. Figure 24 shows an example and a simplified overview of the repercussions of such an event on the airspace users and neighbouring ANSPs.

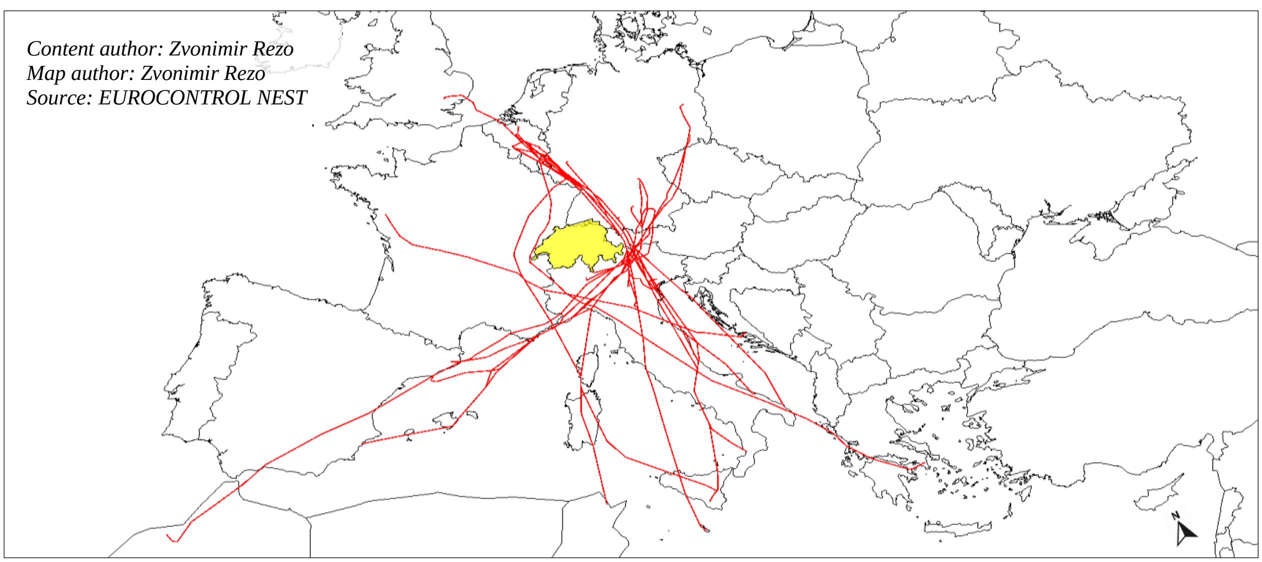


Figure 24. Simplified overview of the avoidance of spatial outlier

3.3. Data manipulation framework

Before processing input data, they first need to be placed in their spatial context. Since the graph theory can precisely describe the structure of many real-world systems (including the ATM system), it was used to design a network model. The network model was formed as a directed graph with nodes and arcs. Each node represents one spatial object whereas each spatial object represents AoR of one ANSP. After forming a network model, a spatial weights matrix W has been derived from it. It represents the $n \times n$ square matrix that expresses connectivity in a binary form:

$$W = \begin{cases} 1 & i \text{ and } j \text{ are neighbours} \\ & i \neq j \\ 0 & i \text{ and } j \text{ are not neighbours} \end{cases} \tag{7}$$

By convention, the self-neighbor relation w_{ii} is excluded. Furthermore, since spatial weights are in practice seldom used in binary form, they were row-standardized as follows:

$$W^* = \frac{w_{ij}}{\sum_j w_{ij}} \tag{8}$$

As a result, a row-standardized weights matrix is built, where each row sum of the row-standardization weights equals 1. After placing input data in their spatial context and after data standardization, the data manipulation process can start. In so doing, it includes the conduction of several complementary assessments (as shown in Figure 25).

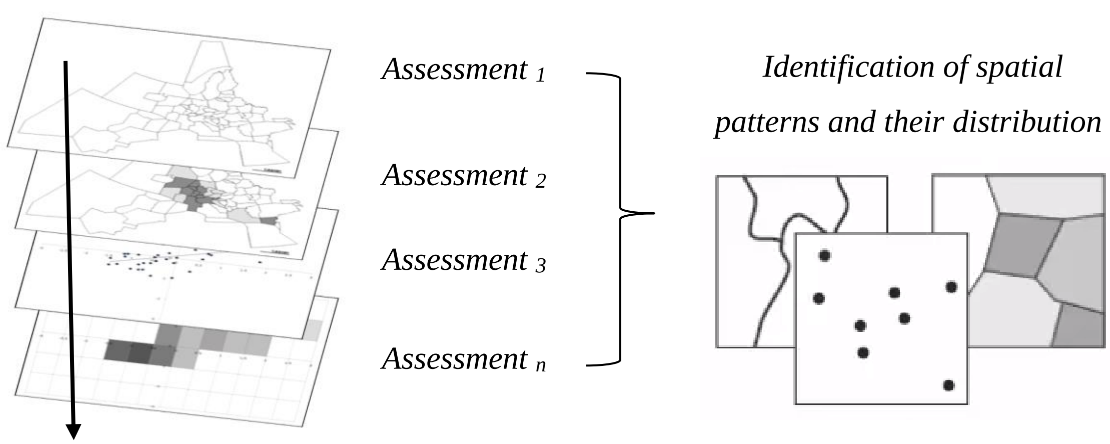


Figure 25. Overview of the conceptual framework of the data manipulation process

A sense of spatial distribution is firstly obtained by determining the spatial similarity index r. It is conceptualized so as to quantify the compliance level between the performances of the neighbouring spatial objects:

$$r_i = \sum_{j=1}^{n} \left| \frac{x_i}{x_j} \right| \tag{9}$$

where the interpretation of the results is analogous to the Spearman’s correlation coefficient interpretation. After estimating spatial compliance, further data manipulation process through the study of spatial autocorrelation identifies patterns of spatial association. Spatial autocorrelation represents one of the relatively small sets of methods which deals simultaneously with spatial and attribute feature [85]. It is counted globally and locally (where both assessments are based on Moran’s I [86,87]). Global Moran's I quantifies the spatial autocorrelation across the entire network model. On the other hand, the local indicator of spatial association measures the degree of spatial autocorrelation of each spatial object. It is calculated as follows:

$$I_i = \frac{(x_i - \bar{x}) \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \, (x_j - \bar{x})}{(\sum_{j-1}^{n} (x_j - \bar{x})^2)/n} \tag{10}$$

where x_i designates the value of the observed spatial object, $\bar{x}$ marks the average value of the observed data set, w_{ij} denotes the value of the spatial weight matrix, x_j marks the value of the adjacent spatial object, while n represents the number of spatial objects. After computing local indicators of spatial association, global Moran's I can be obtained. It equals:

$$I = \frac{1}{n} \sum_{i=1}^{n} I_i \tag{11}$$

Based on the estimated global Moran’s I, it is possible to make conclusions about the spatial autocorrelation. A negative result indicates that spatial objects of similar attribute features are scattered over the network model (and vice versa). Furthermore, since spatial autocorrelation is inferential statistics, it enables testing of the assumption of a random spatial patterns distribution. In doing so, global Moran’s I first needs to be standardized as follows:

$$z - score = \frac{I - E(I)}{\sqrt{Var_{(I)}}} \tag{12}$$

where the expected value of Moran's I $E(I)$ is calculated as follows:

$$E(I) = \frac{-1}{(n-1)} \tag{13}$$

while the variance of Moran's I $Var(I)$ equals:

$$VAR(I) = E(I^2) - E(I)^2 \tag{14}$$

$$E(I^2) = \frac{A-B}{C} \tag{15}$$

$$A = \; n[(n^2 - 3n + 3)S_1 - nS_2 + 3S_0^2] \tag{16}$$

$$B = \; b_2[(n^2 - n)S_1 - 2nS_2 + 6S_0^2] \tag{17}$$

$$C = \; (n-1)^{(3)} S_0^2 \tag{18}$$

where n is the number of spatial objects, S_0 is the total of the weights matrix $\sum_i \sum_j w_{ij}$, $n^{(b)}$ denotes the product $n(n-1)(n-2)(n-3) \ldots (n-b+1)$, while S_1 and S_2 are estimated as follows:

$$S_1 = \frac{\sum_{i=1}^{N} \sum_{j=1}^{N, j \neq i} \left(w_{ij} + w_{ji}\right)^2}{2} \tag{19}$$

$$S_2 = \sum_{i=1}^{N} \left(w_{i.} + w_{.j}\right)^2 \tag{20}$$

where $w_{i.}$ and $w_{.j}$ are the row and column totals of the weight matrix, $\sum_i w_{ij}$ and $\sum_j w_{ji}$ respectively, while b_2 is the sample kurtosis coefficient that equals:

$$b_2 = \frac{m_4}{m_2^2} \tag{21}$$

where m_4 is the fourth and m_2 the second sample moment about the mean:

$$m_4 = \frac{\sum_{i=1}^{N} (z_i - \bar{z})^4}{n} \tag{22}$$

$$m_2 = \frac{\sum_{i=1}^{N} (z_i - \bar{z})^2}{n} \tag{23}$$

After computing z-score, the assumption of random spatial patterns distribution may be tested. As defined by the European Commission [88] and advised by EUROCONTROL [89], the confidence level was set at 95%. Hence, in order to reject the assumption of random spatial patterns distribution, standard deviation should be -1.96 < z-score > 1.96, while the probability should be p-value < 0.05. In cases when the aforementioned assumption cannot be rejected, it can be concluded that the spatial distribution is the result of a random spatial process. In other words, the European airspace is fragmented from the performance-based aspect. Otherwise, when the assumption of random spatial patterns distribution can be rejected, it means that the European airspace is not fragmented, i.e., the high-value and low-value spatial distribution in the data set is spatially clustered. Figure 26 shows an example of the spatial patterns distribution range.

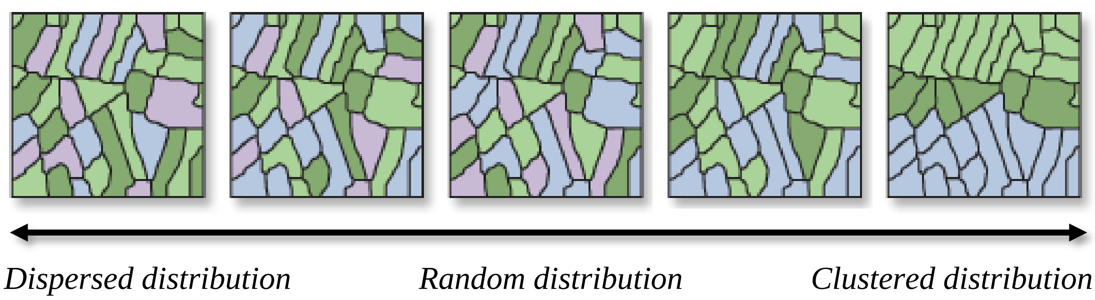


Figure 26. Spatial pattern distribution range

Further data manipulation framework through the Moran's I scatter plot identifies spatial outliers, i.e., identifies local instability in spatial associations. It is conceptualized so that its horizontal axis denotes the observed values y_i, while the vertical axis marks the spatial lag $[Wy]_i$ as follows:

$$[Wy]_i = \sum_{j=1}^{n} w_{i,j} y_j \tag{24}$$

Determining spatial outliers is performed based on four indicators (arising from four quadrants of the scatter plot). Quadrant I (representing high values in a high value neighbourhood) and quadrant III (low values in a low value neighbourhood) denote spatial objects that are spatially aligned with neighbouring spatial objects. On the other hand, spatial objects that fall under quadrant II or IV represent spatial outliers. Quadrant II reveals spatial outliers of a low value in a high value neighbourhood, while quadrant IV denotes spatial outliers of a high value in a low value neighbourhood. Figure 27 shows concept of Moran's I scatter plot.

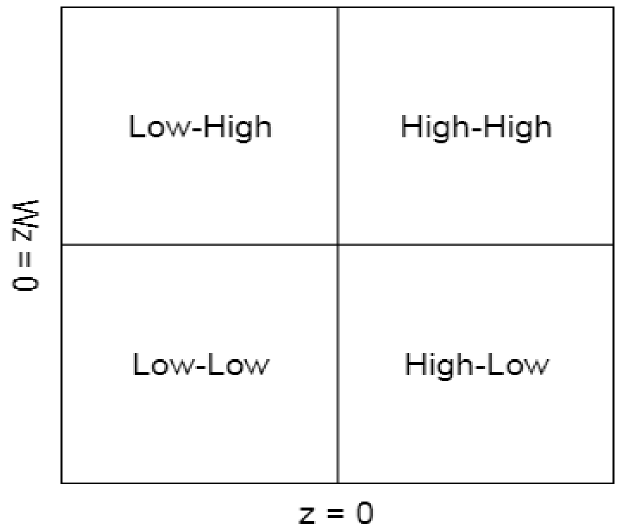


Figure 27. The Moran's I scatter plot concept

In order to facilitate the spatio-temporal analyses, findings obtained by the Moran's I scatter plot are also used in form of a control chart. Its main goal is to determine performance gaps between performance levels of spatial objects, regulatory defined levels and neighbours' levels. As a result, it identifies spatial objects with under-defined and over-defined performance targets, i.e., strategic goals. Thereby, a regulatory gap y_{rg} between the achieved or planned performance level of one spatial object (denoted by x_i) in respect to regulatory determined performance target (x_{rt}) equals:

$$y_{rg} = |x_i - x_{rt}| \tag{25}$$

The local gap y_{lg} between the achieved or planned performance level of each spatial object (denoted by x_i) in respect to performance level of their first-order adjacency (x_{lt}) equals:

$$y_{lg} = |x_i - x_{lt}| \tag{26}$$

The performance gap y_{pg} quantifying the difference between the regulatory-defined (x_{rt}) and performance level of the ANSPs' first-order adjacency (x_{lt}) equals to:

$$y_{pg} = |x_{rt} - x_{lt}| \tag{27}$$

Figure 28 below shows a simplified example of a control chart.

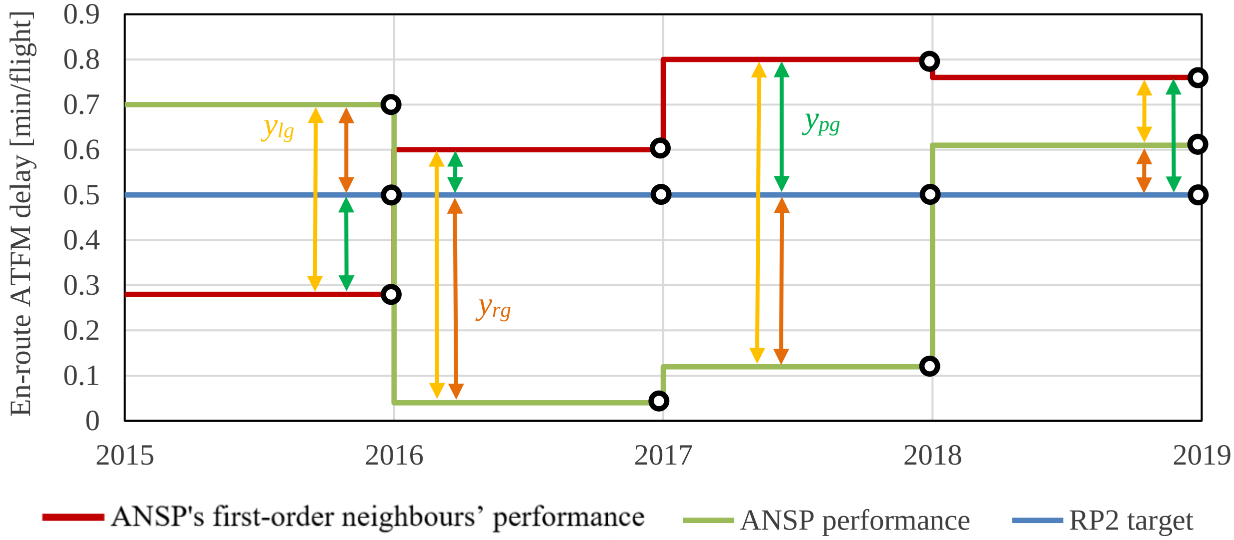


Figure 28. Example of a control chart

Conceptually, the Moran's I scatter plot is complemented with a linear regression which has global Moran's I as the slope:

$$y = a + bx \tag{28}$$

where coefficients *a* and *b* equal:

$$a = \frac{\sum_i y_i \sum_i {x_i}^2 - \sum_i x_i \sum_i x_i y_i}{n \sum_i {x_i}^2 - (\sum_i x_i)^2} \tag{29}$$

$$b = \frac{n \sum_i x_i y_i - \sum_i x_i \sum_i y_i}{n \sum_i {x_i}^2 - (\sum_i x_i)^2} \tag{30}$$

Also, it is supplemented with a standard distance assessment and quadrant analysis. Standard distance represents the spatial equivalent of standard deviation applied with a goal to estimate absolute dispersion in a point pattern. After determining the mean centre, the standard distance incorporates the straight-line of each point from the mean centre as follows:

$$S_D = \sqrt{\frac{\sum(x_i - \bar{x}_c)^2 + \sum(y_i - \bar{y}_c)^2}{n}} \tag{31}$$

Similar to spatial autocorrelation, it is calculated globally and locally. However, in a different way from spatial autocorrelation, it provides information about spatial compliance by considering performance levels of spatial objects and their neighbours. The shorter the distance between points, the more similar they are (and vice versa). The quadrant analysis is used to determine the frequency of a point pattern distribution. Once a set of 0.5×0.5 cells is superimposed over the Moran's I scatter plot, the number of points within each cell is calculated as follows:

$$\lambda = \frac{n}{A} \tag{32}$$

where *n* denotes the number of spatial objects within the cell and *A* marks the cell size.

Since Moran's I scatter plot gives no information on where significant patterns appear [90,91], data manipulation framework was complemented by two more assessments. One the one hand, local significance assessment identifies spatial objects whose performance level significantly differs from the neighbours' level. Figure 29 shows a conceptual framework of the pattern distribution analysis within framework of local significance assessment.

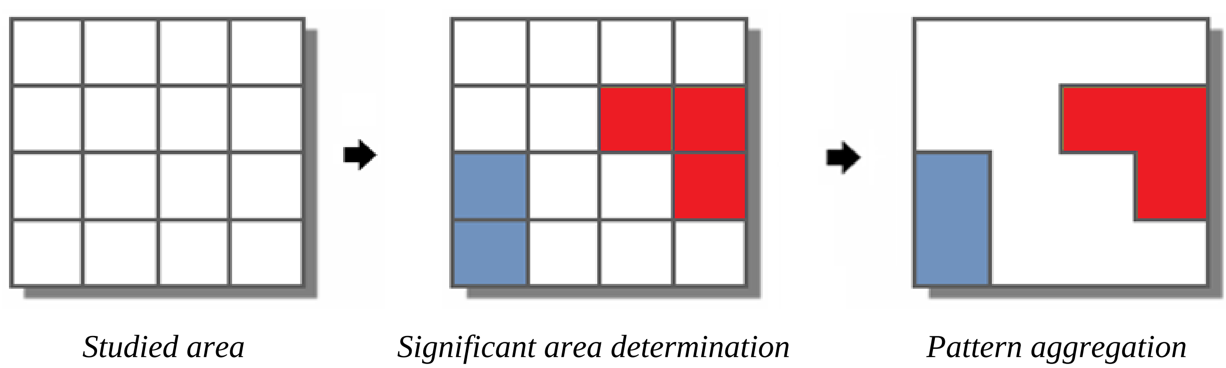


Figure 29. Conceptual framework of the significant area distribution identification

On the other hand, local clustering assessment detects locally significant patterns of spatial association. Thereby, both assessments are based on the standardization of local indicators of spatial autocorrelation where their significance is tested based on the assumption of a standard normal distribution:

$$f(z) = \frac{1}{\sqrt{2\pi}}\, e^{-\frac{z^2}{2}} \qquad N(0,1) \tag{33}$$

The confidence level is of the order of a two-sigma effect for the local clustering assessment. For the local significance assessment, it is determined based on the significance scale that corresponds to empirical rule (also known as the 68-95-99.7 rule) as shown in Figure 30.

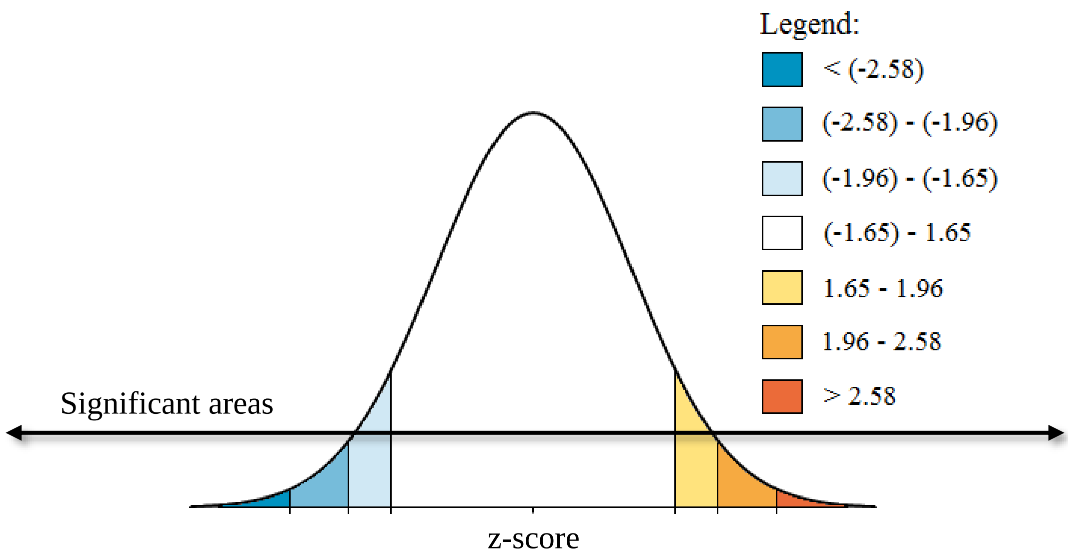


Figure 30. Significance scale

Lastly, to determine spatially optimal performance levels and targets, what-if analysis is included within the data manipulation framework. Its purpose is to identify changes in the network model resulting from the change of one or more input data. As a result of its application, it captures the change ratio in the input and output data. What-if analysis is followed by sensitivity assessment which captures the ratio of the percentage change in the output by the percentage change in the input. The higher the sensitivity figure, the more sensitive the output is to change in the input. Figure 31 shows a conceptual framework of application of the what-if analysis on the patterns distribution testing.

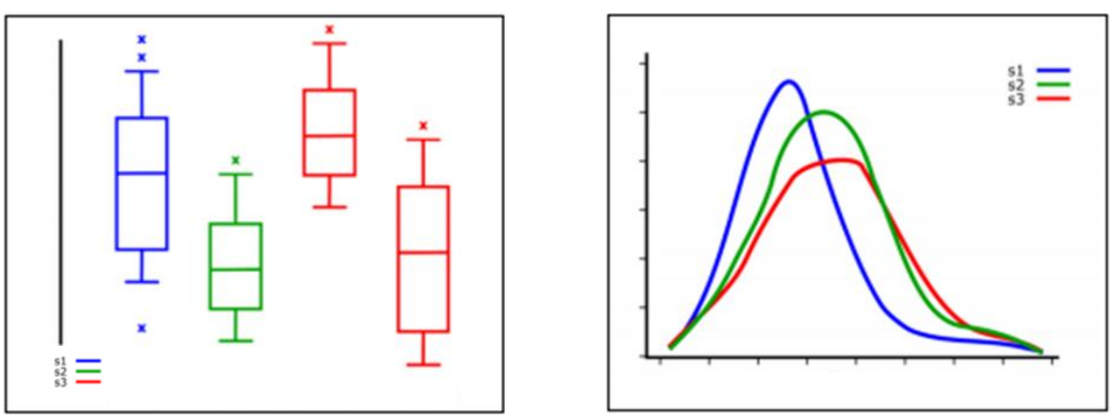


Figure 31. What-if analysis application on patterns distribution testing

3.4. Methodological limitations

Before the model applicability overview, a few methodological limitations need to be considered. First of all, it needs to be outlined that it is a particularly undesirable situation when a spatial object does not have neighbours. Hence, each spatial object should have at least one neighbour. In case there is a spatial object with no neighbours, it is referred to as an isolate or island. As a result, all elements in a row in the spatial weights matrix corresponding to such spatial object will equal $w_{ij} = 0$, ∀j. As spatial analysis is about interactions, and isolates do not interact, such spatial objects must be excluded from the data set. Example from practice can be found when performing a cost-efficiency based assessment. Besides the EUROCONTROL Member States, several affiliate Member States also participate in the ANS charging scheme. One of the affiliate Member States is Uzbekistan. However, Uzbekistan is not spatially connected with the rest of the area where the ANS charging scheme is applicable. Therefore, as Figure 32 shows, it represents an island from the viewpoint of model application. Consequently, its data, although available, should not be considered.

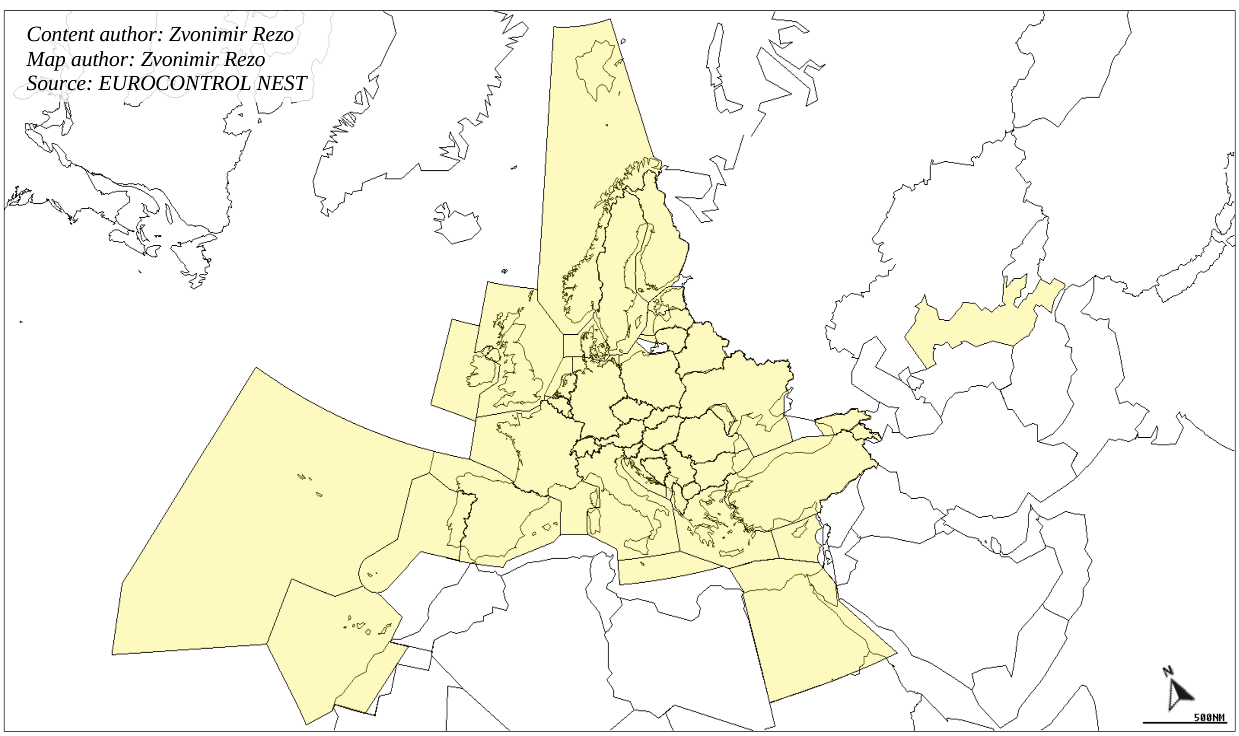


Figure 32. Example of isolate or island in the context of the model application

Secondly, no spatial object can be adjacent to all other spatial objects. Further, it should be emphasized that data manipulation is based on first-order adjacency. Nevertheless, it is possible to perform data manipulation so that it considers second-order adjacency. In such case, two spatial objects *i* and *j* are second-order adjacent if a third area *k* exists. Therefore, *i* and *k* are adjacent, *k* and *j* are adjacent, but *i* and *j* are not adjacent. However, due to different sizes of the spatial objects, using this approach would result with distance threshold being highly variable. Therefore, since empirical studies show that the spill-over effect decreases with spatial distance, [92] first-order adjacency is preferred. Thereby, context spill-over effect occurs within the ATM when certain activity or situation begins to affect another situation or stakeholder, especially in an unpleasant or unwanted way.

The issue of input data collection can also be outlined as methodological limitation. By obtaining the data capturing performance level of the lower geographical or operational level, i.e., by changing the measurement scale, it would be possible to identify spatial instabilities in spatial associations more accurately. This issue is mainly related to performance data source (data originator) whereas, for instance, the PRU makes publicly available only the data aggregated at national, ANSP, AoR or FIR level.

The last methodological limitation is associated with the fact that within the ATM system in Europe it is unfortunately often difficult to improve one performance segment without compromising other segment(s) [93]. In that respect, Figure 33 shows an overview of a trend analysis between two conflicting performance areas on system-wide level. In addition, since causal relationship exists within the performances of one ANSP, consequent findings supporting the European airspace defragmentation from one performance area may also require adjustments within other performance areas.

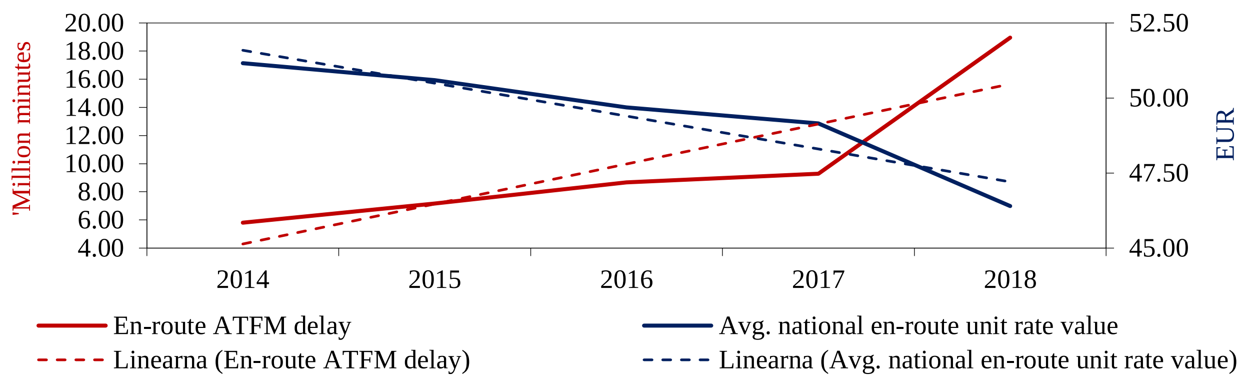


Figure 33. Trend analysis of capacitive and cost-efficiency performances over time

3.5. Model utilisation framework

Aeronautical data and information of appropriate quality are undoubtedly required to ensure a safe, efficient and competent future development of the ATM system in Europe. With a goal to simultaneously enable time-savings and the option of turning large sets of data into useful information, the developed model was turned into a technological solution by using the Visual Studio/c# programming tool/language in further R&D activities. During the development phase, recommendations and lessons learned specified in Rezo et al. [94] were applied. Thereby, Figure 34 shows a simplified overview of model application within the function of strategic planning and development of the ATM system, while Figure 35 represents a flowchart that lists activities conducted within the development phase. It also shows activities that need to be conducted as part of model utilisation framework.

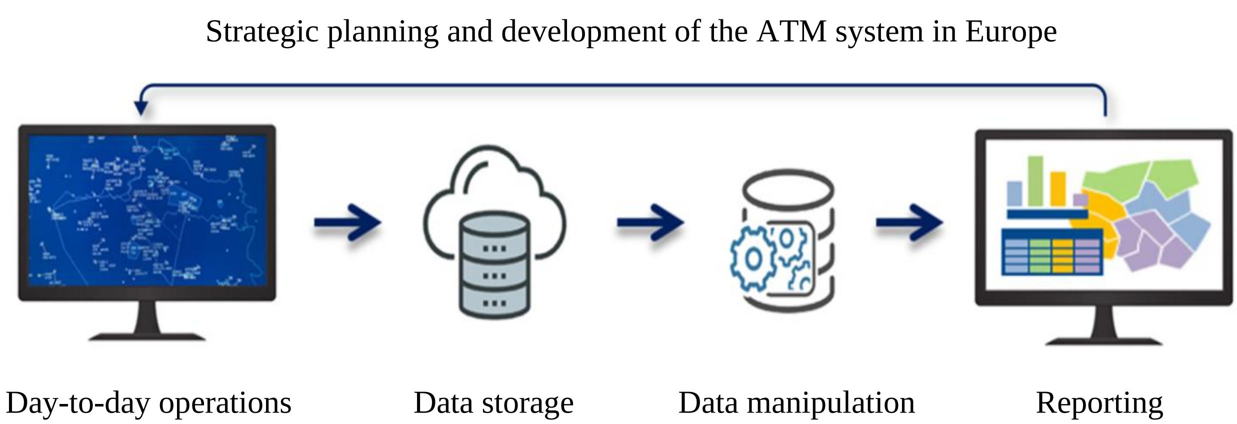


Figure 34. Model application within strategic planning and development of the ATM system

From the aspect of model utilisation, it needs to be outlined that the model firstly needs to be configured according to the research determinants. Some of the research determinants that must be considered include determination of a reference period to be studied and validation of the input data specifications (e.g., determination of data originator, whether data was validated and verified in respect to data accuracy, resolution, integrity, timeliness, completeness etc.) as recommended by the Annex 15 to the Convention on International Civil Aviation [95]. Also, geographical scope and observation scale, i.e., the determinants of the studied area must be considered. Primarily as they have impact on the configuration of the network graph, and as such on the data manipulation and research outcomes.

Furthermore, it can be outlined that the model utilisation is based on a two-step approach. The first step deals with the assessment of the European airspace fragmentation level, while the second step deals with defragmentation testing. The first step results with a report containing information on the European airspace fragmentation in respect to the selected performance indicator. Also, these reports contain information on spatial objects requiring corrective measures.

Based on the research findings obtained within the first step, the second step delivers approximations of the required performance levels by which the identified spatial object(s) requiring corrective measures become aligned with their first-order neighbours. More precisely, by determining the Spatial Performance Indicator (SPI), the performance target that contributes to the European airspace defragmentation is determined. Thereby, SPI is a novel indicator introduced with a goal to facilitate airspace fragmentation estimation and monitoring. It is a theoretical and scale-independent indicator obtained by conducting what-if analyses. It enables identification of performance gaps which need to be overcome in order to achieve performance-based airspace defragmentation. Also, it indicates whether spatial objects have an over-defined or under-defined performance level with respect to performance target, i.e., strategic goal determined by the Performance Scheme. Upon its identification, a change impact analysis can be conducted.

Last but not least, in order to verify that airspace defragmentation from one performance area would not lead to the creation of fragmentation from some other performance area, a performance trade-off situation needs to be considered. Therefore, an iterative process begins which is from conceptual and methodological aspect equal to the previous research activities.

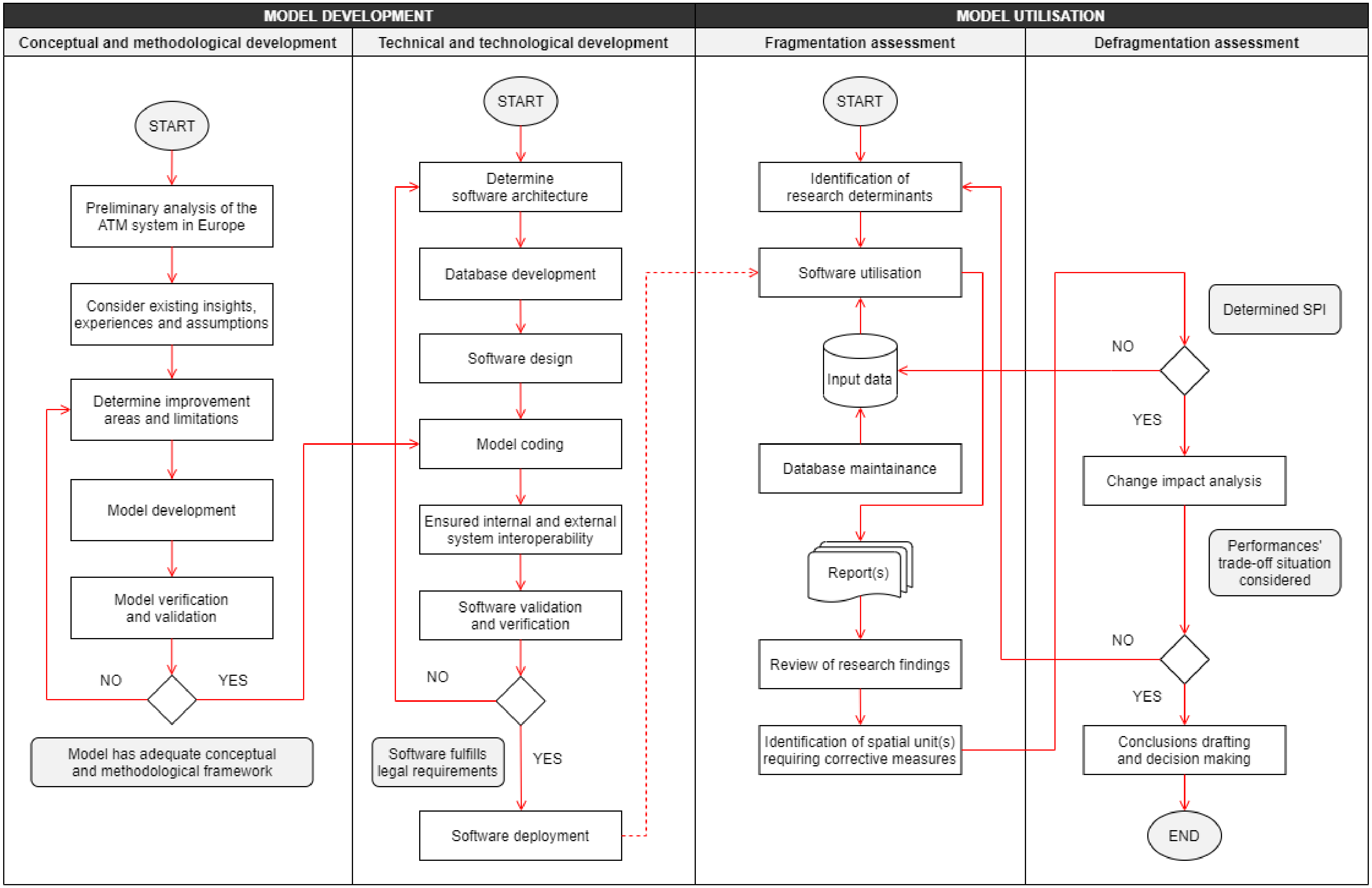


Figure 35. From research activities and development phase to model utilisation

3.6. Model applicability overview

Nowadays, many successful aviation businesses manage to grow simply because they understand their business environment. In order to be competitive in the market, it is necessary to know how to, for instance, optimize performances to the ones coming from the business environment. Nowadays many aviation business face difficulties regarding how to interpret and exploit the information obtained. Therefore, the ability to develop new technological solutions with strong analytical capabilities became a key factor of one’s market success.

The applicability of the developed model arises from several aspects. First of all, the developed model is SES compatible as it contributes to the performance-based airspace defragmentation through determination of spatially optimal performance levels. In addition, from the methodological aspect, it enriches the SES postulates of the collaborative and coordinated airspace and air traffic flow management.

The developed model also meets generally acceptable measurement characteristics such as validity, reliability, sensitivity, repeatability and objectivity. Moreover, its applicability arises from the fact that air traffic demand could be highly spatially variable in the future [30].

In principle, within the ATM domain a certain decision can often be deemed good or bad a few years or decades after it was made. However, as the ATM is a safety-critical system, applying such an approach is not an option. Therefore, models - as the one developed, are usually used with a goal to foresee the outcomes of how a certain change (event, phenomenon, etc.) may reflect on the performances of the ATM system or impact ANSPs, airspace users, society etc. Accordingly, the applicability of the developed model also stems from the fact that it can facilitate the evidence-based decision-making processes and consequently mitigate business risks.

Figure 36 shows a simplified overview of model integration within the aeronautical data chain of strategic planning and development of the ATM system in Europe. However, it should be noted that the aeronautical data chain is, in practice, far more complex. That primarily refers to the situation in Europe, where a substantial number of aviation stakeholders are involved.

The aeronautical data chain starts at some point in time when data value is associated with a data item when someone creates this value. The person or organisation that undertakes the role of data creation is known as (*1*) data originator. Thereby, it is important to emphasise that the data creation can refer to creation of the first value for a data item or it can refer to creation of a new modified value. Accordingly, this role can appear multiple times in a frame of the aeronautical data chain. The next phase of the aeronautical data chain is usually (*2*) data handling. Data handling refers to any action that requires interaction with aeronautical data and information regardless of whether the aeronautical data and information may be altered by that interaction or not. Data handling is usually followed by the (*3*) data processing phase. Data processing includes any action that requires interaction with aeronautical data and that results in its alteration or the creation of new aeronautical data and/or aeronautical information. After new aeronautical data and/or information is obtained, it needs to be stored in order to make it available for later use. Hence, (*4*) data storage refers to entering aeronautical data and information into a repository in which it is held for further use. Lastly, (*5*) data transfer covers the activities whereby the obtained aeronautical data and aeronautical information are transferred from one person/organization to another, and so on until they reach the end user.

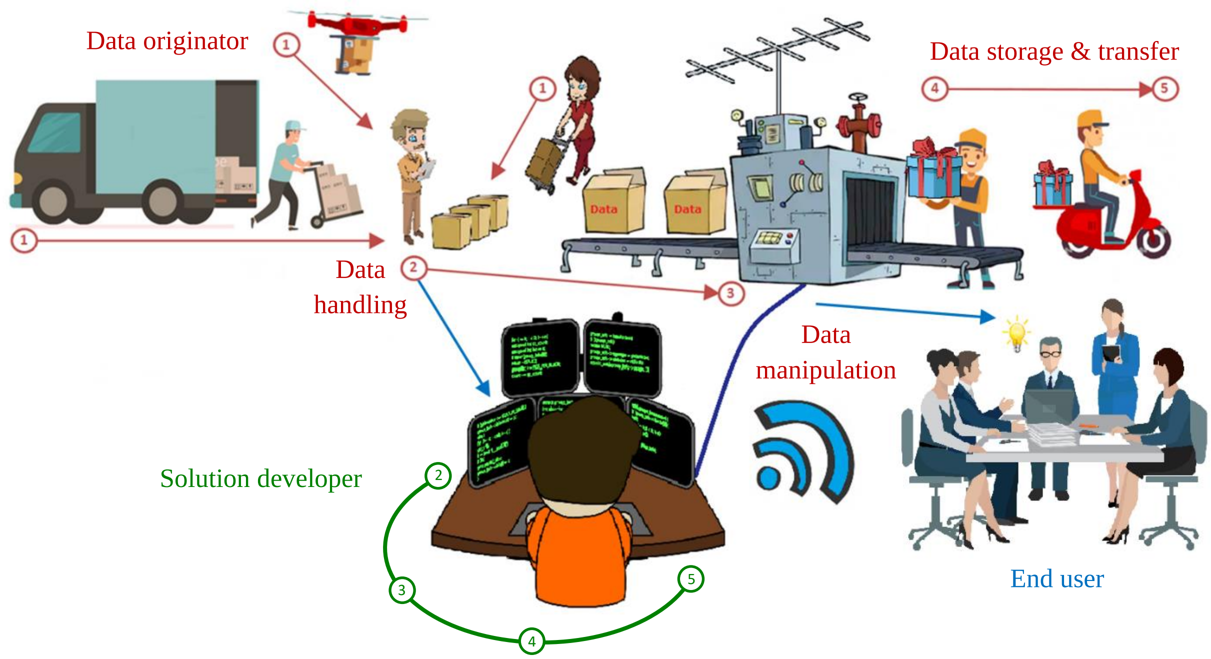


Figure 36. Simplified overview of model integration within the aeronautical data chain

The applicability of a developed model also stems from a fact that it can be further combined with other technologies and solutions with a purpose to create a more comprehensive information. For instance, by combining the developed model with models or solutions dealing with time-series analysis, it is possible to create a spatio-temporal forecasts. Spatio-temporal forecasts are forecasts created through utilisation of models that use information from the neighbouring spatial objects to improve the forecasts of a target spatial object. Accordingly, spatio-temporal forecasts are concerned with making an inference or prediction based on data analysis that have labels showing when (temporal feature) and where (spatial feature) they were collected. Through extraction of unknown and implicit knowledge on spatio-temporal relationships and patterns not explicitly stored as such (but rather as raw data), spatio-temporal forecasts contribute to a better understanding of the ATM system in Europe. As such, spatio-temporal forecasting models go beyond the "conventional" forecasting models in the ATM domain as they mutually correlate attribute, temporal and spatial features of the studied performance data set. Figure 37 shows the simplified example of the difference in the conceptual design of attributive, spatial and spatio-temporal forecasting models within the ATM context.

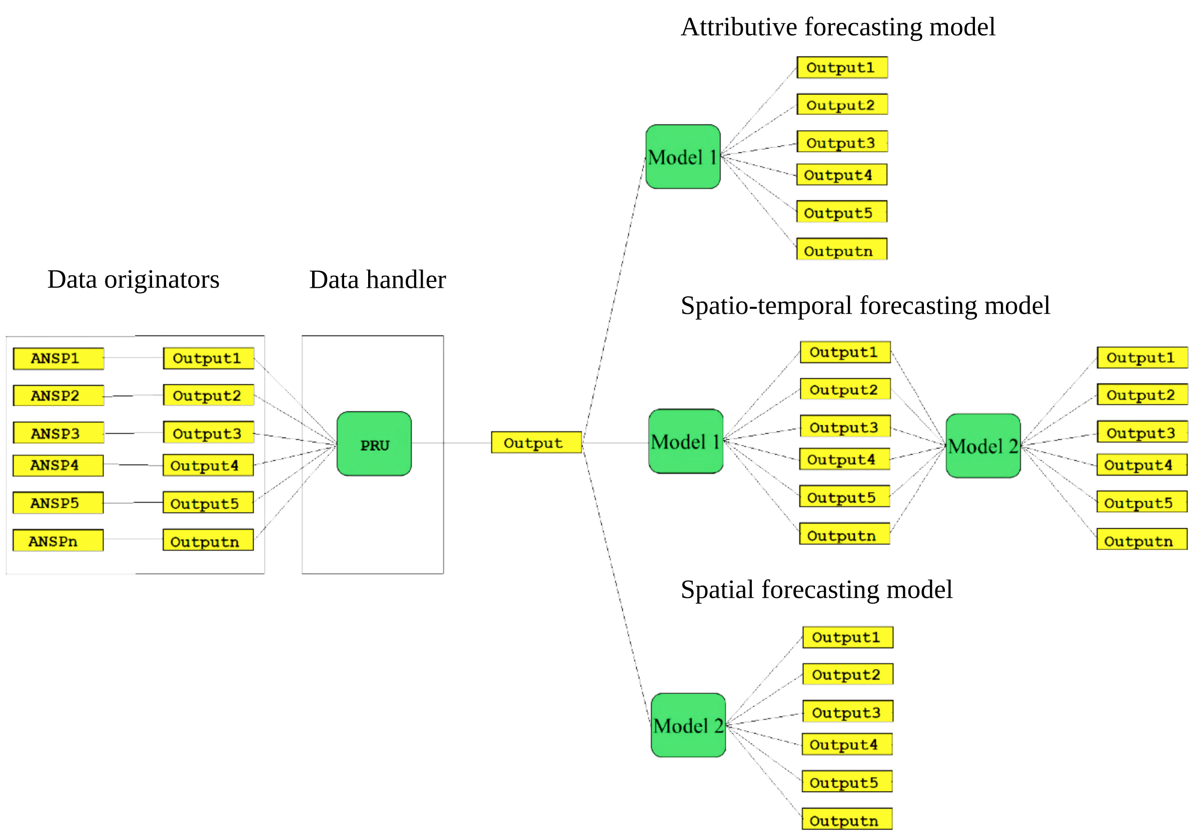


Figure 37. Simplified overview of the difference in conceptual design

In principle, spatio-temporal forecasts could easily be made by taking into account forecasts, i.e., data listed within the Network Operations Plans (NOPs) as input data and combining it with the developed model. Also, as within preliminary testing, the developed model can be coupled with the attribute forecasting model which is based on the Artificial Neural Network (ANN). After model training, the developed spatio-temporal forecasting model was applied for the purpose of revealing the capacity-demand imbalances for the reference year of 2018. The obtained preliminary research findings indicate that the applied ANN-based attribute forecasting model has in 64.85% cases provided more accurate forecasts for 2018 than it was specified with NOP. In addition, in the sense of measurement error, the ANN-based attributive forecasting model delivered 34.23% more accurate forecasts in respect to the NOP forecast reference delay. Figure 38 depicts the gap difference between the forecasted and actual 2018 figures.

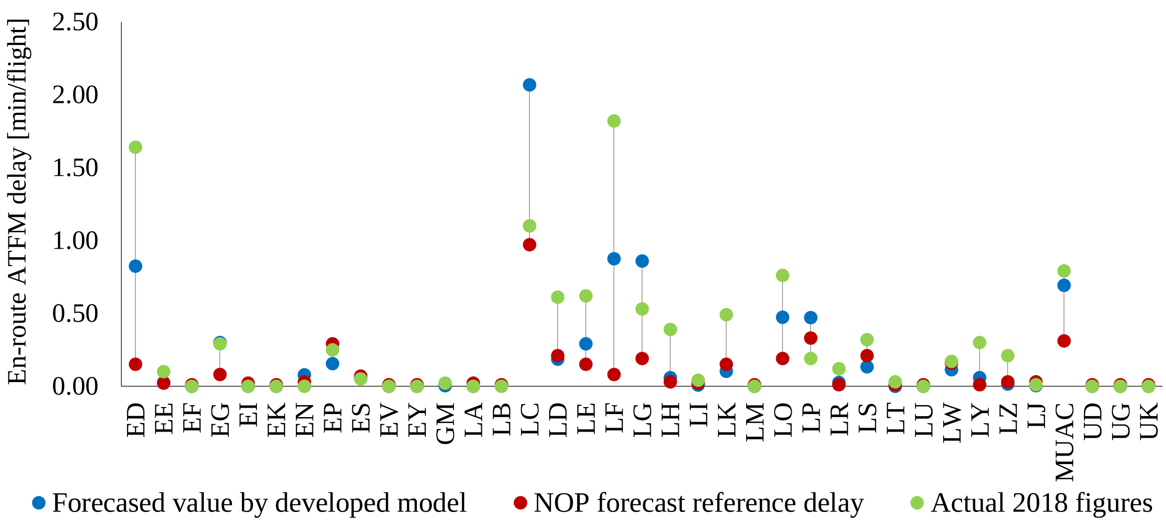


Figure 38. Overview of the gap difference between the forecasted and actual figures (2018)

Considering the significant variability level of en-route ATFM delay figures during 2018 with respect to previous years (increase of 97.73% compared to the 2017 figures), it can be defined that the ANN-based attribute forecasting model delivered highly accurate forecasts. Thereby, Figure 39 provides insight into the variability of annual en-route ATFM delay over the years.

Considering the aforementioned, the development of the European airspace fragmentation assessment model should not be perceived as an ultimate outcome, but rather as an enabler of further development of the ATM system in Europe.

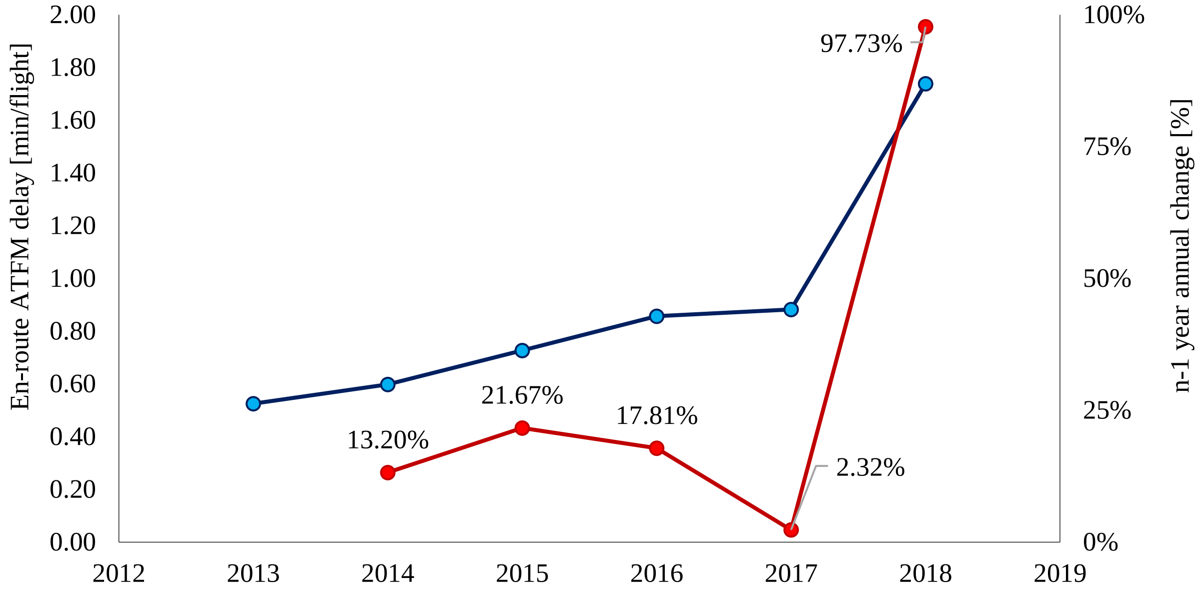


Figure 39. Variability overview of annual en-route ATFM delay over the years

The applicability of the developed model also stems from the need of the ANSPs to monitor performance levels in their business environment with a goal to be able to cope with the business pressures and risks, as well as with the complexity and dynamism of their business environment. Through application of the business environment analysis, the developed model enables identification of the performance interdependencies, performance trade-offs and goal conflicting situations.

In short, performance interdependences between the ANSPs may occur as a result of certain ATFM irregularities in one part of the ATM network whereas that may reflect on the remote geographical areas. Thereby, a more significant impact is likely to be reflected on areas closer to the site with ATFM irregularities. As a result of significant number of aircraft rerouting, some ANSPs will be left without a certain amount of traffic (lost revenue even though capacity was ensured). On the other hand, some ANSPs will have to face an increased demand, which they had not foreseen earlier. Within the ATM domain, performance trade-offs also occur at all levels of system management. They are occurring in every layer of the decision-making process within the ATM system in Europe. In principle, performance trade-offs can be constantly present, or they can occur occasionally. Some of them can have a major and others a minor effect on the system. Furthermore, their implications can last over years or just for few seconds. Usually, they are the result of non-complementary planning while sometimes they are the result of operational activities. They can also be the result of incorrect performance target setting, plan non-compliance, measuring limitations, existence of partial policies, technical or technological limitations etc. However, performance trade-offs cannot ultimately be defined as either positive or adverse. Lastly, goal conflicts can be defined as visible consequences of invisible day-to-day performance trade-offs. Thereby, some goals can have a short-term and others long-term focus. Achievement of some goals may be externally imposed to ANSPs, while realisation of others may be internally motivated. Some goals concern technical, others concern operational service delivery. Within the ATM system in Europe, some goals are placing focus on national potentials, while others promote local or regional interests. Some goals relate well to quantitative measures, while others do not. Sometimes some goals are more reactive, while others are more proactive.

In order to able to spot, but also create changes and trends in their business environment, the developed model supports the conduction of four major activities of the business environment analysis process: environmental scanning, monitoring, spatio-temporal forecasting and validation. Figure 40 shows a simplified overview of the business environment analysis process.

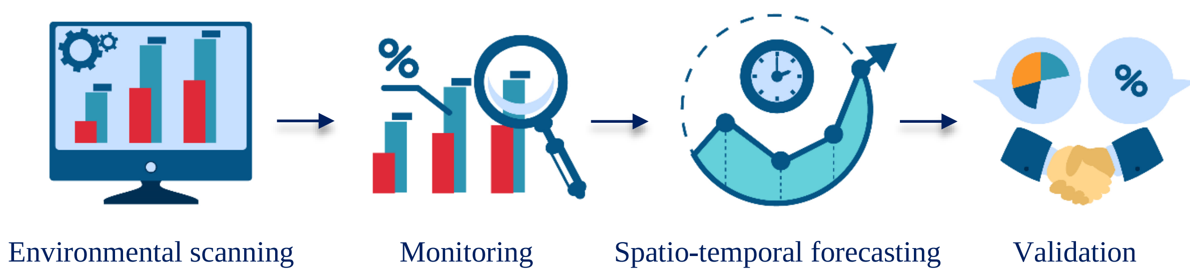


Figure 40. Simplified overview of business environment analysis

The first phase, environmental scanning, represents an activity that measures the degree of interactivity between ANSPs and their business environment. Its main functions are recognition of events and trends, establishing relationships between them, and giving meaning to data. In addition, it captures any potential changes in the business environment. The second phase of the business environment analysis process starts when potential changes and trends in the business environment are identified. Monitoring also deals with the discovery of the meaning of specific trends in the business environment. The result of the monitoring phase is the identification and recording of specific trends that occur.

The spatio-temporal forecasting represents the third phase of the business environment analysis process. Unlike environmental scanning and monitoring, which deal with describing the relevant business environment at a particular point in time, this phase is future-oriented. Based on the identified trends, spatio-temporal forecasting includes the development of projections of the expected outcomes. Without the last phase of the analysis of the business environment, the obtained knowledge would be meaningless. Accordingly, the information gained through the first three phases of the business environment analysis are further validated and interpreted with a goal to determine what might be the repercussions of identified trends and changes in the ANSPs' business environment.

Through application of the business environment analysis, the developed model can be used to determine heterogeneity and homogeneity of business environments. A heterogeneous business environment is the one that consists of many different features, while a homogeneous business environment consists of the similar features between one ANSP and its business environment. Information on heterogeneity, i.e., homogeneity of business environments can be further linked with the information on the dynamism of the business environment. It represents research of the variability of the homogeneity-heterogeneity relationship of the business environment over a certain period. By studying the dynamism of the business environments, information on their stability-instability can be also obtained. It involves studying the frequency of feature changes in the business environments. If the features are constant during the observed period, the business environment may be categorized as stable. The opposite situation marks unstable business environments. ANSPs with such business environments should undergo constant process of learning and change at the same pace as features coming from the business environment change.

In principle, every time some ANSP undertakes a business activity or decision, its business environment changes. After every change begins a cycle of learning, interpretation, adaptation and re-learning for that ANSP and neighbouring ANSPs. In so doing, the significance of business environment changes and corrective actions needed depend on the significance of the decision made. Therefore, the process of analysing the business environment in the context of the ATM domain represents one of the most complex, but strategically one of the most important processes. Also, the application of this analysis makes the difference between proactive ANSPs and those who passively wait impulses from their business environment and adapt to them – more or less successfully.

4. CASE STUDY: CAPACITY-BASED ASSESSMENT

4.1. Airspace capacity management

Airspace capacity management can be defined as an activity by which the airspace is being organized and managed in accordance with AUs' requirements. It is based on the application of the following three-step approach: phases: strategic phase, pre-tactical phase and tactical phase. The strategic phase consists of the definition of the national airspace policy and establishment of predetermined airspace structures. The pre-tactical phase starts just after the strategic phase ends. It includes day-to-day allocation of airspace structures. The last tactical phase includes real-time use of airspace structures simultaneously ensuring safe operations for Operational Air Traffic (OAT) and GAT. Unlike the other two phases, the strategic phase does not include direct operational activities. It mainly involves conduction of numerous activities aiming to identify areas requiring performance improvement (such as higher airspace availability, higher airspace utilization level, route optimizations, etc.). Also, the purpose of strategic phase is to identify bottlenecks and situations (periods) where capacity is scarce. More importantly, it includes conduction of tasks aiming to reduce intervals of capacity shortfalls. Within the strategic phase preconditions and resources enabling implementation of appropriate corrective measures also need to be defined and ensured (where needed). As opposed to the strategic phase, the other two phases are performed by the interconnected operational units. That includes the Airspace Management (ASM), Air Traffic Control (ATC) and ATFM unit. Figure 41 shows a conceptual design of the operational units that are in direct charge of ensuring the airspace availability. Last but not least, it should be noted that airspace capacity differs from the ATC capacity. Airspace capacity represents the maximum number of aircraft that can enter a specified airspace thus giving to ATCOs a certain level of workload that they must perform in a safe manner over a given period [96]. It is divided into controlled and uncontrolled volume, and it is greater than the ATC capacity. Namely, for the calculation of the ATC capacity only the controlled airspace is considered. In that respect, it can be outlined that further research deals with capacity-based airspace fragmentation from the aspect of the ATC capacity, i.e., lack of ATC capacity.

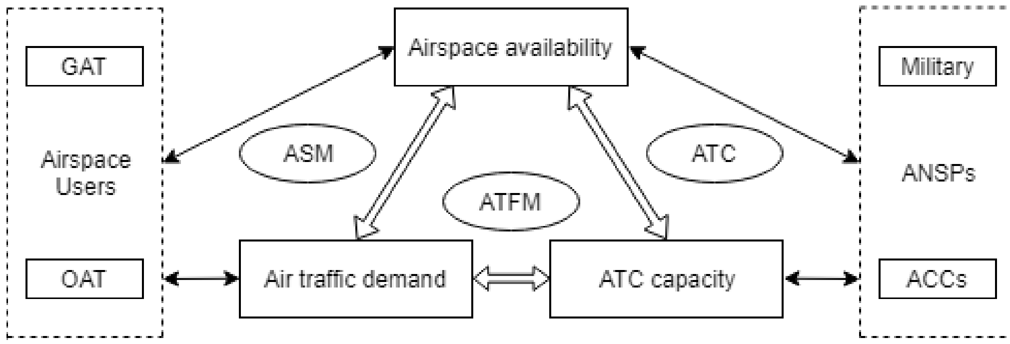


Figure 41. Pre-tactical and tactical phases overview [97]

In the events when it is anticipated that the traffic demand will exceed the declared ATC capacity, after coordination with the Flow Management Position (FMP), the Network Manager Operations Centre (NMOC) decides on the activation of ATFM regulation(s). In principle, they are imposed to adjust the demand to the capacity of given Area Control Centre (ACC). As such, the ATFM regulations represent a safeguard method applied to match traffic demand to the available ATC capacity. Depending on the type and the entity responsible for the reference location protected by the ATFM regulation, the ATFM delay can be classified as either an airport or an en-route ATFM delay. Accordingly, it can be attributed to the relevant ANSP or airport. Thereby, since ground delays are less harmful to the environment, they are more preferable than airborne delays [98].

In respect to the above, further research content places focus on the strategic phase of airspace capacity management and on the en-route ATFM delay. In short, the en-route ATFM delay represents an ATFM delay caused by regulations applied by the NMOC at the request of the FMP to protect en-route ATC sectors from overload. It is calculated by the central unit of the ATFM (Network Manager) and expressed as the difference between the Estimated Take-Off Time (ETOT) requested by the AU in the last submitted Flight Plan (FP) and the Calculated Take-Off Time (CTOT) allocated by the Network Manager. For the purposes of this indicator, ETOT denotes the forecast of time when the aircraft will become airborne calculated by the Network Manager, while CTOT marks the time allocated by the Network Manager on the day of operation, as a result of tactical slot allocation, at which a flight is expected to become airborne [99]. Table 1 shows the classification of the causes of the en-route ATFM delay. Lastly, it is important to emphasise that the causes for the regulation allocation are indicated by the responsible FMPs and that they are subject to post-ops performance revision.

Table 1. Classification of the causes of the en-route ATFM delay

Regulation cause	Code	Application description
ATC Capacity	C	Demand exceeds or complexity reduces the declared or expected ATC capacity.
ATC Industrial Action	I	Reduction in any capacity due to industrial action by the ATC staff.
ATC Routings	R	Network solutions/scenarios used to balance demand and capacity.
ATC Staffing	S	Unplanned staff shortage reducing the expected capacity.
ATC Equipment	T	Reduction of expected or declared capacity due to the non-availability or degradation of equipment used to provide an ATC service.
Airspace Management	M	Reduction in declared or expected capacity following changes in airspace/route availability due to small scale military activity.
Special Event	P	Reduction in planned, declared or expected capacity or when demand exceeds the above capacities as a result of a major sporting, governmental or social event. It may also be used for ATM system upgrades and transitions. Large multinational military exercises may also use this. This category should only be used with prior approval during the planning process.
Weather	W	Reduction in expected capacity due to any weather phenomena. This includes when weather impacts the airport infrastructure capacity, but where aerodrome services are operating as planned/expected.
Environmental Issues	V	Reduction in any capacity or when demand exceeds any capacity due to agreed local noise, runway usage or similar procedures. This category should only be used with prior agreement in the planning process.
Other	O	This code should only be used in exceptional circumstances when no other category is sufficient. An explanatory ANM remark must be given to allow post ops analysis.

4.2. Research determinants

4.2.1. Reference period

For the purpose of model validation by application, the year 2018 was selected as the reference year of the case study. Primarily because the performance level during the following two years did not convincingly reflect the usual performance level of the ATM system in Europe. During these two years, performance levels were significantly affected by the exogenous factors. En-route ATFM delays during 2019 were significant due to en-route disruptions (mostly due to occurrence of several significant ATC industrial actions) while 2020 was marked by the SARS-CoV-2 pandemic and a lack of demand. Nonetheless, the year of 2018 also brought some challenges. However, they mostly fall under the domain of airspace capacity management.

During the studied year, there were on average 30,168 daily flights. That represents an increase of 3.80% compared to the 2017 figures. Accordingly, the research requirement in the sense of data set representativeness (sample size) has been met. Even though September was the month with the lowest traffic growth, the busiest day during 2018 on the system-wide level was Friday, 7 September with 37,088 flights [100]. It can be defined that the level of the generated en-route ATFM delay on the system-wide level within first months of 2018 was slightly better than the year before. However, as the year went on the level of generated en-route ATFM delay became significant. Even though during 2018 NMOC achieved savings of 2.7 million minutes in the en-route ATFM delay, 2018 was marked by a record number of ATFM regulations at the time (with over 400 regulations applied on some days). In addition, it was not uncommon for flights to be subject to up to seven regulations at once, making rerouting and delay mitigation sometimes virtually impossible. In addition, 2018 was marked by changes in traffic patterns as some AUs used different routes compared to the ones used in previous years mainly due to network redefinition (due to the gradual FRA concept deployment). However, despite improvements in terms of network optimization, AUs were frequently not able to fully exploit the FRA benefits due to airspace saturation and capacity constraints. Moreover, during 2018 AUs frequently had to fly at suboptimal Flight Levels (FL), thus increasing their operating costs as a result of higher fuel consumption. Lastly, it can be outlined that IATA [101] argued that air traffic flow disruptions during 2018 were significant primarily due to the fact that the planned ATC capacity improvements were not achieved in accordance with earlier defined national capacity plans.

4.2.2. Geographical scope and input data

The ATM system in Europe comprises of different spatial and temporal scales. The selection of appropriate observation scale depends on the research question one is interested in. In that respect, this research has two geographical scopes and therefore two network models were designed as direct graphs. On the one hand, for the purpose of capacity-based assessment lateral boundaries of 38 ANSP were taken into account. More precisely, airspace class C represents a reference area. On the other hand, for the purpose of trade-off identification, a second geographical scope included lateral boundaries of 42 charging zones superimposed over the European airspace. Figure 42 shows a spatial overview of studied geographical areas and their breakdown into spatial objects, while Figure 43 shows the resulting connectivity histograms. Table 2 below shows a tabular overview with classification of the studied spatial objects.

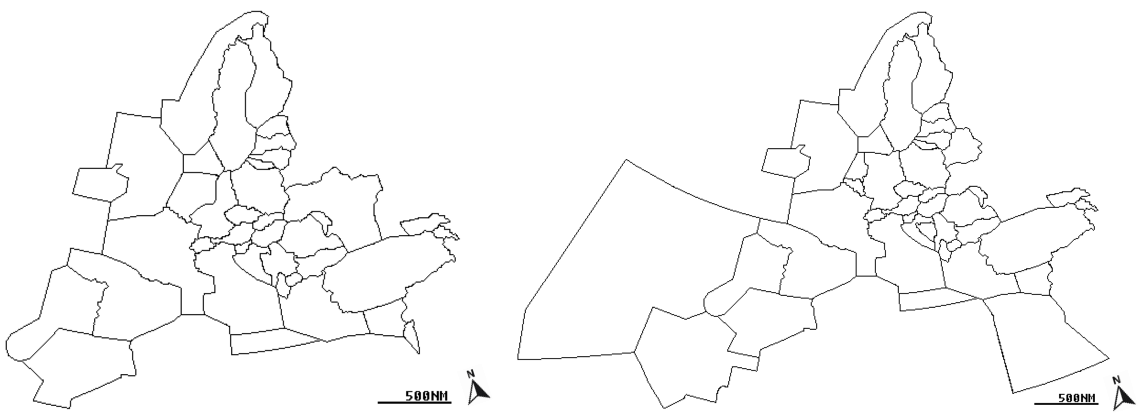


Figure 42. Spatial overview of the studied area

Geographical scopes considered within this case study highly depend on the input data collected for the purpose of the case study. Input data were mostly obtained from the EUROCONTROL PRU using the 2016 NM v.20.0 software (data originator). More precisely, input data refer to en-route ATFM delay figures detailing performance levels of 38 ANSPs and to national en-route unit rates of 42 ANS charging zones. For the purpose of data manipulation, data on day-to-day performance levels of en-route ATFM delay was aggregated in form of the average annual figures. That was also done in order to enable performance valorisation within the strategic planning and development of ATM system in Europe. Thereby, the same approach was not applied for national en-route unit rates as they are defined on the annual basis. In addition, it can be outlined that input data has been validated and verified by the PRU and that input data has been subject to the post-ops performance adjustment process [102].

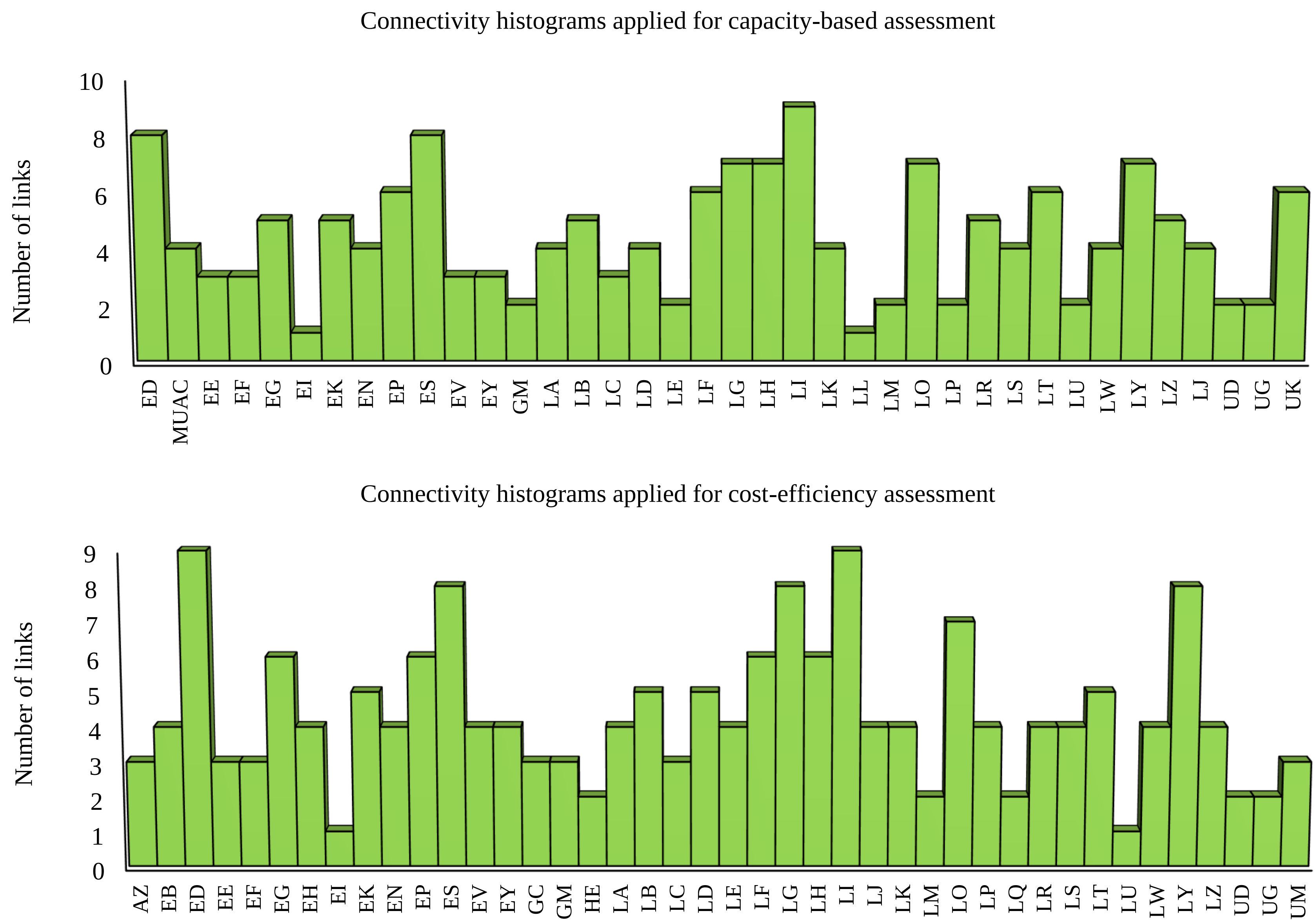


Figure 43. Connectivity histograms

Table 2. Classification of the studied spatial objects

ICAO Member State	ICAO code	ANSP name	AoR [km^2]
Portuguese Republic: S. Maria	AZ	NAV Portugal	5,180,000
Kingdom of Belgium	EB	Skeyes	39,500
Federal Republic of Germany	ED	DFS	390,000
Republic of Estonia	EE	EANS	77,400
Republic of Finland	EF	ANS Finland	409,000
United Kingdom of Great Britain and North Ireland	EG	NATS*	880,000
Kingdom of the Netherlands	EH	LVNL	53,100
Ireland	EI	IAA	457,000
Kingdom of Denmark	EK	NAVIAIR	158,000
Kingdom of Norway	EN	Avinor	731,000
Republic of Poland	EP	PANSA	334,000
Kingdom of Sweden	ES	LFV	627,000
Republic of Latvia	EV	LGS	74,800
Republic of Lithuania	EY	Oro Navigacija	95,900
Kingdom of Spain: Canarias	GC	ENAIRE	1,685,000
Republic of Albania	LA	Albcontrol	36,000
Republic of Bulgaria	LB	BULATSA	145,000
Republic of Cyprus	LC	DCAC Cyprus	174,000
Republic of Croatia	LD	Croatia Control	88,000
Kingdom of Spain	LE	ENAIRE	506,000
French Republic	LF	DSNA	1,010,000
Hellenic Republic	LG	HCAA	537,000
Hungary	LH	HungaroControl	92,600
Republic of Italy	LI	ENAV	732,000
Republic of Slovenia	LJ	Slovenia Control	20,400
Czech Republic	LK	ANS CR	76,300
State of Israel	LL	Israel AA	22,100
Republic of Malta	LM	MATS	231,000
Republic of Austria	LO	Austro Control	80,900
Portuguese Republic	LP	NAV Portugal*	671,000
Bosnia and Herzegovina	LQ	BHANSA	51,200
Romania	LR	ROMATSA	254,000
Swiss Confederation	LS	Skyguide	69,700
Republic of Turkey	LT	DHMI	982,000
Republic of Moldova	LU	MOLDATSA	34,800
Republic of North Macedonia	LW	M-NAV	24,700
Republic of Serbia – Mont.	LY	SMATSA	129,000
Slovak Republic	LZ	LPS	48,700
Republic of Armenia	UD	ARMATS	29,700
Georgia	UG	Sakaeronavigatsia	88,700
Ukraine	UK	UkSATSE	776,000
Republic of Belarus	UM	BELAERONAVIGATSIA	208,000
Arab Republic of Egypt	HE	NANSC	1,010,000
Kingdom of Morocco	GM	ONDA	447,000

**Continental AoR*

4.3. Main research findings

4.3.1. Fragmentation assessment

The main research findings of the capacity-based assessment in the sense of compliance level of attributive features between the first-order neighbours, measured by the attribute samples similarity index, indicate the existence of a medium similarity level over the studied area. After the determination of the first-order compliance level, patterns of spatial association were identified through the study of spatial autocorrelation. As global Moran's I (measuring the spatial autocorrelation across the entire network model) has a positive value (0.230891), the existence of a grouping tendency of similar values over the studied area can be outlined. After data standardization, the assumption of random spatial patterns distribution was tested. It was determined that it can be rejected. As the obtained p-value (0.00280) is statistically significant (< 0.05), while the z-score (2.76826) is a significantly positive value, it can be concluded that the performance-based airspace fragmentation from the capacitive aspect in 2018 was a result of the clustered patterns distribution.

The results of the local indicators of spatial association indicate that 34.21% of the overall studied data set, i.e., 32.10% of the overall studied area (11,800,700 km^2) tends to cluster. Thereby, it was identified that the performance levels of ENAV and Israel AA represent spatial objects that deviate in opposite direction from their neighbourhood, thus scattering a positive exogenous effect on their first-order neighbours. On the other hand, in 2018 DFS and DSNA represented spatial objects that deviated from their neighbourhood in the sense that they were scattering a negative exogenous effect on their first-order neighbours.

Through the utilisation of the Moran’s I scatter plot, local instabilities in spatial associations were determined. In that respect, research findings indicate the existence of a few spatially homogeneous patterns, i.e., areas with spatially similar en-route ATFM delay figures. However, they are unevenly sized and scattered over the European airspace. In respect to the overall figure, the spatial outliers whose performance level differ and appear inconsistent with respect to their neighbours hold a share of 39.48% from the attribute and 33.73% from the spatial aspect. Out of these figures, high-value spatial objects surrounded by primarily low-values hold a share of 13.16% in the attribute share and 8.65% in the spatial share. Low-value spatial objects rounded primarily by high-values make up the remaining share. Figure 44 shows a graphical overview of the obtained research findings.

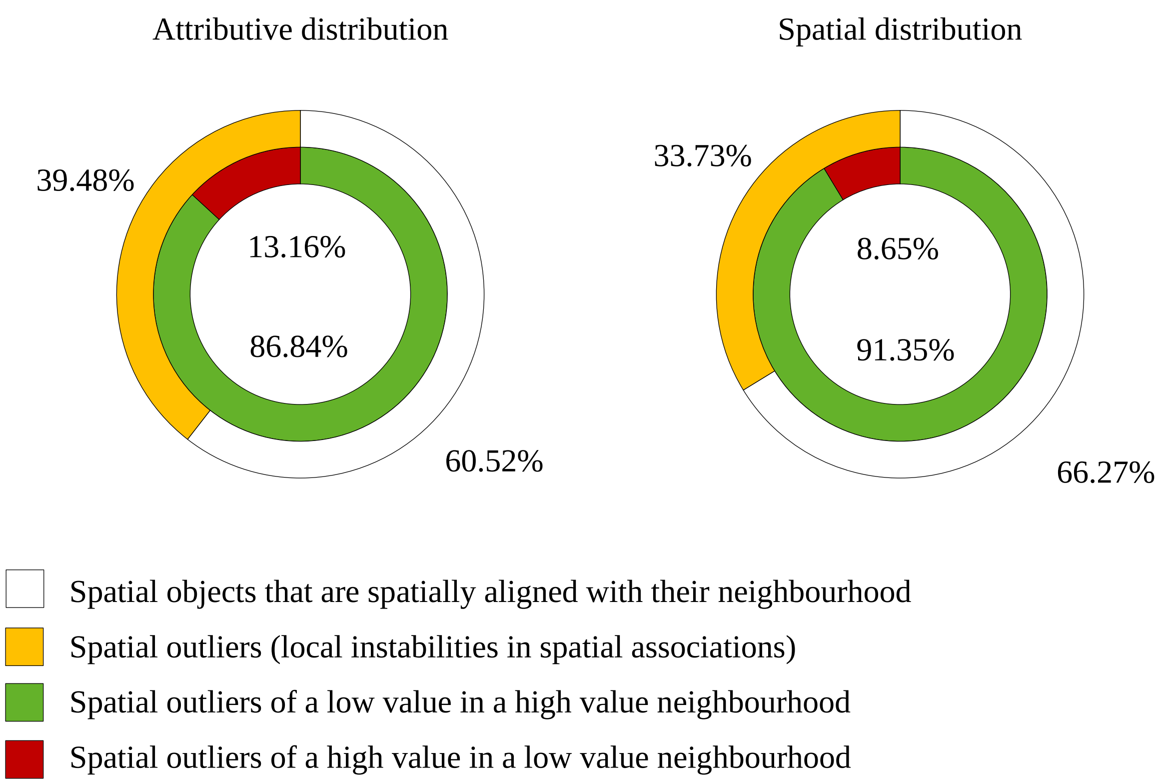


Figure 44. Overview of the local instabilities in spatial associations

Spatial objects whose performance level significantly differs with respect to their first-order neighbours were determined through the adoption of the empirical rule. In that regard, the obtained research findings indicate that 5.26% and 11.86% from the attributive and spatial aspect of the overall figures, respectively, represent spatial objects whose performance levels significantly deviate (> 3σ) from their first-order neighbours. Two neighbouring spatial objects, i.e., AoRs of DFS and DSNA represent spatial objects whose performance level deviates significantly with respect to their first-order neighbours. A more detail overview of the research findings on the capacity-based airspace fragmentation assessment can be found within Appendix 1 and within Appendix 2.

4.3.2. Defragmentation assessment

Efficient airspace management is a fundamental prerequisite to increase the capacity, to provide the optimum response to various AU requirements and to achieve the most flexible use of airspace [103]. In addition, the ICAO defined within the Doc 4444 titled Procedures for Air Navigation Services that the appropriate authority should periodically review the ATC capacities in relation to traffic demand. In the case that traffic demand regularly exceeds the ATC capacity or it becomes apparent that the forecasted traffic demand will exceed the ATC capacity, the appropriate authority should maximize the use of the existing system capacity and develop plans to increase capacity to meet the actual or forecasted demand [104]. In that respect, research findings indicate that the spatial object, i.e., AoR of Department of Civil Aviation of Cyprus (DCAC), significantly deviates from its first-order neighbours. That combined with its geographical position within the ATM system in Europe makes it an entry-exit bottleneck of the South East Axis. Therefore, further research activities have dealt with the study of the performance-based airspace defragmentation by focusing on that spatial object. Performance data review of the DCAC indicates that by the end of 2018 it has generated an average en-route ATFM delay figure of 1.10 [min/flight]. More precisely, for the 393,558 IFR operations handled, it has generated 433,836 minutes of en-route ATFM delay. Figure 45 shows a breakdown of its en-route ATFM delay figure. It indicates that the major delay generators were ATC staffing (43.25% of an overall figure) and ATC capacity (37.14% of an overall figure) [81]. Therefore, performance improvement that would enable airspace defragmentation from capacitive aspect was sought after in these two segments.

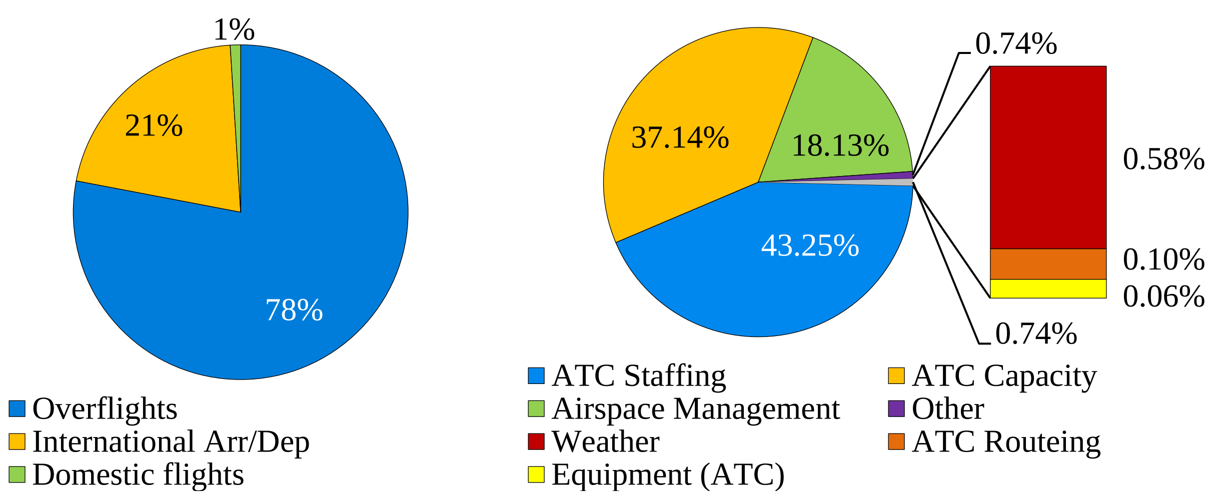
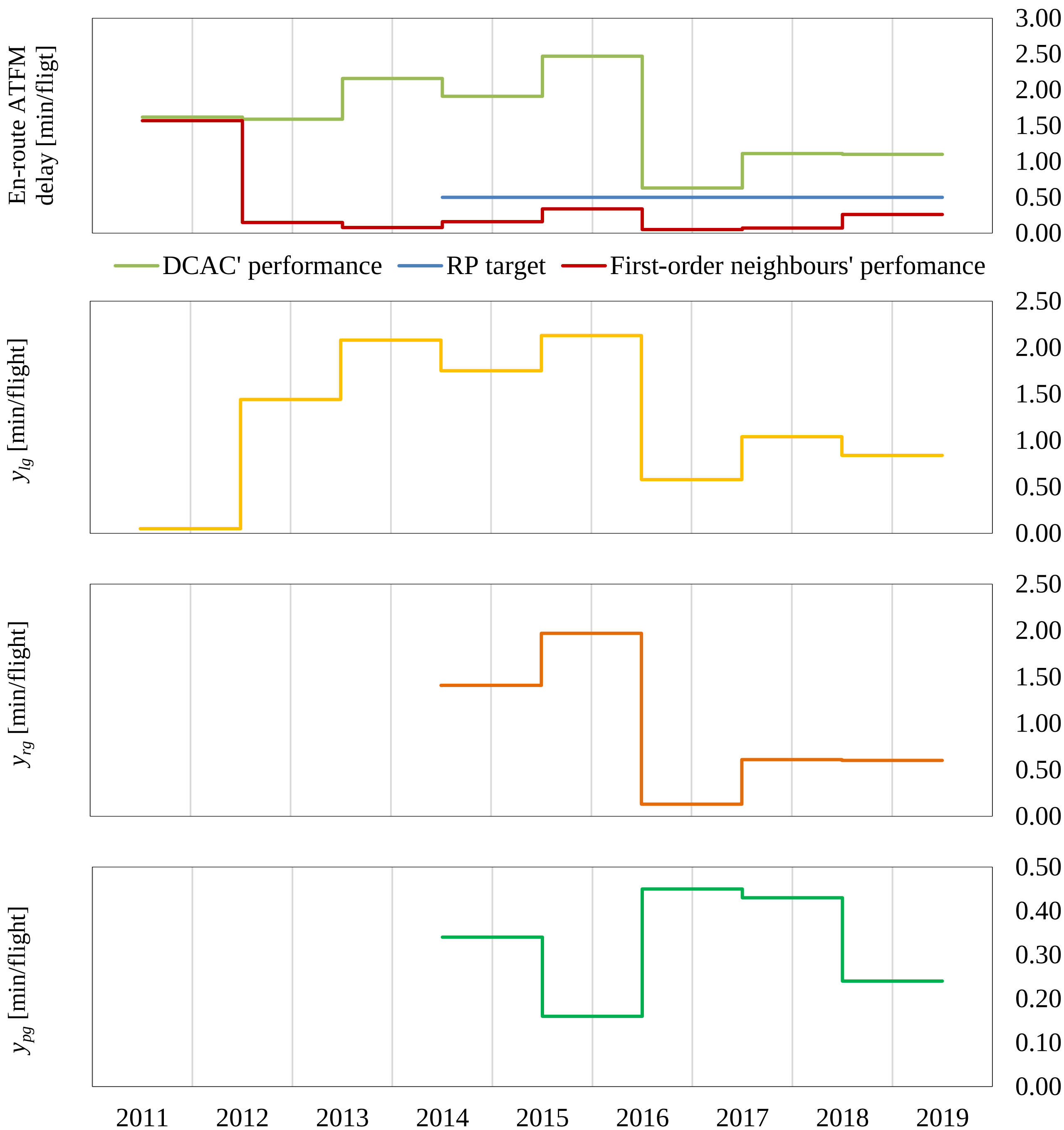


Figure 45. DCAC traffic and en-route ATFM delay distribution (2018) [81,105]

Before determining the marginal SPI for DCAC, a longitudinal study of its alignment with its first-order neighbourhood from capacitive aspect was conducted. The study covered a period from 2011 to end of 2018. Based on the obtained findings, it can be concluded that the DCAC continuously represented a spatial outlier over the studied period, as shown in Figure 46.



**2011-2015 data set has not undergone post-ops adjustments*

Figure 46. Overview of the process control results for DCAC aggregated on annual level

Determination of the marginal SPI for DCAC in the sense of en-route ATFM delay for 2018 was performed by applying the what-if analysis. By conducting ten thousand what-if analyses, with the setting of a gradual decrease of 0.01%, it was determined that the marginal SPI for DCAC equals to an en-route ATFM delay of 0.24 [min/flight]. That figure represents a decrease of 77.76% compared to its actual 2018 figure. By adopting an assumption that the DCAC will manage to achieve a marginal SPI, it was identified that the distribution of spatial patterns over the European airspace would become more clustered. Table 3 shows the changes in the reduction of variance and p-value as well as the increase of Moran's I and z-score. Also, a slight change in share of spatial outliers would occur. Apart from that, a slight change in share of spatial objects whose performance levels significantly differ in respect to their first-order neighbours would also occur. In the sense of results interpretation of other assessments on the system-wide level, no other significant changes would occur.

Table 3. Overview of the main research outputs relevant for the system-wide assessment

	Moran's index	Expected value	Variance	z-score	p-value
2018	0.23089	- 0.02703	0.19186	2.76826	0.00280
Marginal SPI	0.27346	- 0.02703	0.17405	3.32361	0.00045

By focusing on the DCAC, the results of the change impact analysis indicate that, as a result of reducing the en-route ATFM delay to the level of marginal SPI, it would no longer represent a spatial object whose performance level significantly differs (> 2σ) with respect to its first-order neighbours. As such, it would no longer represent an entry-exit bottleneck of the South East Axis. Also, it would shift from being a spatial outlier of high value surrounded by low value neighbourhood into a spatial object spatially aligned with its neighbourhood. Furthermore, as Figure 47 shows, by achieving the identified marginal SPI, the neighbouring samples similarity index (left) would increase with respect to the performance levels of Israel AA and DHMI, while a slight decrease would occur with respect to HCAA. The right-hand side of Figure 47 shows a change effect on local indicators of spatial autocorrelation of the DCAC first-order neighbours. It can be seen that HCAA would become more unaligned, Israel AA would become more aligned with its neighbours, while DHMI would become the spatial object of positive cluster spreading. A more detail overview of research findings on the cost-efficiency based airspace fragmentation assessment can be found in Appendix 3 and Appendix 4.

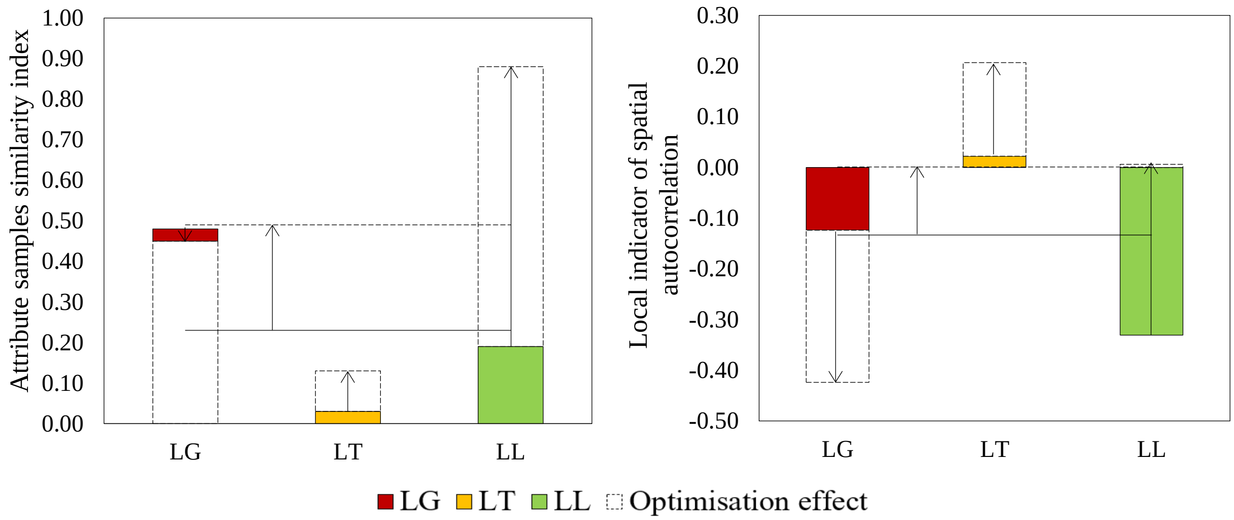


Figure 47. Effects of DCAC capacity improvement on its first-order neighbourhood

Review of the historical performance achievements of the DCAC indicates that it can achieve capacity improvement through allocation of certain financial investments in human resources, organizational and operational improvements. To verify that defragmentation from capacitive aspect would not lead to the creation of fragmentation within certain other performance areas, performance trade-off situations have been considered. As the performance trade-off situation arises between capacity and cost-efficiency, previously conducted research activities were replicated from the cost-efficiency aspect. These research findings indicate that the DCAC charging zone represents a spatial object aligned with its first-order neighbourhood. As such, they form a spatial pattern of low value area surrounded by the same value area. Additionally, a spatio-temporal analysis was conducted upon which was determined that DCAC had been continuously aligned with its first-order neighbourhood from the cost-efficiency aspect over the studied period from 1998 to the end of 2020. Figure 48 shows a consolidated overview of the obtained research findings.

The determination of the marginal SPI for DCAC in the sense of the cost-efficiency was also performed by conducting ten thousand what-if analyses. However, with the difference of applying the setting of a gradual increase of 0.01%. The obtained findings indicate that the marginal SPI from the cost-efficiency aspect equals to a 30.65% increase compared to the 2018 figure. Figure 49 shows the results of the what-if analysis on Moran's I, z-score and p-value distribution. It can be noted that the conducted change did not bring a significant change in pattern distribution as it remained clustered.

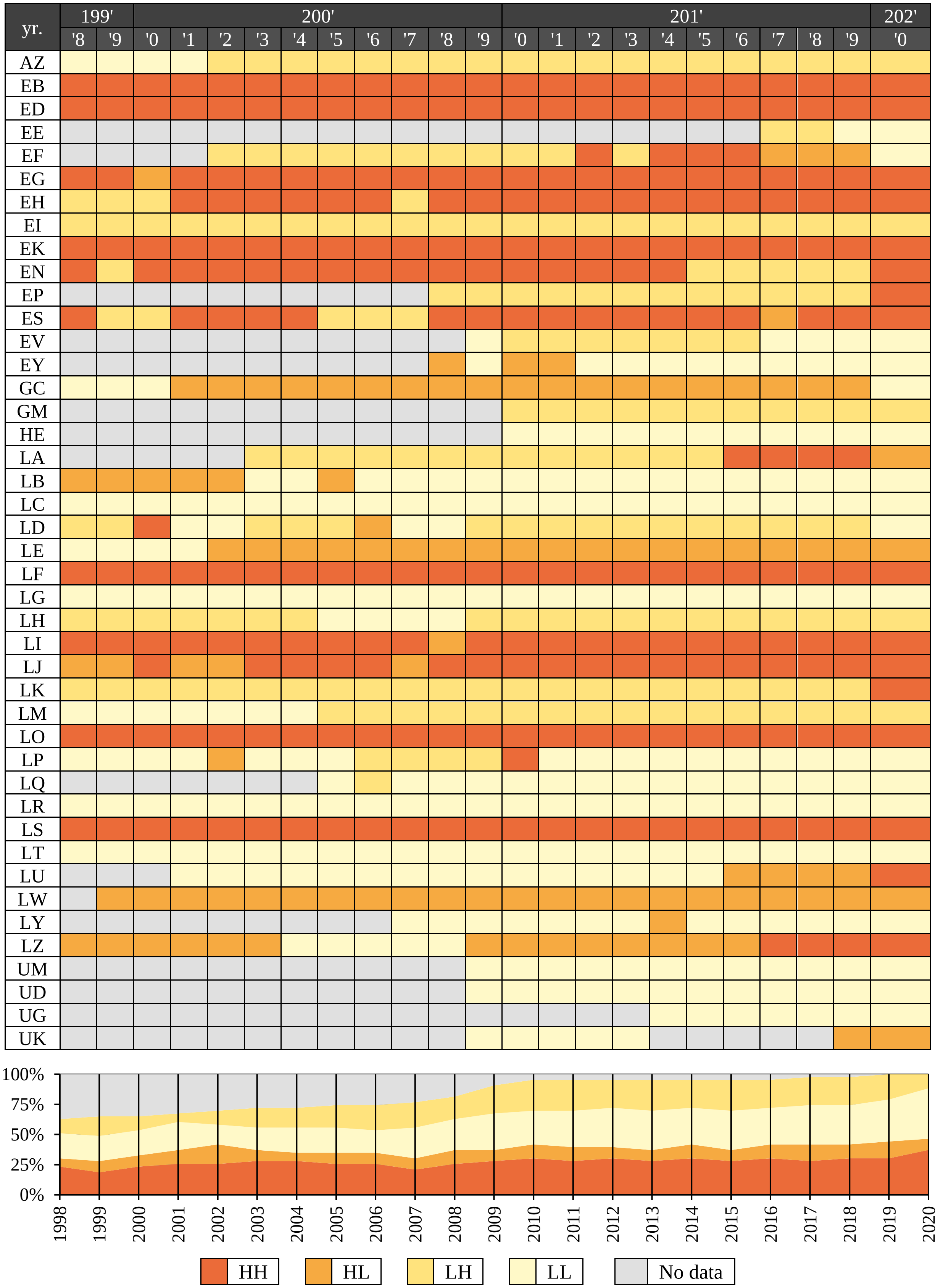


Figure 48. Overview of the local instabilities in spatial associations from the cost-efficiency aspect [106]

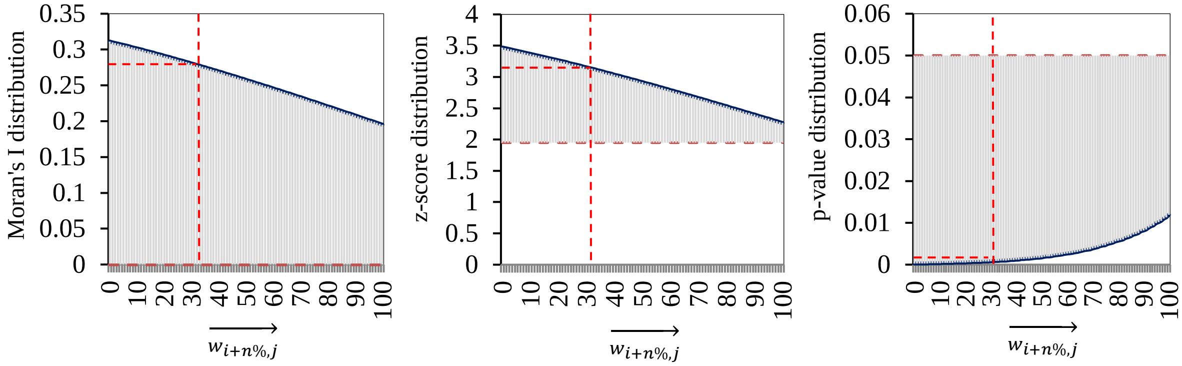


Figure 49. Overview of the what-if analysis results on the system-wide pattern distribution

Research findings also indicate that the change of the DCAC en-route unit rate on the system-wide level did not have an impact on the compliance level of the first-order neighbour attributive features. It remained at 0.70 indicating a high similarity level. By focusing on DCAC and its first-order neighbours, Figure 50 shows results of the conducted what-if analyses. As it can be seen, the foreseen change brings reduction to both aspects of compliance levels; between DCAC's first-order neighbours and between their first-order neighbours.

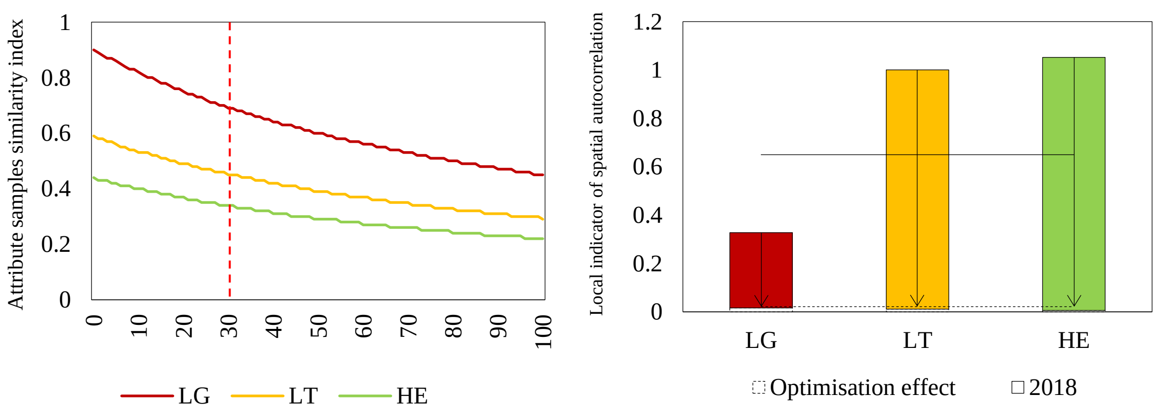


Figure 50. Overview of the what-if analysis results on the DCAC and its first-order neighbours

Within further research activities ecological effects of foreseen changes were taken in to account. As capacitive and environmental performance effects are interdependent, capacity improvement also results in environment preservation. Based on the Standard Inputs for Cost-Benefit Analysis [107], environmental (social) benefits were approximated that can be achieved through the capacity-based airspace defragmentation. Thereby, it was determined that if the DCAC reduces its en-route ATFM delay to marginal SPI, it would result in a 52,383,643.20 kilograms of carbon dioxide emissions reduction, 20,570,973.54 kilograms of water vapour emissions reduction and 13,968.97 kilograms of sulphur dioxide emissions reduction.

5. DISSCUSION

Strategic planning and development of the ATM system should be oriented towards creating and enabling the prerequisites required to further improve system efficiency. However, in Europe development of the ATM system heavily relies on the regulatory framework introduced with the establishment of the SES initiative. Consequently, ambiguities in the regulatory framework also appear as flaws of the strategic planning and development of the ATM system in Europe.

Even though sometimes the “but it says here” syndrome is less dangerous than the syndrome “I didn't know” (which usually means that the damage is already done), research findings indicate that from the capacitive viewpoint the administrative understanding of the performance targets, i.e., strategic goals introduced for the purpose of airspace defragmentation should be avoided.

In principle, if the elimination of one mistake at an early-stage of development costs one unit, then in laboratories it costs ten, while in operation a hundred times more. In that context, it has been identified that during the eight-year period, from 2011 to end of 2018, an additional 1% reduction of the generated en-route ATFM delay at system-wide level would approximately result with savings of 893,639.21 minutes. That approximately corresponds to savings of EUR 89,363,921.00 to AUs. In addition, that would approximately result in 43,788,321.29 kg of saved fuel. Consequently, that would lead to a reduction of 137,933,212.06 kg of carbon dioxide emissions, 53,859,635.19 kg of water vapour emissions and 36,782.19 kg of sulphur dioxide emissions reduction. Thereby, the scale of the presented findings and the associated effects indicates the high relevance of the question of applicability of the regulatory-defined capacitive performance targets introduced to contribute to airspace defragmentation and to increase the efficiency of the ATM system in Europe.

The obtained findings also indicate that the adoption of the one-size-fits-all principle from the capacitive aspect rarely delivers full business benefits. In that context, by studying performance-based airspace fragmentation from a capacitive aspect, it was found that within the ATM system in Europe there is a significant share of ANSPs with over-defined and under-defined performance targets, i.e., strategic goals from the capacitive aspect. Figure 51 shows the identified performance gaps for 2018. It is important to emphasise that compared to the situations with over-defined performance target, situations with under-defined performance target are far more hazardous from the aspect of strategic planning and development. Primarily because the performance gap between the regulatory-defined and desired business situation (performance level) can sometimes be quite significant.

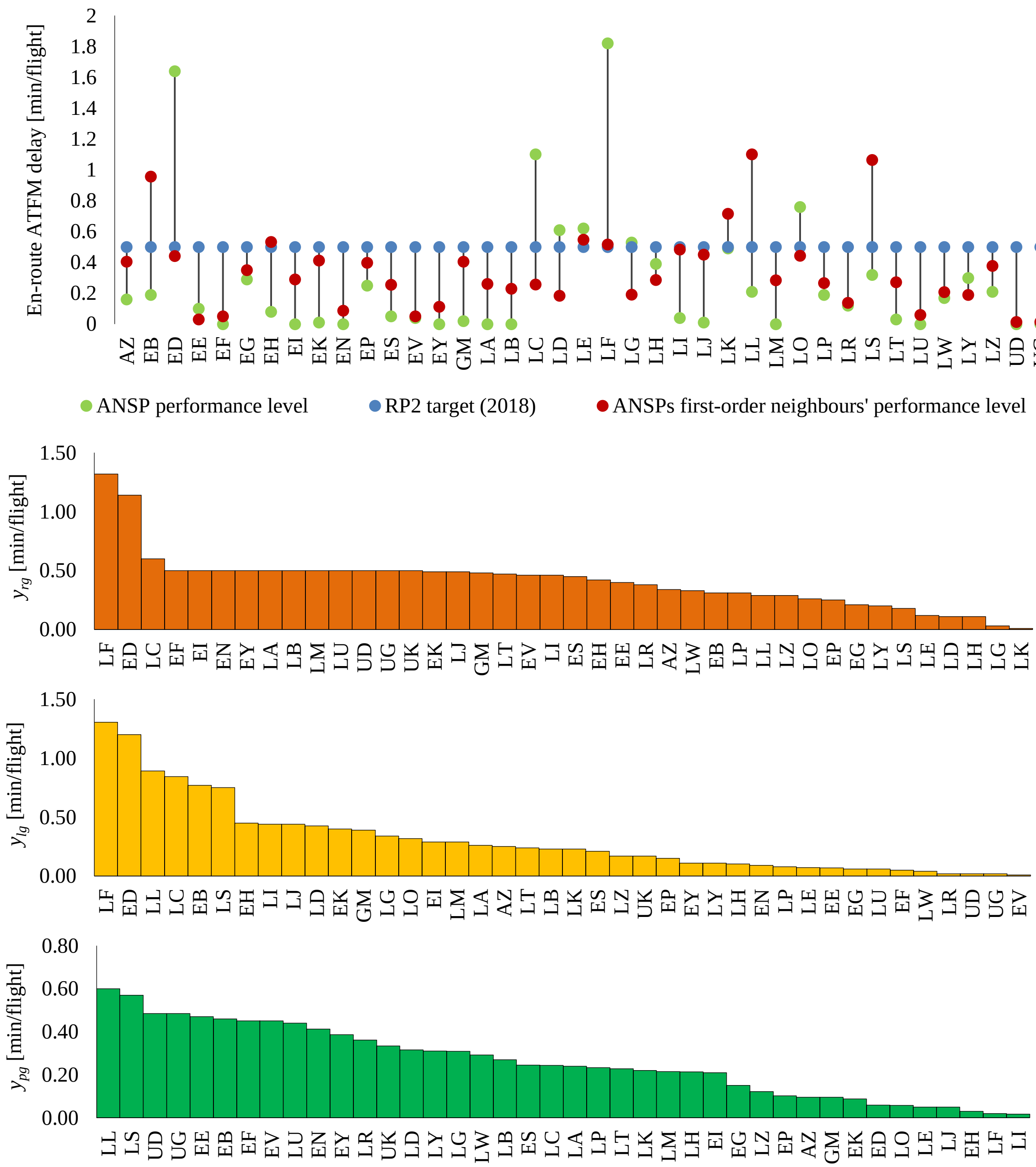


Figure 51. Comparative overview of the performance gaps (2018)

Considering the scale of the identified performance gaps, it can be defined that the conceptual and methodological assumptions of the currently applicable strategic planning and development framework of the ATM system in Europe need to be modified in a way that performance targets actually contribute to performance-based airspace defragmentation. Accordingly, the development of novel conceptual and methodological assumptions and spatially-oriented performance indicators can be viewed as one of the drivers of further efficiency improvement of the ATM system in Europe.

As mentioned earlier, strategic planning and development of the ATM system in Europe is a highly challenging task for numerous reasons. Setting down targets for different performance areas and indicators must be done cautiously primarily due to their interdependencies. For instance, setting a strict target for one indicator may limit the maximum achievable target in other areas. As such, corrective measures introduced to improve one performance area may produce unintended negative consequences in other performance areas. In that respect, this research has placed an emphasis on the issue of performance interdependencies by studying the European airspace (de)fragmentation from capacitive aspect. The main research findings indicate that airspace defragmentation from capacitive aspect would result in both positive (win-win) and negative (win-lose) effect in context of performance interdependencies. On the one hand, a positive effect can be expected as capacity improvement also brings environmental benefits. On the other hand, a negative effect occurs between the performance areas of capacity and cost-efficiency as capacity improvement comes with a requirement of certain investments.

Within this research DCAC' AoR has been identified as a spatial outlier, i.e., as a contributor to performance-based airspace fragmentation from capacitive aspect. In short, the DCAC represents a state-owned entity, i.e., a governmental department of the Ministry of Transport, Communications and Works. For the last few years, it has been undertaking preparations for deploying a "new" ANSP. However, the transition has been postponed several times so far. The DCAC operates one ACC responsible for the ATC provision within the limits of Nicosia FIR. With respect to GAT and OAT interference, there are R/TRA/TSA located mostly in the South-East part of Nicosia FIR. Figure 52 shows their spatial distribution over Nicosia FIR. Thereby, GAT does not significantly interfere with OAT. Division Flight Level (DFL) for DCAC is set up at FL195 as shown in Figure 53.

It needs to be emphasised that the DCAC represents a marginal spatial area of the NMOC and the Integrated Initial Flight Plan Processing System (IFPS) zone. As such, it is affected by the traffic coming from the Middle East which is not subject to ATFM regulations. However, recently an improvement was made as Israel (Israel AA) and Egypt (NANSC) became adjacent areas of the IFPS zone – whereas in these areas NMOC may provide a limited ATFM service.

With respect to the overall figure, major region-pairs for DCAC in the sense of delivered service units are Europe-Europe with 38.40%, Europe-Middle East (and vice versa) with 25.80% and Europe-Africa (and vice versa) with the median value of 8.60% [108].

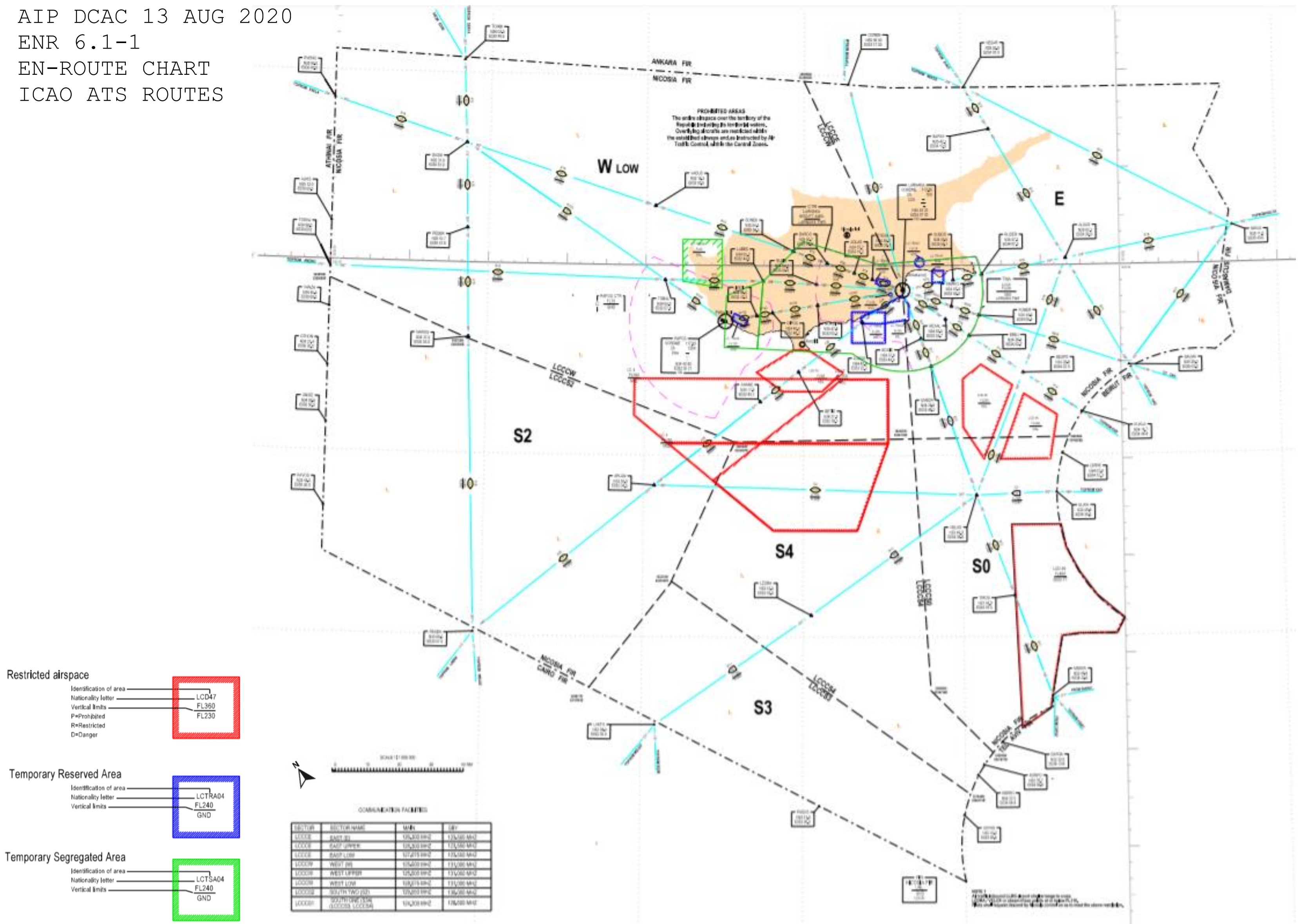


Figure 52. Spatial overview of R/TRA/TSA within Nicosia FIR [109]

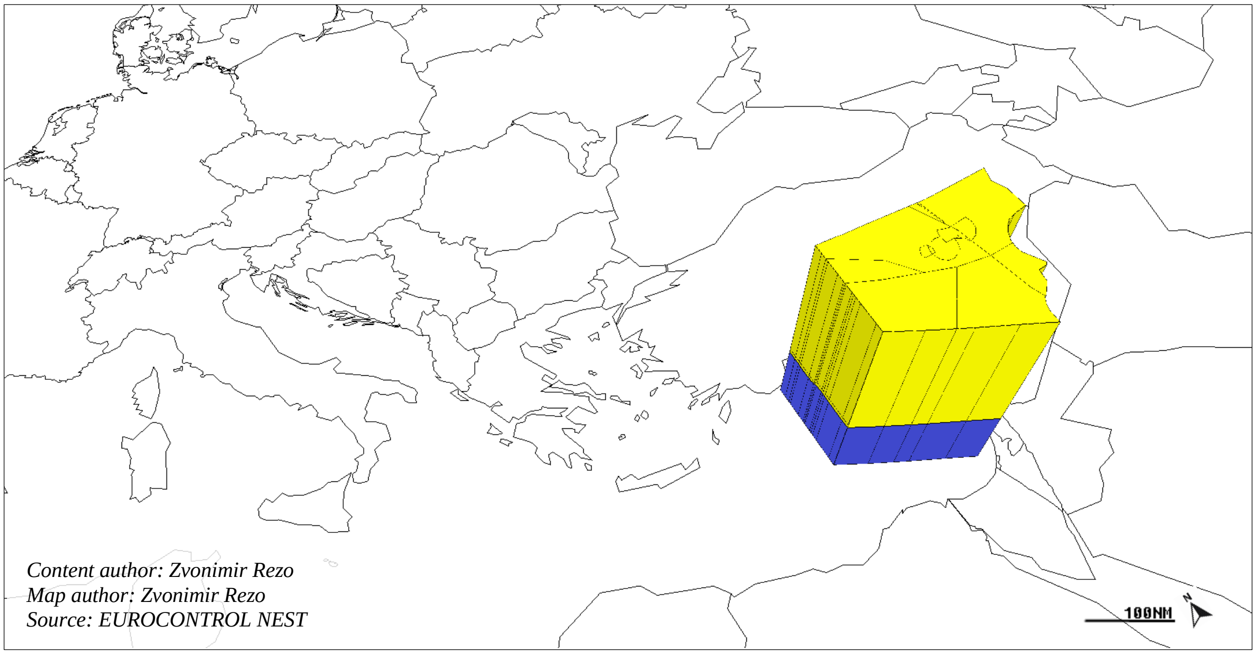


Figure 53. Spatial overview of lower and upper airspace area of Nicosia FIR with DFL 195

By placing the obtained research findings of capacitive and cost-efficiency assessments in comparison to the existing regulatory framework, it can be outlined that they do not go hand in hand. For instance, to minimise the occurrence of en-route ATFM delays caused by ATC staff shortage, DCAC needs to hire more ATCOs. Apart from a fact how difficult and costly it is to hire new ATCOs, if DCAC eventually manages to hire additional ATCOs, due to cost-base increase it would not comply with performance targets set by the Performance Scheme. Otherwise, if additional ATCOs would not be employed, AUs would have to continue to cover higher operating costs. Undoubtedly, such situation places them in an unenviable position. Furthermore, considering that from the capacitive aspect the marginal SPI for DCAC is 52% lower than the 2018 performance target and that the cost-base increase goes in the opposite direction from the regulatory requirements, in case of the DCAC it can be concluded that the regulatory-defined performance targets, i.e., strategic goals of the ATM system in Europe for the KPA of capacity do not contribute to the performance-based airspace defragmentation.

In an ideal world, aircraft would fly directly from point of departure to point of arrival. However, practice shows that frequently that is not possible due to operational constraints and existence of various business interests. As AUs' interest is to achieve the lowest possible operating costs, 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. Accordingly, observation of the performance-based airspace fragmentation from cost-efficiency aspect might be viewed differently by different types of aviation stakeholders. On the one hand, due to fragmentation existence AUs have the option to utilise comparative advantages of individual charging zones (spatial objects) with respect to their neighbourhood. Primarily due to the fact that in Europe all capacity related costs are borne by the AUs. Thereby, given that the capacity provision has its cost, lack of capacity (resulting in ATFM delays) is even more expensive for the AU as they need to cover the chargeable costs of providing capacity and the costs of the ATFM delay. The computation of the chargeable cost of providing en-route capacity is based on the cost-base of each ANSP, while the computation of the cost of the en-route ATFM delay is based on the European airline delay cost reference values [110]. In that respect, the PRU expresses the cost of one minute of ATFM delay in the price base of the year under review by using the average EU inflation rate published by EUROSTAT. The estimated average en-route ATFM delay cost for 2018 amounted to 104 EUR/min. In that respect, Figure 54 shows cost distribution covered by the AUs for DCAC and its neighbouring ANSPs (spatial objects) for the year of 2018. It can be defined that the cost of ATFM delay of DCAC in 2018 amounted to 46.44% of the total costs borne by the AUs. This indicates more than an urgent need for capacity improvement in AoR of the DCAC. It was also identified that in order to avoid the situation of becoming a spatial outlier from the cost-efficiency aspect, by adopting assumptions of maintaining the same level of traffic demand, i.e., number of service units, DCAC can conduct a capacity improvement up to the maximum value of its cost-base in the amount of EUR 67,997,228.87. Accordingly, DCAC has the investment potential of EUR 15,951,894.87 to remain spatially coherent with its first-order neighbours. Figure 55 depicts the trend of the financial indicators for DCAC over the past years.

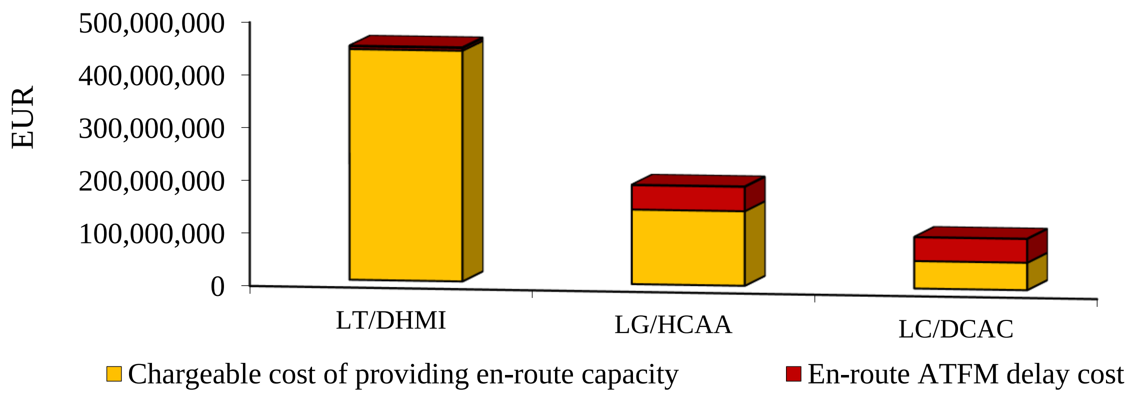
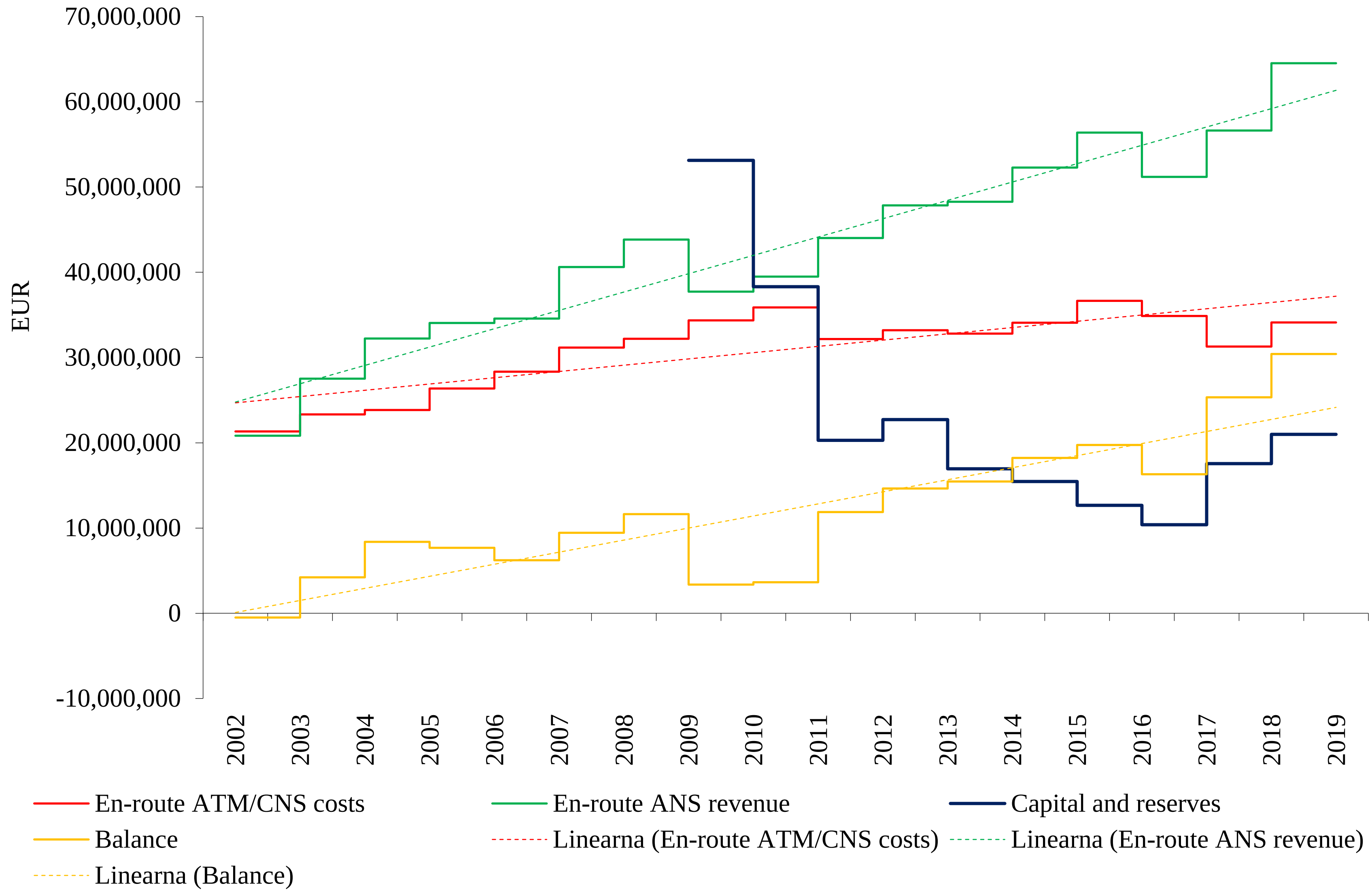


Figure 54. Overview of the overall en-route cost generators to AUs during 2018



Note: *There is no data on the capital and reserves category for the period from 2002 to 2009*

Figure 55. Overview of the DCAC main financial indicators over the past years [4,18,56,57,111-124]

On the other hand, there are no "double standards" when it comes to observing performance-based airspace fragmentation from a capacitive aspect. Its existence is not acceptable to anyone (and least of all to AUs as it leads to greater operating costs). By adopting the assumption of maintaining the same level of traffic demand, it can be outlined that in 2018 DCAC generated a surplus of 339,382 minutes of ATFM delay, i.e., en-route ATFM delay of 0.86 [min/flight] with respect to its first-order neighbours. Furthermore, by adopting the aforementioned assumption and by reducing its en-route ATFM delay figure to the level of marginal SPI, DCAC would generate 94,454 minutes of en-route ATFM delay. In event that DCAC manages to employ additional ATCOs and completely reduce en-route ATFM delay generated due to ATC staffing, the performance gap to SPI of 151,760 minutes of ATFM delay would still remain as ATC staffing is a major, but not the only en-route ATFM delay generator in case of DCAC. Hence, the remaining performance gap should be closed by investing in ATC capacity improvement. As such DCAC can contribute to the performance-based airspace defragmentation from the capacitive aspect. The direct economic contribution of the given improvements, leading to defragmentation, includes cost reduction for AUs in the amount of approximately EUR 19,343,841.66. Thereby, it should be noted that that each dollar of the output made in the aviation industry worldwide creates a demand of a USD 3.25 output in other industries [125]. Hence, the multiplier effect of undertaking improvements in the identified areas would result in additionally generated economic contribution in the value of EUR 62,867,485.40. Figure 56 shows a consolidated overview of the additional effects that can be achieved by changing the performance levels of DCAC to its marginal SPIs.

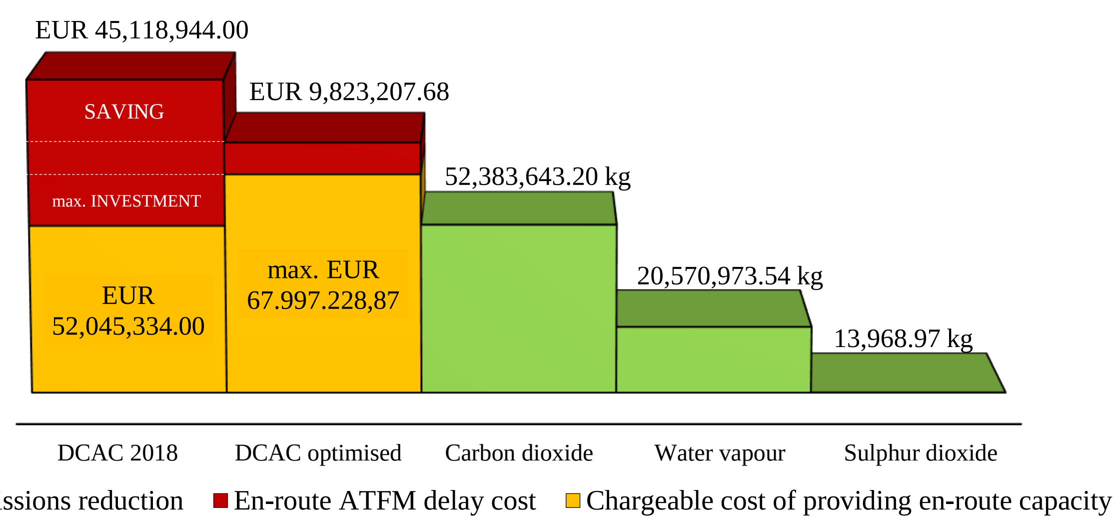


Figure 56. Consolidated overview of the defragmentation effects

Considering major delay generators in case of DCAC, with a goal to minimise occurrence of demand-capacity imbalances, certain corrective measures and investments need to be undertaken. The conventional way of capacity improvement includes a list of several improvement areas. In principle, slight performance improvements can be achieved by making a better use of the existing resources, e.g., through the adaptation of rosters, shift times and through better adaptation of sector opening times to traffic demand patterns. However, with respect to the system-wide performance level, in 2018 DCAC had one of highest figures of ATCO productivity, number of average hours on duty per ATCO, average hours on duty per ATCO in OPS and a significant amount of overtime hours of ATCOs in OPS [126]. Hence, rather than consuming financial resources on overtime costs, DCAC should invest in employing more ATCOs. Also, performance gap caused by ATCOs' shortage indicates that it should reconsider its employment plans. Review of Cyprus' Local Single Sky Implementation Plans (LSSIPs) indicates that even though forecasts did indicate an increase of traffic volume over past years, the information was not accompanied by adequate activities in the domain of additional ATCOs' education and employment. Figure 57 shows a comparative overview of DCAC performance in respect to ATCOs' employment plans during a ten-year period. Thereby, for the purpose of analysis, an assumption was made that Cyprus' LSSIPs are more credible, in the sense of ATCOs employment, as their deployment period approaches (meaning that *n-1* year-based plans have been used as a reference source).

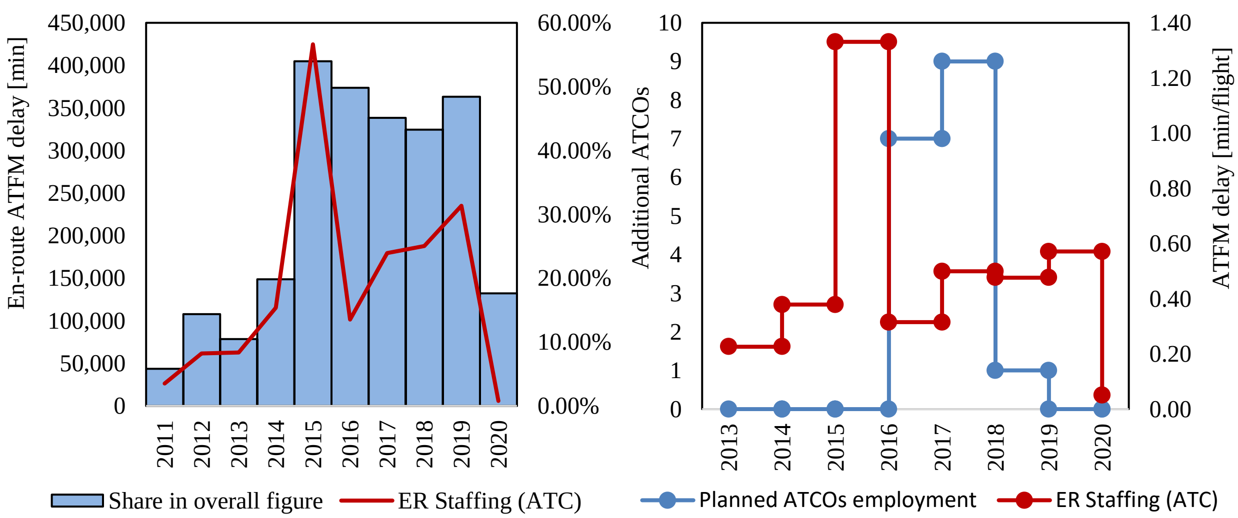


Figure 57. ATC staffing delay evolution with respect to ATCOs' employment plans [81,127]

From organisational and management aspect, DCAC can achieve further capacity improvement through better sector management, i.e., through change of the sector configuration as well as through increase of the number of sectors and higher flexibility in sector configuration openings. Figure 59 shows some of DCAC sector configurations. Furthermore, as DCAC represents an insignificant area from the aspect of airspace complexity [128], it should not spend efforts and resources in achieving capacity improvements by reducing the complexity figures. Moreover, even though it might result with a slight increase of airspace complexity and changes of patterns of air traffic flow, in case of DCAC the advantages of implementing the FRA concept (its deployment is foreseen to be realise by the end of 2022) outweigh its potential shortcomings (repercussions). Also, for the years Nicosia FIR represents mainly a transitional area, whereas the overflights in 2018 had a share of 77% of the overall figure [105]. Therefore, the efforts and resources invested in domain of the balancing the arrival and departure capacity for aerodrome operation (shown by Figure 58) would not deliver significant effect. Conversely, further capacity improvement should be strived to in the area of flight level management. Particularly in respect to the main air traffic flows shown by Figure 60. Last but not least, a significant capacity improvement can be expected after the reduction of the longitudinal separation minima. The application of satellite-based technology can be of great help in that respect.

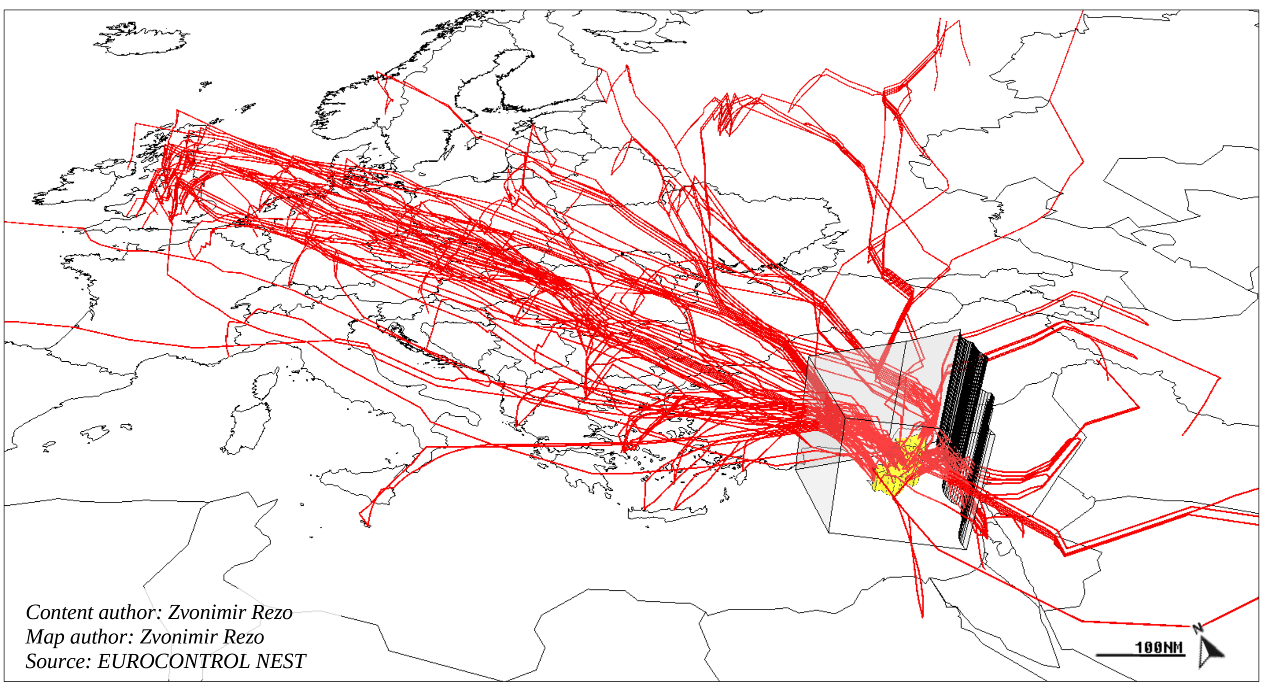
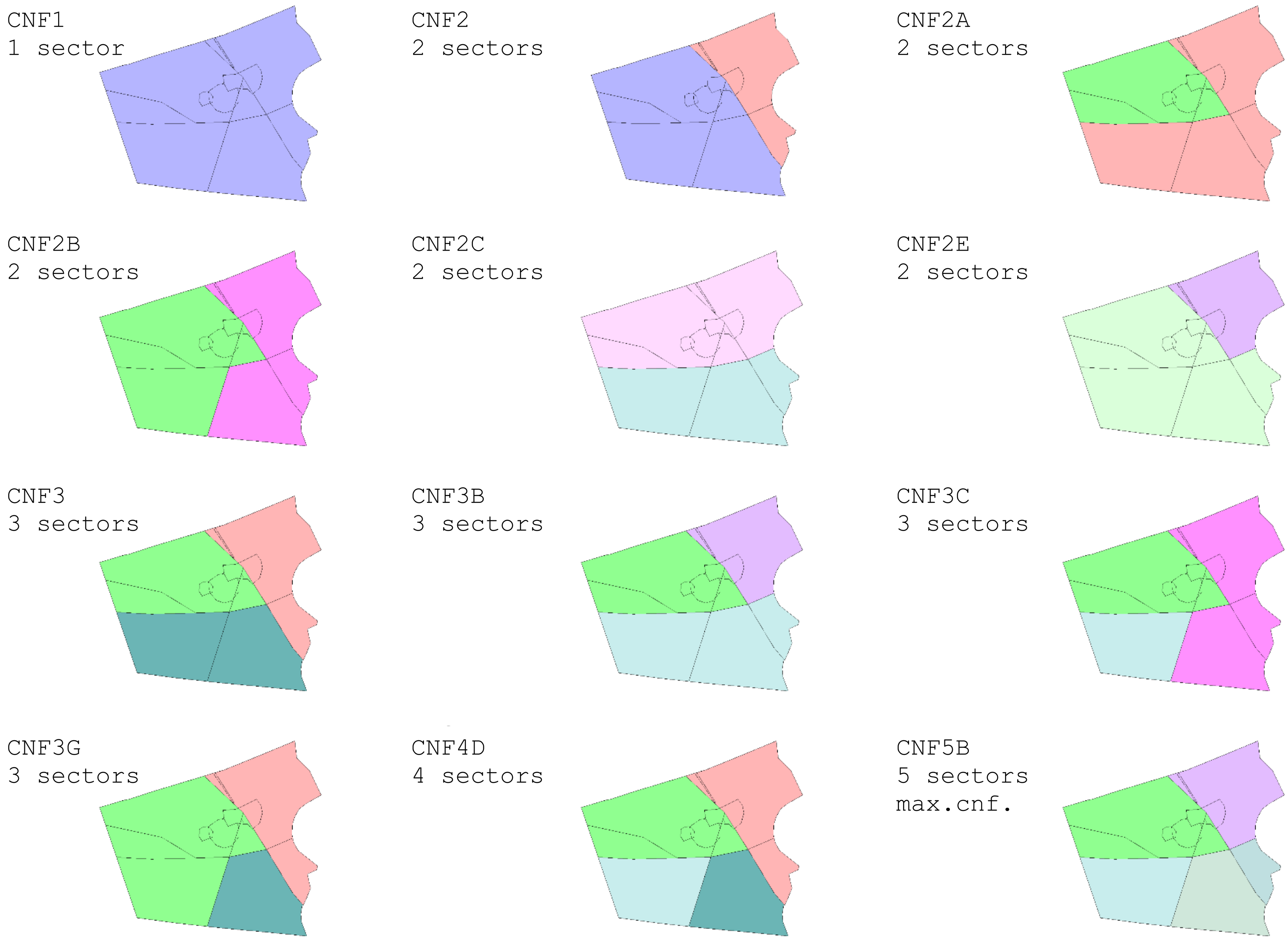


Figure 58. Spatial overview of international arr/dep flight patterns



Content author: Zvonimir Rezo
Map author: Zvonimir Rezo
Source: EUROCONTROL NEST

Figure 59. Overview of some of DCAC sector configurations

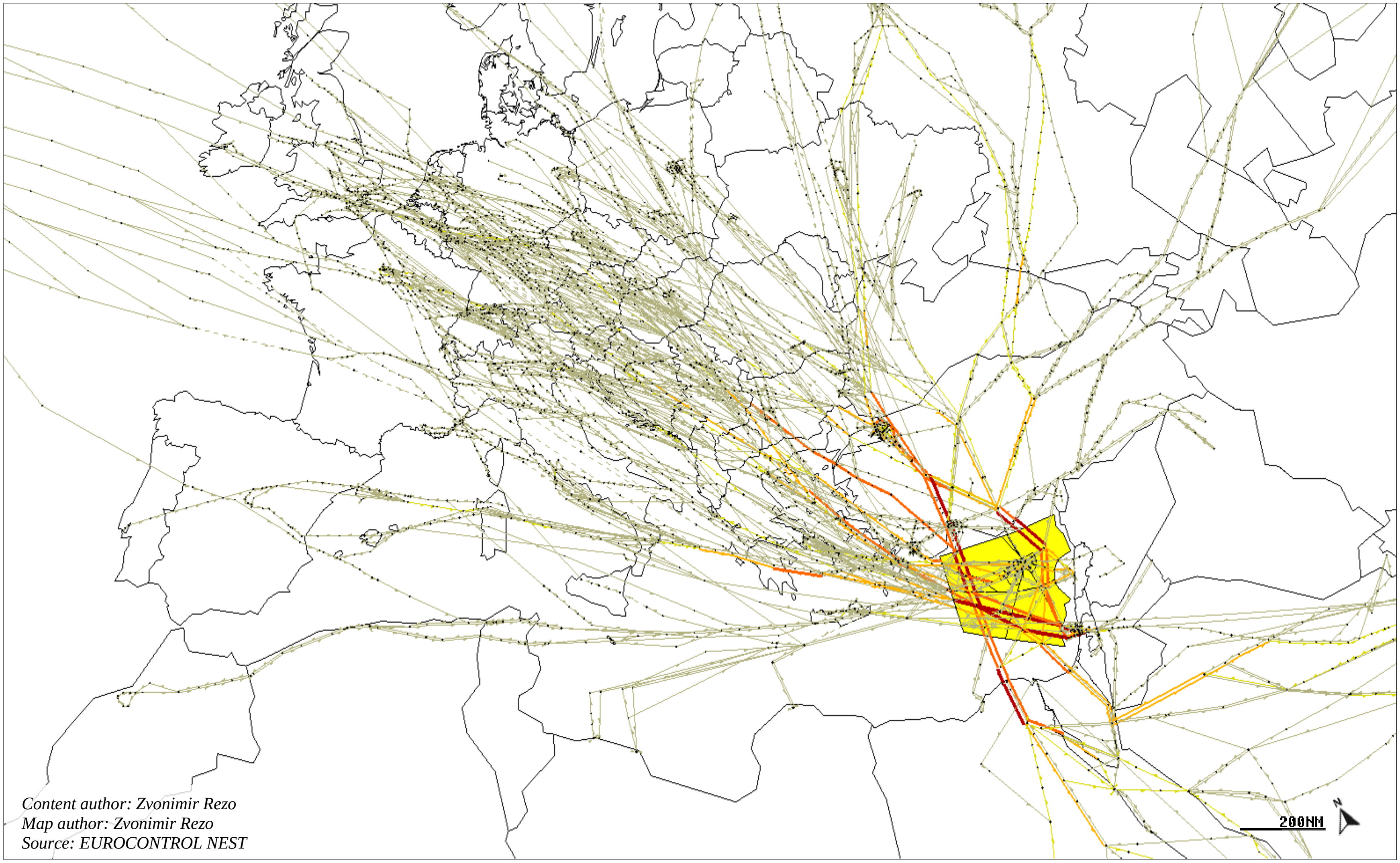


Figure 60. Spatial overview of Nicosia FIR with respect to its main air traffic flows and their segment loads

6. CONCLUSION

Since the ATM system in Europe represents a dynamic system characterized by its complexity and performance interdependencies, it is often the case that one needs to provide a simple, but comprehensive answer to a complex issue. Therefore, nowadays one of the most sought after and key skills required to perform strategic planning and development of the ATM system in Europe is the ability to manage the ever-growing streams of data and the ability to manipulate it by turning raw data into useful information and knowledge.

The issue of fragmented design of the European airspace has been officially recognized by the European Commission back in 1990s. Years later, in 2004, the European Commission initiated the establishment of the SES initiative. However, although reduction of airspace fragmentation has been one of the strategic determinants of planning and development of the ATM system in Europe ever since, minor progress has been achieved over time. Even now it remains unclear how to measure fragmentation and when airspace can be perceived as fragmented or defragmented. Accordingly, it a terminological, conceptual and methodological framework has not been set by which the notion of the European airspace fragmentation could be unambiguously defined and measured. Therefore, the main objective of this paper was to develop a model for assessing the European airspace fragmentation based on the spatial distribution of the values of performance indicators of the ATM system.

After model development, the further research interest was placed on the study of how fragmented the European airspace is from the performance-based aspect. More precisely, it was studied whether performance-based airspace fragmentation from a capacitive aspect is the result of a random spatial process, clustered pattern distribution or whether it is the result of a scattered patterns distribution. Later on, it was studied where and how performance-based airspace defragmentation can be achieved from capacitive aspect. Thereby, by studying performance-based airspace (de)fragmentation from a capacitive aspect it was also possible to observe its relationship with respect to organisational and operational settings of the ATM system in Europe, conceptual and methodological assumptions of the strategic planning and development framework of the ATM system in Europe as well with respect to various regional development agendas and national development plans. Also, it was possible to observe its cause-effect relationship with respect to regulatory framework introduced to support the realisation of the SES initiative. Performance trade-offs and performance interdependencies, potential benefits that can be expected as a result of the defragmentation process, but also threats standing in the way of the performance-based airspace defragmentation also represent topics that came alongside with the study of the performance-based airspace fragmentation from a capacitive aspect. In that respect, by applying an interdisciplinary research approach for the purpose of developing a novel model that overcomes conceptual, methodological and other shortcomings identified throughout literature review, and by its practical application in the case study, this paper enhances the knowledge level in the field of research.

Considering the obtained research findings in the context of strategic planning and development of the ATM system in Europe, it can be outlined that in order to contribute to the performance-based airspace defragmentation from a capacitive aspect, its conceptual and methodological assumptions need to be modified in a way that they more accurately reflect real-world. For instance, even though the ATM system in Europe is a highly interdependent system, its regulatory defined performance valorisation framework is based on the adoption of a methodological assumption of statistically independent observations. Moreover, even though the existence of spatial outliers undoubtedly has an adverse effect on the air traffic flow management, airspace capacity management and ANSPs performance in general, within the currently applicable performance valorisation framework it is irrelevant whether an ANSP represents a spatial outlier and deviates from neighbouring ANSPs, or whether it forms a pattern of spatially similar values. Also, causal-relationships between performance achievements, performance interdependencies, performance trade-off, goal conflicting situations etc. and their repercussions between ANSPs are not appropriately addressed, which also contributes to the existence of performance-based airspace fragmentation from a capacitive aspect.

Determining the spatial pattern of airspace fragmentation from the viewpoint of the impact on the airspace capacity is an important criterion in postulating guidelines on where and how to achieve defragmentation and increase airspace capacity. In that respect, the main research findings of the conducted case study indicate that in 2018 performance-based airspace fragmentation from a capacitive aspect was the result of a clustered spatial patterns distribution. Thereby, research results pointed out DCAC as a spatial outlier acting as the entry-exit bottleneck of the South East Axis. Therefore, it was selected as a spatial object where defragmentation capability will be tested. It was found out that from a capacitive aspect the European airspace would become defragmented if DCAC manages to decrease its 2018 en-route ATFM delay figure by at least 77.76%. By defragmenting airspace from a capacitive aspect, patterns distribution would become more clustered. In a broader sense, that would enable dissemination of a positive effect (the need for en-route ATFM reduction) to other adjacent spatial objects. Furthermore, as capacity improvement is linked with cost-efficiency and environment effects, to ensure that defragmentation from a capacitive aspect does not lead to the creation of fragmentation within other performance areas, performance trade-off situations were considered. Thereby, it was found out that airspace defragmentation from capacitive aspect would also deliver environmental (social) benefits. More precisely, it would deliver a reduction of 52,383,643.20 kilograms of carbon dioxide emissions, reduction of 20,570,973.54 kilograms of water vapour emissions and reduction of 13,968.97 kilograms of sulphur dioxide emissions.

In addition, it was found out that DCAC can increase its national en-route unit rate maximally for 30.65% with respect to the 2018 figure. It was determined that even though investment in capacity improvement would lead to an increase of the national en-route unit rate of DCAC, by adopting corrective measures as advised, on the annual level the AUs would save approximately EUR 19,343,841.66 in operating costs. Apart from that direct economic contribution to AUs enabled by performance-based airspace defragmentation, the multiplier effect of making performance improvement as specified also generates an economic contribution in other industries in the amount of EUR 62,867,485.40. As such, a total economic benefit of undertaking capacity improvement in AoR of DCAC brings approximately EUR 82,211,327.06. Accordingly, each euro invested would result with return of EUR 1.21 in form of direct economic contribution, EUR 3.94 in form of multiplier effect, whereas the overall return of each euro invested delivers EUR 5.15 in return. As such, the Return on Investment (ROI) varies from 21.26% for direct economic contribution, 294.10% for multiplied effect, to 415.37% for total economic contribution. Thereby, all estimations are based on the adoption of the assumption of maintaining the same level of traffic demand, i.e., number of service units, which makes the analyses comparable. In addition, it should be emphasised that the investment in capacity improvement can be perceived as economically feasible also because of the geographic position of DCAC within the ATM system in Europe. As a result of capacity improvement and its subsequent utilisation, the initial increase of the value of national en-route unit rate would decrease in the following years. As such, there is a high probability that the approximated ROIs could be even higher. Thereby, when time would come that the investment in additional capacity no longer meets the traffic demand and DCAC starts to generate significant amount of en-route ATFM delay, a re-learning process should be initiated (in addition to the process of continuous monitoring). Also, as DCAC is facing the chronic lack of ATCOs and since it takes three years to educate ATCOs, DCAC should use the post-COVID years to invest significantly in capacity improvements. Particularly as it is expected that by the 2025 traffic demand will recover and that demand for ANS delivery will reach the 2019 figures.

In the sense of the obtained research findings received through model application, it can be concluded that in 2018 performance-based airspace fragmentation from the capacity-based aspect was a result of the clustered patterns distribution. That indicates that in 2018 the spatial distribution of high values and/or low values in the data set is more spatially clustered than it would be expected if underlying spatial processes were random. In addition, it can be concluded that regulatory-determined performance targets, i.e., strategic goals from a capacitive aspect do not contribute to the European airspace defragmentation from a capacitive aspect because over the years regulatory-defined performance targets were over-promising and under-delivered.

As a result of the adoption of one-size-fits-all principle within performance target determination, across the ATM system in Europe there is significant share of ANSPs with significantly over-defined and under-defined performance targets. In that respect, an example of DCAC can be outlined. For instance, performance target set by the Performance Scheme for 2018 does not contribute to performance-based airspace defragmentation from a capacitive aspect because performance gap of 0.26 [min/flight] of the en-route ATFM delay would remain between the regulatory-required and a performance target that leads to performance-based airspace defragmentation. As such DCAC represents an example of spatial object with under-defined performance target.

Furthermore, the developed model opposes the existing regulatory framework in the sense of applied conceptual and methodological assumptions. Also, it differs from the frequently applied data manipulation framework. However, conceptual and methodological assumptions adopted within the process of model development combined with adequate research determinants reflect real-world, i.e., settings of the ATM system in Europe more conveniently than the currently applicable assumptions of strategic planning and development of the ATM system in Europe.

Lastly, this paper and its content are equally relevant from a scientific and professional aspect. It meets generally acceptable measurement characteristics, complements scientific literature in the field of research and provides new insights that can serve as basis for further industry development. Moreover, it facilitates evidence-based decision making and enables data-driven argumentations. In addition, the developed model is SES compatible as it enriches the SES postulates of the collaborative and coordinated airspace and air traffic flow management through determination of spatially optimal performance levels. Also, it contributes to the ultimate SES objective – to defragment the European airspace from a performance-based aspect. The relevance of the developed model also arises from the fact that it is of high importance to monitor performance changes occurring at regional and local level as they may also reflect on the strategic plans of the development of a national ATM system, and vice versa.

To sum up, it was determined that from the conceptual and methodological viewpoint, strategic planning and development of the ATM system in Europe needs to turn to research, development and application of novel conceptual and methodological assumptions, approaches, solutions and spatially-oriented performance indicators offering new perspectives. Apart from that, the framework of the strategic planning and development of the ATM system in Europe needs to undergo adjustments as the current regulatory framework does not contribute to the reduction of the performance-based airspace fragmentation. Primarily because the spatial feature of performance data, as well as the performance interdependencies between neighbouring ANSPs, are not taken into account when valorising the performance levels of the ANSPs and of the ATM system in Europe. As it was presented, the developed model better reflects the settings of the ATM system in Europe in relation to the often-applied methods and models because it takes into account the methodological assumption of spatially dependent observations. Therefore, it can be concluded that strategic planning and development of the ATM system at national, local and regional level in Europe can be further enhanced through utilization of the developed model. Primarily as it represents a solution that can analyse various sets of performance data relevant to the ATM system in Europe by simultaneously correlating all three features of performance data (attribute, temporal and spatial features). Therefore, in combination with adequate experience and knowledge in the field of research, model development and its subsequent application contribute to a more inclusive, smart, environmentally-friendly and spatially oriented future development of the ATM system in Europe.

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ABBREVATIONS

ACC – Area Control Centre
ANN – Artificial Neural Network
ANS – Air Navigation Service
ANSP – Air Navigation Service Provider
AoR – Area of Responsibility
ASM – Airspace Management
ATC – Air Traffic Control
ATCO – Air Traffic Control Officer
ATFM – Air Traffic Flow Management
ATM – Air Traffic Management
AU – Airspace User
CNF - Configuration
CTOT – Calculated Take-Off Time
D – Dangerous area
DCAC – Department of Civil Aviation of Cyprus
DFL – Division Flight Level
EC – European Commission
ECA – European Court of Auditors
ETOT – Estimated Take-Off Time
EU – European Union
EUR – European Monetary Unit
EUROCONTROL – European Organisation for the Safety of Air Navigation
FAB – Functional Airspace Block
FDP – Flight Data Processing system
FIR – Flight Information Region
FL – Flight Level
FMP – Flow Management Position
FP – Flight Plan
FRA – Free Route Airspace
FUA – Flexible Use of Airspace
GAT – General Air Traffic
H24 – 24 hours a day operation
IATA – International Air Transport Association
ICAO – International Civil Aviation Organization
IFPS – Integrated Initial Flight Plan Processing System
IFR – Instrument Flight Rules
KPA – Key Performance Area
KPI – Key Performance Indicator
LSSIP – Local Single Sky Implementation Plans
NM – Nautical Mile
NMOC – Network Manager Operations Centre
NOP – Network Operation Plan
OAT – Operational Air Traffic
OPS – Operations
P – Prohibited area
PRB – Performance Review Body
PRU – Performance Review Unit
R – Restricted area
R&D – Research and Development
RDP – Radar Data Processing system
ROI – Return on Investment
RP – Reference Period
SES – Single European Sky
SESAR – Single European Sky ATM Research
SJU – SESAR Joint Undertaking
SPI – Spatial Performance Indicator
TRA – Temporarily Reserved Area
TSA – Temporarily Segregated Area

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Appendix 1. Capacity based airspace fragmentation assessment results preview

Overview of the research results:

	Data share	Spatial share
1. European airspace clustering analysis		
1.1. Non-clustered airspace area:	65,79[%]	67,90[%]
1.2. Clustered airspace area:	34,21[%]	32,10[%]
2. European airspace critical areas analysis		
2.1. Very high critical value:	5,26[%]	11,86[%]
2.2. High critical value:	0,00[%]	0,00[%]
2.3. Medium high critical value:	2,63[%]	1,47[%]
2.4. Not significant area:	92,11[%]	86,66[%]
2.5. Medium low critical value:	0,00[%]	0,00[%]
2.6. Low critical value:	0,00[%]	0,00[%]
2.7. Very low critical value:	0,00[%]	0,00[%]
3. European airspace spatial outliers analysis		
3.1. High-High value:	18,42[%]	27,14[%]
3.2. High-Low value:	13,16[%]	8,65[%]
3.3. Low-Low value:	42,11[%]	39,12[%]
3.4. Low-High value:	26,32[%]	25,08[%]

1. European airspace clustering analysis

Airspace/ANSP	n.ANSPs	Value	LISA I(i)	GISA I(i)	E(i)
Albania	4	0	0,046046	0,230891	- 0,0270270
Armenia	2	0	0,410267	0,230891	- 0,0270270
Austria	7	0,66	0,280444	0,230891	- 0,0270270
Bulgaria	5	0	0,087350	0,230891	- 0,0270270
Croatia	4	0,61	- 0,177242	0,230891	- 0,0270270
Cyprus	3	1,1	- 0,133255	0,230891	- 0,0270270
Czech Republic	4	0,39	0,223923	0,230891	- 0,0270270
Denmark	5	0	- 0,429318	0,230891	- 0,0270270
Estonia	3	0,1	0,253180	0,230891	- 0,0270270
Finland	3	0	0,352692	0,230891	- 0,0270270
France	6	1,84	2,684115	0,230891	- 0,0270270
Georgia	2	0	0,410267	0,230891	- 0,0270270
Germany	8	1,72	1,832870	0,230891	- 0,0270270
Greece	7	0,53	- 0,123731	0,230891	- 0,0270270
Hungary	7	0,39	- 0,008122	0,230891	- 0,0270270
Ireland	1	0	- 0,002767	0,230891	- 0,0270270
Israel	1	0,21	- 0,330725	0,230891	- 0,0270270
Italy	9	0,03	- 0,244682	0,230891	- 0,0270270
Latvia	3	0,04	0,308046	0,230891	- 0,0270270
Lithuania	3	0	0,262576	0,230891	- 0,0270270
Maastricht	4	0,8	1,799030	0,230891	- 0,0270270
Malta	2	0	0,012253	0,230891	- 0,0270270
Moldova	2	0	0,342679	0,230891	- 0,0270270
Morocco	2	0,02	- 0,149333	0,230891	- 0,0270270
North Macedonia	4	0,17	0,049674	0,230891	- 0,0270270
Norway	4	0,01	0,294542	0,230891	- 0,0270270
Poland	6	0,25	- 0,021250	0,230891	- 0,0270270
Portugal	2	0,19	- 0,011175	0,230891	- 0,0270270
Romania	5	0,12	0,131610	0,230891	- 0,0270270
Serbia-Montenegro	7	0,3	- 0,006147	0,230891	- 0,0270270
Slovakia	5	0,21	- 0,020304	0,230891	- 0,0270270
Slovenia	4	0,01	- 0,194772	0,230891	- 0,0270270
Spain	3	0,6	0,642313	0,230891	- 0,0270270
Sweden	8	0,05	0,028747	0,230891	- 0,0270270
Switzerland	4	0,28	- 0,032926	0,230891	- 0,0270270
Turkey	6	0,03	0,022190	0,230891	- 0,0270270
Ukraine	6	0	0,182473	0,230891	- 0,0270270
United Kingdom	5	0,29	0,002322	0,230891	- 0,0270270
Data set arithmetic mean:		0,29	0,230891		
Standard deviation value:		0,44	0,093170		

Global Moran's I results summary

Moran's Index (I):	0,23089
Expected Index E(I):	- 0,02703
Variance Var[I]:	0,19186
z-score value:	2,76826
p-value:	0,00280

Input data frequency distribution table:

k	h	f	fi
1	0,000000 - 0,306667	28	0,73684
2	0,306667 - 0,613333	5	0,13158
3	0,613333 - 0,920000	2	0,05263
4	0,920000 - 1,226667	1	0,02632
5	1,226667 - 1,533333	0	0,00000
6	1,533333 - 1,840000	2	0,05263

LISA frequency distribution table:

k	h	f	fi
1	(- 0,429318) - 0,089588	22	0,57895
2	0,089588 - 0,608493	12	0,31579
3	0,608493 - 1,127399	1	0,02632
4	1,127399 - 1,646304	0	0,00000
5	1,646304 - 2,165209	2	0,05263
6	2,165209 - 2,684115	1	0,02632

Critical value frequency distribution table:

k	h	f	fi
1	< (-2,58)	0	0,00000
2	(-2,58) - (-1,96)	0	0,00000
3	(-1,96) - (-1,65)	0	0,00000
4	(-1,65) - 1,65	35	0,92105
5	1,65 - 1,96	1	0,02632
6	1,96 - 2,58	0	0,00000
7	> 2,58	2	0,05263

Neighboring values frequency distribution table:

k	h	f	fi
1	(- 0,623627) - (- 0,210779)	13	0,34211
2	(- 0,210779) - 0,202068	11	0,28947
3	0,202068 - 0,614915	7	0,18421
4	0,614915 - 1,027763	4	0,10526
5	1,027763 - 1,440610	0	0,00000
6	1,440610 - 1,853457	3	0,07895

2. European airspace focal areas analysis

Airspace/ANSP	Value	f(x)	z-score	f(z)	Indicator
Albania	0	0,733568	- 0,657872	0,321314	NIL
Armenia	0	0,733568	- 0,657872	0,321314	NIL
Austria	0,66	0,635226	0,848926	0,278239	NIL
Bulgaria	0	0,733568	- 0,657872	0,321314	NIL
Croatia	0,61	0,695320	0,734774	0,304561	NIL
Cyprus	1,1	0,163476	1,853457	0,071605	MHCV
Czech Republic	0,39	0,886507	0,232508	0,388303	NIL
Denmark	0	0,733568	- 0,657872	0,321314	NIL
Estonia	0,1	0,830522	- 0,429570	0,363781	NIL
Finland	0	0,733568	- 0,657872	0,321314	NIL
France	1,84	0,001713	3,542897	0,000750	VHCV
Georgia	0	0,733568	- 0,657872	0,321314	NIL
Germany	1,72	0,004355	3,268934	0,001908	VHCV
Greece	0,53	0,782031	0,552132	0,342541	NIL
Hungary	0,39	0,886507	0,232508	0,388303	NIL
Ireland	0	0,733568	- 0,657872	0,321314	NIL
Israel	0,21	0,896411	- 0,178437	0,392641	NIL
Italy	0,03	0,765580	- 0,589381	0,335335	NIL
Latvia	0,04	0,775749	- 0,566551	0,339790	NIL
Lithuania	0	0,733568	- 0,657872	0,321314	NIL
Maastricht	0,8	0,460156	1,168549	0,201555	NIL
Malta	0	0,733568	- 0,657872	0,321314	NIL
Moldova	0	0,733568	- 0,657872	0,321314	NIL
Morocco	0,02	0,755151	- 0,612212	0,330767	NIL
North Macedonia	0,17	0,878253	- 0,269758	0,384688	NIL
Norway	0,01	0,744475	- 0,635042	0,326091	NIL
Poland	0,25	0,907346	- 0,087115	0,397431	NIL
Portugal	0,19	0,888211	- 0,224097	0,389050	NIL
Romania	0,12	0,846090	- 0,383909	0,370600	NIL
Serbia-Montenegro	0,3	0,910463	0,027036	0,398797	NIL
Slovakia	0,21	0,896411	- 0,178437	0,392641	NIL
Slovenia	0,01	0,744475	- 0,635042	0,326091	NIL
Spain	0,6	0,706898	0,711944	0,309632	NIL
Sweden	0,05	0,785643	- 0,543721	0,344123	NIL
Switzerland	0,28	0,910638	- 0,018625	0,398873	NIL
Turkey	0,03	0,765580	- 0,589381	0,335335	NIL
Ukraine	0	0,733568	- 0,657872	0,321314	NIL
United Kingdom	0,29	0,910788	0,004206	0,398939	NIL

f(x)max value: 0,910796
f(z)max value: 0,398942

	n	Data share:	Spatial share:	Spatial size:
Very high critical value:	2	5,26[%]	11,86[%]	1400000[km^2]
High critical value:	0	0,00[%]	0,00[%]	0[km^2]
Medium high critical value:	1	2,63[%]	1,47[%]	174000[km^2]
Not significant area:	35	92,11[%]	86,66[%]	10226700[km^2]
Medium low critical value:	0	0,00[%]	0,00[%]	0[km^2]
Low critical value:	0	0,00[%]	0,00[%]	0[km^2]
Very low critical value:	0	0,00[%]	0,00[%]	0[km^2]

3. European airspace spatial outliers analysis

Airspace/ANSP	Value	z-score	Wz(i)	Indicator
Albania	0	- 0,657872	- 0,069993	LL
Armenia	0	- 0,657872	- 0,623627	LL
Austria	0,66	0,848926	0,330352	HH
Bulgaria	0	- 0,657872	- 0,132776	LL
Croatia	0,61	0,734774	- 0,241220	HL
Cyprus	1,1	1,853457	- 0,071895	HL
Czech Republic	0,39	0,232508	0,963077	HH
Denmark	0	- 0,657872	0,652585	LH
Estonia	0,1	- 0,429570	- 0,589381	LL
Finland	0	- 0,657872	- 0,536111	LL
France	1,84	3,542897	0,757604	HH
Georgia	0	- 0,657872	- 0,623627	LL
Germany	1,72	3,268934	0,560693	HH
Greece	0,53	0,552132	- 0,224097	HL
Hungary	0,39	0,232508	- 0,034932	HL
Ireland	0	- 0,657872	0,004206	LH
Israel	0,21	- 0,178437	1,853457	LH
Italy	0,03	- 0,589381	0,415150	LH
Latvia	0,04	- 0,566551	- 0,543721	LL
Lithuania	0	- 0,657872	- 0,399129	LL
Maastricht	0,8	1,168549	1,539541	HH
Malta	0	- 0,657872	- 0,018625	LL
Moldova	0	- 0,657872	- 0,520891	LL
Morocco	0,02	- 0,612212	0,243923	LH
North Macedonia	0,17	- 0,269758	- 0,184144	LL
Norway	0,01	- 0,635042	- 0,463815	LL
Poland	0,25	- 0,087115	0,243923	LH
Portugal	0,19	- 0,224097	0,049866	LH
Romania	0,12	- 0,383909	- 0,342815	LL
Serbia-Montenegro	0,3	0,027036	- 0,227359	HL
Slovakia	0,21	- 0,178437	0,113791	LH
Slovenia	0,01	- 0,635042	0,306707	LH
Spain	0,6	0,711944	0,902196	HH
Sweden	0,05	- 0,543721	- 0,052870	LL
Switzerland	0,28	- 0,018625	1,767844	LH
Turkey	0,03	- 0,589381	- 0,037650	LL
Ukraine	0	- 0,657872	- 0,277368	LL
United Kingdom	0,29	0,004206	0,552132	HH

	n	Data share:	Spatial share:	Spatial size:
High-High value:	7	18,42[%]	27,14[%]	3203200[km^2]
High-Low value:	5	13,16[%]	8,65[%]	1020600[km^2]
Low-Low value:	16	42,11[%]	39,12[%]	4617000[km^2]
Low-High value:	10	26,32[%]	25,08[%]	2959900[km^2]

4. Neighbouring samples similarity

Airspace/ANSP	(i,1)	(i,2)	(i,3)	(i,4)	(i,5)	(i,6)	(i,7)	(i,8)	(i,9)
Albania	LW	LG	LI	LY					
Armenia	UG	LT							
Austria	LK	LJ	ED	LH	LI	LZ	LS		
Bulgaria	LW	LG	LR	LY	LT				
Croatia	LJ	LH	LI	LY					
Cyprus	LG	LT	LL						
Czech Republic	LO	ED	EP	LZ					
Denmark	ED	EN	ES	EG	MUAC				
Estonia	EF	EV	ES						
Finland	EE	EN	ES						
France	ED	LI	LE	LS	EG	MUAC			
Georgia	UD	LT							
Germany	LO	LK	EK	LF	EP	ES	LS	MUAC	
Greece	LA	LB	LC	LW	LI	LM	LT		
Hungary	LO	LD	LJ	LR	LY	LZ	UK		
Ireland	EG								
Israel	LC								
Italy	LA	LO	LD	LJ	LF	LG	LM	LY	LS
Latvia	EE	EY	ES						
Lithuania	EV	EP	ES						
Maastricht	EK	LF	ED	EG					
Malta	LG	LI							
Moldova	LR	UK							
Morocco	LP	LE							
North Macedonia	LA	LB	LG	LY					
Norway	EK	EF	ES	EG					
Poland	LK	ED	EY	LZ	ES	UK			
Portugal	LE	GM							
Romania	LB	LH	LU	LY	UK				
Serbia-Montenegro	LA	LB	LD	LW	LH	LI	LR		
Slovakia	LO	LK	LH	EP	UK				
Slovenia	LO	LD	LH	LI					
Spain	LF	LP	GM						
Sweden	EK	EE	EF	ED	EV	EY	EN	EP	
Switzerland	LO	LF	ED	LI					
Turkey	UD	LB	LC	UG	LG	UK			
Ukraine	LH	LU	EP	LR	LZ	LT			
United Kingdom	EK	LF	EI	EN	MUAC				

Airspace/ANSP	(i,1)	(i,2)	(i,3)	(i,4)	(i,5)	(i,6)	(i,7)	(i,8)	(i,9)	r[%]
Albania	0,00	0,00	0,00	0,00						0,00
Armenia	0,00	0,00								0,00
Austria	0,59	0,02	0,38	0,59	0,05	0,32	0,42			0,34
Bulgaria	0,00	0,00	0,00	0,00	0,00					0,00
Croatia	0,02	0,64	0,05	0,49						0,30
Cyprus	0,48	0,03	0,19							0,23
Czech Republic	0,59	0,23	0,64	0,54						0,50
Denmark	0,00	0,00	0,00	0,00	0,00					0,00
Estonia	0,00	0,40	0,50							0,30
Finland	0,00	0,00	0,00							0,00
France	0,93	0,02	0,33	0,15	0,16	0,43				0,34
Georgia	0,00	0,00								0,00
Germany	0,38	0,23	0,00	0,93	0,15	0,03	0,16	0,47		0,29
Greece	0,00	0,00	0,48	0,32	0,06	0,00	0,06			0,13
Hungary	0,59	0,64	0,03	0,31	0,77	0,54	0,00			0,41
Ireland	0,00									0,00
Israel	0,19									0,19
Italy	0,00	0,05	0,05	0,33	0,02	0,06	0,00	0,10	0,11	0,08
Latvia	0,40	0,00	0,80							0,40
Lithuania	0,00	0,00	0,00							0,00
Maastricht	0,00	0,43	0,47	0,36						0,32
Malta	0,00	0,00								0,00
Moldova	0,00	0,00								0,00
Morocco	0,11	0,03								0,07
North Macedonia	0,00	0,00	0,32	0,57						0,22
Norway	0,00	0,00	0,20	0,03						0,06
Poland	0,64	0,15	0,00	0,84	0,20	0,00				0,30
Portugal	0,32	0,11								0,21
Romania	0,00	0,31	0,00	0,40	0,00					0,14
Serbia-Montenegro	0,00	0,00	0,49	0,57	0,77	0,10	0,40			0,33
Slovakia	0,32	0,54	0,54	0,84	0,00					0,45
Slovenia	0,02	0,02	0,03	0,33						0,10
Spain	0,33	0,32	0,03							0,23
Sweden	0,00	0,50	0,00	0,03	0,80	0,00	0,20	0,20		0,22
Switzerland	0,42	0,15	0,16	0,11						0,21
Turkey	0,00	0,00	0,03	0,00	0,06	0,00				0,01
Ukraine	0,00	0,00	0,00	0,00	0,00	0,00				0,00
United Kingdom	0,00	0,16	0,00	0,03	0,36					0,11
Average neighbouring samples similarity:										0,17

Appendix 2. Capacity based airspace defragmentation assessment results preview

Overview of the research results:

	Data share	Spatial share
1. European airspace clustering analysis		
1.1. Non-clustered airspace area:	71,05[%]	74,92[%]
1.2. Clustered airspace area:	28,95[%]	25,08[%]
2. European airspace critical areas analysis		
2.1. Very high critical value:	5,26[%]	11,86[%]
2.2. High critical value:	0,00[%]	0,00[%]
2.3. Medium high critical value:	0,00[%]	0,00[%]
2.4. Not significant area:	94,74[%]	88,14[%]
2.5. Medium low critical value:	0,00[%]	0,00[%]
2.6. Low critical value:	0,00[%]	0,00[%]
2.7. Very low critical value:	0,00[%]	0,00[%]
3. European airspace spatial outliers analysis		
3.1. High-High value:	23,68[%]	28,52[%]
3.2. High-Low value:	7,89[%]	6,39[%]
3.3. Low-Low value:	44,74[%]	38,83[%]
3.4. Low-High value:	23,68[%]	26,26[%]

1. European airspace clustering analysis

Airspace/ANSP	n.ANSPs	Value	LISA I(i)	GISA I(i)	E(i)
Albania	4	0	0,012509	0,273456	- 0,0270270
Armenia	2	0	0,382687	0,273456	- 0,0270270
Austria	7	0,66	0,378693	0,273456	- 0,0270270
Bulgaria	5	0	0,054488	0,273456	- 0,0270270
Croatia	4	0,61	- 0,164572	0,273456	- 0,0270270
Cyprus	3	0,2464	0,001001	0,273456	- 0,0270270
Czech Republic	4	0,39	0,317312	0,273456	- 0,0270270
Denmark	5	0	- 0,470630	0,273456	- 0,0270270
Estonia	3	0,1	0,224375	0,273456	- 0,0270270
Finland	3	0	0,324171	0,273456	- 0,0270270
France	6	1,84	3,204664	0,273456	- 0,0270270
Georgia	2	0	0,382687	0,273456	- 0,0270270
Germany	8	1,72	2,239731	0,273456	- 0,0270270
Greece	7	0,53	- 0,300118	0,273456	- 0,0270270
Hungary	7	0,39	0,005115	0,273456	- 0,0270270
Ireland	1	0	- 0,037102	0,273456	- 0,0270270
Israel	1	0,21	0,006174	0,273456	- 0,0270270
Italy	9	0,03	- 0,276659	0,273456	- 0,0270270
Latvia	3	0,04	0,279690	0,273456	- 0,0270270
Lithuania	3	0	0,232581	0,273456	- 0,0270270
Maastricht	4	0,8	2,139030	0,273456	- 0,0270270
Malta	2	0	- 0,021837	0,273456	- 0,0270270
Moldova	2	0	0,313995	0,273456	- 0,0270270
Morocco	2	0,02	- 0,182527	0,273456	- 0,0270270
North Macedonia	4	0,17	0,031995	0,273456	- 0,0270270
Norway	4	0,01	0,265450	0,273456	- 0,0270270
Poland	6	0,25	- 0,011660	0,273456	- 0,0270270
Portugal	2	0,19	- 0,019268	0,273456	- 0,0270270
Romania	5	0,12	0,106889	0,273456	- 0,0270270
Serbia-Montenegro	7	0,3	- 0,015201	0,273456	- 0,0270270
Slovakia	5	0,21	- 0,023137	0,273456	- 0,0270270
Slovenia	4	0,01	- 0,230355	0,273456	- 0,0270270
Spain	3	0,6	0,802158	0,273456	- 0,0270270
Sweden	8	0,05	0,000861	0,273456	- 0,0270270
Switzerland	4	0,28	0,065488	0,273456	- 0,0270270
Turkey	6	0,03	0,184563	0,273456	- 0,0270270
Ukraine	6	0	0,151167	0,273456	- 0,0270270
United Kingdom	5	0,29	0,036908	0,273456	- 0,0270270
Data set arithmetic mean:		0,27	0,273456		
Standard deviation value:		0,42	0,090409		

*n.ANSPs - Number of neighbouring Air Navigation Service Providers (ANSPs)
*LISA - Local Indicator of Spatial Autocorrelation
*GISA - Global Indicator of Spatial Autocorrelation

Global Moran's I results summary

Moran's Index (I):	0,27346
Expected Index E(I):	- 0,02703
Variance Var[I]:	0,17405
z-score value:	3,32361
p-value:	0,00045

Input data frequency distribution table:

k	h	f	fi
1	0,000000 - 0,306667	29	0,76316
2	0,306667 - 0,613333	5	0,13158
3	0,613333 - 0,920000	2	0,05263
4	0,920000 - 1,226667	0	0,00000
5	1,226667 - 1,533333	0	0,00000
6	1,533333 - 1,840000	2	0,05263

LISA frequency distribution table:

k	h	f	fi
1	(- 0,470630) - 0,141919	22	0,57895
2	0,141919 - 0,754468	12	0,31579
3	0,754468 - 1,367017	1	0,02632
4	1,367017 - 1,979566	0	0,00000
5	1,979566 - 2,592115	2	0,05263
6	2,592115 - 3,204664	1	0,02632

Critical value frequency distribution table:

k	h	f	fi
1	< (-2,58)	0	0,00000
2	(-2,58) - (-1,96)	0	0,00000
3	(-1,96) - (-1,65)	0	0,00000
4	(-1,65) - 1,65	36	0,94737
5	1,65 - 1,96	0	0,00000
6	1,96 - 2,58	0	0,00000
7	> 2,58	2	0,05263

Neighbouring values frequency distribution table:

k	h	f	fi
1	(- 0,600901) - (- 0,182435)	14	0,36842
2	(- 0,182435) - 0,236032	11	0,28947
3	0,236032 - 0,654498	7	0,18421
4	0,654498 - 1,072965	4	0,10526
5	1,072965 - 1,491431	0	0,00000
6	1,491431 - 1,909898	2	0,05263

2. European airspace focal areas analysis

Airspace/ANSP	Value	f(x)	z-score	f(z)	Indicator
Albania	0	0,780722	- 0,636856	0,325715	NIL
Armenia	0	0,780722	- 0,636856	0,325715	NIL
Austria	0,66	0,611783	0,945128	0,255235	NIL
Bulgaria	0	0,780722	- 0,636856	0,325715	NIL
Croatia	0,61	0,680255	0,825281	0,283801	NIL
Cyprus	0,2464	0,955220	- 0,046248	0,398516	NIL
Czech Republic	0,39	0,914725	0,297953	0,381621	NIL
Denmark	0	0,780722	- 0,636856	0,325715	NIL
Estonia	0,1	0,883722	- 0,397161	0,368687	NIL
Finland	0	0,780722	- 0,636856	0,325715	NIL
France	1,84	0,000774	3,773522	0,000323	VHCV
Georgia	0	0,780722	- 0,636856	0,325715	NIL
Germany	1,72	0,002197	3,485889	0,000917	VHCV
Greece	0,53	0,782375	0,633525	0,326405	NIL
Hungary	0,39	0,914725	0,297953	0,381621	NIL
Ireland	0	0,780722	- 0,636856	0,325715	NIL
Israel	0,21	0,947760	- 0,133497	0,395403	NIL
Italy	0,03	0,815196	- 0,564947	0,340098	NIL
Latvia	0,04	0,826073	- 0,540978	0,344636	NIL
Lithuania	0	0,780722	- 0,636856	0,325715	NIL
Maastricht	0,8	0,421119	1,280700	0,175690	NIL
Malta	0	0,780722	- 0,636856	0,325715	NIL
Moldova	0	0,780722	- 0,636856	0,325715	NIL
Morocco	0,02	0,804001	- 0,588917	0,335427	NIL
North Macedonia	0,17	0,931415	- 0,229375	0,388584	NIL
Norway	0,01	0,792503	- 0,612886	0,330631	NIL
Poland	0,25	0,955566	- 0,037619	0,398660	NIL
Portugal	0,19	0,940632	- 0,181436	0,392430	NIL
Romania	0,12	0,899675	- 0,349222	0,375342	NIL
Serbia-Montenegro	0,3	0,953015	0,082228	0,397596	NIL
Slovakia	0,21	0,947760	- 0,133497	0,395403	NIL
Slovenia	0,01	0,792503	- 0,612886	0,330631	NIL
Spain	0,6	0,693646	0,801311	0,289388	NIL
Sweden	0,05	0,836614	- 0,517008	0,349034	NIL
Switzerland	0,28	0,955681	0,034289	0,398708	NIL
Turkey	0,03	0,815196	- 0,564947	0,340098	NIL
Ukraine	0	0,780722	- 0,636856	0,325715	NIL
United Kingdom	0,29	0,954621	0,058258	0,398266	NIL

f(x)max value: 0,956242
f(z)max value: 0,398942

	n	Data share:	Spatial share:	Spatial size:
Very high critical value:	2	5,26[%]	11,86[%]	1400000[km^2]
High critical value:	0	0,00[%]	0,00[%]	0[km^2]
Medium high critical value:	0	0,00[%]	0,00[%]	0[km^2]
Not significant area:	36	94,74[%]	88,14[%]	10400700[km^2]
Medium low critical value:	0	0,00[%]	0,00[%]	0[km^2]
Low critical value:	0	0,00[%]	0,00[%]	0[km^2]
Very low critical value:	0	0,00[%]	0,00[%]	0[km^2]

3. European airspace spatial outliers analysis

Airspace/ANSP	Value	z-score	Wz(i)	Indicator
Albania	0	- 0,636856	- 0,019642	LL
Armenia	0	- 0,636856	- 0,600901	LL
Austria	0,66	0,945128	0,400679	HH
Bulgaria	0	- 0,636856	- 0,085558	LL
Croatia	0,61	0,825281	- 0,199413	HL
Cyprus	0,2464	- 0,046248	- 0,021640	LL
Czech Republic	0,39	0,297953	1,064975	HH
Denmark	0	- 0,636856	0,738991	LH
Estonia	0,1	- 0,397161	- 0,564947	LL
Finland	0	- 0,636856	- 0,509018	LL
France	1,84	3,773522	0,849250	HH
Georgia	0	- 0,636856	- 0,600901	LL
Germany	1,72	3,485889	0,642514	HH
Greece	0,53	0,633525	- 0,473726	HL
Hungary	0,39	0,297953	0,017168	HH
Ireland	0	- 0,636856	0,058258	LH
Israel	0,21	- 0,133497	- 0,046248	LL
Italy	0,03	- 0,564947	0,489708	LH
Latvia	0,04	- 0,540978	- 0,517008	LL
Lithuania	0	- 0,636856	- 0,365202	LL
Maastricht	0,8	1,280700	1,670204	HH
Malta	0	- 0,636856	0,034289	LH
Moldova	0	- 0,636856	- 0,493039	LL
Morocco	0,02	- 0,588917	0,309938	LH
North Macedonia	0,17	- 0,229375	- 0,139490	LL
Norway	0,01	- 0,612886	- 0,433115	LL
Poland	0,25	- 0,037619	0,309938	LH
Portugal	0,19	- 0,181436	0,106197	LH
Romania	0,12	- 0,349222	- 0,306077	LL
Serbia-Montenegro	0,3	0,082228	- 0,184860	HL
Slovakia	0,21	- 0,133497	0,173312	LH
Slovenia	0,01	- 0,612886	0,375854	LH
Spain	0,6	0,801311	1,001057	HH
Sweden	0,05	- 0,517008	- 0,001665	LL
Switzerland	0,28	0,034289	1,909898	HH
Turkey	0,03	- 0,564947	- 0,326691	LL
Ukraine	0	- 0,636856	- 0,237365	LL
United Kingdom	0,29	0,058258	0,633525	HH

	n	Data share:	Spatial share:	Spatial size:
High-High value:	9	23,68[%]	28,52[%]	3365500[km^2]
High-Low value:	3	7,89[%]	6,39[%]	754000[km^2]
Low-Low value:	17	44,74[%]	38,83[%]	4582100[km^2]
Low-High value:	9	23,68[%]	26,26[%]	3099100[km^2]

4. Neighbouring samples similarity

Airspace/ANSP	(i,1)	(i,2)	(i,3)	(i,4)	(i,5)	(i,6)	(i,7)	(i,8)	(i,9)
Albania	LW	LG	LI	LY					
Armenia	UG	LT							
Austria	LK	LJ	ED	LH	LI	LZ	LS		
Bulgaria	LW	LG	LR	LY	LT				
Croatia	LJ	LH	LI	LY					
Cyprus	LG	LT	LL						
Czech Republic	LO	ED	EP	LZ					
Denmark	ED	EN	ES	EG	MUAC				
Estonia	EF	EV	ES						
Finland	EE	EN	ES						
France	ED	LI	LE	LS	EG	MUAC			
Georgia	UD	LT							
Germany	LO	LK	EK	LF	EP	ES	LS	MUAC	
Greece	LA	LB	LC	LW	LI	LM	LT		
Hungary	LO	LD	LJ	LR	LY	LZ	UK		
Ireland	EG								
Israel	LC								
Italy	LA	LO	LD	LJ	LF	LG	LM	LY	LS
Latvia	EE	EY	ES						
Lithuania	EV	EP	ES						
Maastricht	EK	LF	ED	EG					
Malta	LG	LI							
Moldova	LR	UK							
Morocco	LP	LE							
North Macedonia	LA	LB	LG	LY					
Norway	EK	EF	ES	EG					
Poland	LK	ED	EY	LZ	ES	UK			
Portugal	LE	GM							
Romania	LB	LH	LU	LY	UK				
Serbia-Montenegro	LA	LB	LD	LW	LH	LI	LR		
Slovakia	LO	LK	LH	EP	UK				
Slovenia	LO	LD	LH	LI					
Spain	LF	LP	GM						
Sweden	EK	EE	EF	ED	EV	EY	EN	EP	
Switzerland	LO	LF	ED	LI					
Turkey	UD	LB	LC	UG	LG	UK			
Ukraine	LH	LU	EP	LR	LZ	LT			
United Kingdom	EK	LF	EI	EN	MUAC				

Airspace/ANSP	(i,1)	(i,2)	(i,3)	(i,4)	(i,5)	(i,6)	(i,7)	(i,8)	(i,9)	r[%]
Albania	0,00	0,00	0,00	0,00						0,00
Armenia	0,00	0,00								0,00
Austria	0,59	0,02	0,38	0,59	0,05	0,32	0,42			0,34
Bulgaria	0,00	0,00	0,00	0,00	0,00					0,00
Croatia	0,02	0,64	0,05	0,49						0,30
Cyprus	0,46	0,12	0,85							0,48
Czech Republic	0,59	0,23	0,64	0,54						0,50
Denmark	0,00	0,00	0,00	0,00	0,00					0,00
Estonia	0,00	0,40	0,50							0,30
Finland	0,00	0,00	0,00							0,00
France	0,93	0,02	0,33	0,15	0,16	0,43				0,34
Georgia	0,00	0,00								0,00
Germany	0,38	0,23	0,00	0,93	0,15	0,03	0,16	0,47		0,29
Greece	0,00	0,00	0,46	0,32	0,06	0,00	0,06			0,13
Hungary	0,59	0,64	0,03	0,31	0,77	0,54	0,00			0,41
Ireland	0,00									0,00
Israel	0,85									0,85
Italy	0,00	0,05	0,05	0,33	0,02	0,06	0,00	0,10	0,11	0,08
Latvia	0,40	0,00	0,80							0,40
Lithuania	0,00	0,00	0,00							0,00
Maastricht	0,00	0,43	0,47	0,36						0,32
Malta	0,00	0,00								0,00
Moldova	0,00	0,00								0,00
Morocco	0,11	0,03								0,07
North Macedonia	0,00	0,00	0,32	0,57						0,22
Norway	0,00	0,00	0,20	0,03						0,06
Poland	0,64	0,15	0,00	0,84	0,20	0,00				0,30
Portugal	0,32	0,11								0,21
Romania	0,00	0,31	0,00	0,40	0,00					0,14
Serbia-Montenegro	0,00	0,00	0,49	0,57	0,77	0,10	0,40			0,33
Slovakia	0,32	0,54	0,54	0,84	0,00					0,45
Slovenia	0,02	0,02	0,03	0,33						0,10
Spain	0,33	0,32	0,03							0,23
Sweden	0,00	0,50	0,00	0,03	0,80	0,00	0,20	0,20		0,22
Switzerland	0,42	0,15	0,16	0,11						0,21
Turkey	0,00	0,00	0,12	0,00	0,06	0,00				0,03
Ukraine	0,00	0,00	0,00	0,00	0,00	0,00				0,00
United Kingdom	0,00	0,16	0,00	0,03	0,36					0,11
Average neighbouring samples similarity:										0,20

Appendix 3. Cost-efficiency based airspace fragmentation assessment results preview

Overview of the research results:

	Data share	Spatial share
1. European airspace clustering analysis		
1.1. Non-clustered airspace area:	59,52[%]	66,26[%]
1.2. Clustered airspace area:	40,48[%]	33,74[%]
2. European airspace critical areas analysis		
2.1. Very high critical value:	2,38[%]	0,37[%]
2.2. High critical value:	0,00[%]	0,00[%]
2.3. Medium high critical value:	2,38[%]	3,86[%]
2.4. Not significant area:	92,86[%]	68,47[%]
2.5. Medium low critical value:	2,38[%]	27,31[%]
2.6. Low critical value:	0,00[%]	0,00[%]
2.7. Very low critical value:	0,00[%]	0,00[%]
3. European airspace spatial outliers analysis		
3.1. High-High value:	30,95[%]	21,85[%]
3.2. High-Low value:	11,90[%]	14,02[%]
3.3. Low-Low value:	33,33[%]	23,46[%]
3.4. Low-High value:	23,81[%]	40,67[%]

1. European airspace clustering analysis

Airspace/ANSP	n.ANSPs	Value	LISA I(i)	GISA I(i)	E(i)
Portugal-S. Maria	3	9,52	- 0,912732	0,306386	- 0,0243902
Belgium	4	67,79	1,192595	0,306386	- 0,0243902
Germany	9	67,2	1,030235	0,306386	- 0,0243902
Estonia	3	28,79	- 0,041278	0,306386	- 0,0243902
Finland	3	54,92	- 0,070212	0,306386	- 0,0243902
United Kingdom	6	68,03	0,506829	0,306386	- 0,0243902
Netherlands	4	58,83	0,759313	0,306386	- 0,0243902
Ireland	1	27,82	- 1,136172	0,306386	- 0,0243902
Denmark	5	59,71	0,533268	0,306386	- 0,0243902
Norway	4	43,23	- 0,095567	0,306386	- 0,0243902
Poland	6	43,39	- 0,032438	0,306386	- 0,0243902
Sweden	8	56,8	0,015762	0,306386	- 0,0243902
Latvia	4	27,6	0,126390	0,306386	- 0,0243902
Lithuania	4	43,72	0,015068	0,306386	- 0,0243902
Spain-Canarias	3	56,74	- 0,534225	0,306386	- 0,0243902
Albania	4	49,23	0,036359	0,306386	- 0,0243902
Bulgaria	5	26,72	0,588914	0,306386	- 0,0243902
Cyprus	3	35,08	0,649840	0,306386	- 0,0243902
Croatia	5	44,47	- 0,012534	0,306386	- 0,0243902
Spain	4	69,67	- 0,555243	0,306386	- 0,0243902
France	6	63,61	1,509249	0,306386	- 0,0243902
Greece	8	31,6	0,327344	0,306386	- 0,0243902
Hungary	6	32,3	- 0,133480	0,306386	- 0,0243902
Italy	9	80,11	0,631516	0,306386	- 0,0243902
Slovenia	4	61,84	0,533555	0,306386	- 0,0243902
Czech Republic	4	42,18	- 0,124451	0,306386	- 0,0243902
Malta	2	16,02	- 0,865694	0,306386	- 0,0243902
Austria	7	71,48	1,192962	0,306386	- 0,0243902
Portugal	4	36,97	0,039972	0,306386	- 0,0243902
Bosnia and Herz.	2	40,68	0,096741	0,306386	- 0,0243902
Romania	4	32,36	0,298010	0,306386	- 0,0243902
Switzerland	4	96,88	3,658287	0,306386	- 0,0243902
Turkey	5	24,56	1,000634	0,306386	- 0,0243902
Moldova	1	58,82	- 0,498791	0,306386	- 0,0243902
North Macedonia	4	51,75	- 0,184433	0,306386	- 0,0243902
Serbia-Montenegro	8	32,82	0,031797	0,306386	- 0,0243902
Slovakia	4	51,66	0,030515	0,306386	- 0,0243902
Armenia	2	29,83	1,020321	0,306386	- 0,0243902
Georgia	2	21,12	1,281154	0,306386	- 0,0243902
Morocco	3	39,86	- 0,144721	0,306386	- 0,0243902
Egypt	2	15,4	1,052343	0,306386	- 0,0243902
Belarus	3	43,13	0,051190	0,306386	- 0,0243902
Data set arithmetic mean:		45,58	0,306386		
Standard deviation value:		18,73	0,096745		

*n.ANSPs - Number of neighbouring Air Navigation Service Providers (ANSPs)
*LISA - Local Indicator of Spatial Autocorrelation
*GISA - Global Indicator of Spatial Autocorrelation

Global Moran's I results summary

Moran's Index (I):	0,30639
Expected Index E(I):	- 0,02439
Variance Var[I]:	350,91396
z-score value:	3,41906
p-value:	0,00031

Input data frequency distribution table:

k	h	f	fi
1	9,520000 - 24,080000	4	0,09524
2	24,080000 - 38,640000	12	0,28571
3	38,640000 - 53,200000	11	0,26190
4	53,200000 - 67,760000	9	0,21429
5	67,760000 - 82,320000	5	0,11905
6	82,320000 - 96,880000	1	0,02381

LISA frequency distribution table:

k	h	f	fi
1	(- 1,136172) - (- 0,337095)	6	0,14286
2	(- 0,337095) - 0,461981	20	0,47619
3	0,461981 - 1,261058	13	0,30952
4	1,261058 - 2,060134	2	0,04762
5	2,060134 - 2,859211	0	0,00000
6	2,859211 - 3,658287	1	0,02381

Critical value frequency distribution table:

k	h	f	fi
1	< (-2,58)	0	0,00000
2	(-2,58) - (-1,96)	0	0,00000
3	(-1,96) - (-1,65)	1	0,02381
4	(-1,65) - 1,65	39	0,92857
5	1,65 - 1,96	1	0,02381
6	1,96 - 2,58	0	0,00000
7	> 2,58	1	0,02381

Neighboring values frequency distribution table:

k	h	f	fi
1	(- 1,213768) - (- 0,750169)	5	0,11905
2	(- 0,750169) - (- 0,286571)	9	0,21429
3	(- 0,286571) - 0,177027	8	0,19048
4	0,177027 - 0,640625	10	0,23810
5	0,640625 - 1,104223	7	0,16667
6	1,104223 - 1,567821	2	0,04762

2. European airspace focal areas analysis

Airspace/ANSP	Value	f(x)	z-score	f(z)	Indicator
Portugal-S. Maria	9,52	0,003340	- 1,924824	0,062574	MLCV
Belgium	67,79	0,010543	1,185780	0,197508	NIL
Germany	67,2	0,010939	1,154284	0,204922	NIL
Estonia	28,79	0,014254	- 0,896141	0,267009	NIL
Finland	54,92	0,018806	0,498746	0,352286	NIL
United Kingdom	68,03	0,010384	1,198592	0,194514	NIL
Netherlands	58,83	0,016582	0,707472	0,310616	NIL
Ireland	27,82	0,013589	- 0,947922	0,254560	NIL
Denmark	59,71	0,016022	0,754449	0,300131	NIL
Norway	43,23	0,021130	- 0,125297	0,395823	NIL
Poland	43,39	0,021152	- 0,116755	0,396232	NIL
Sweden	56,8	0,017798	0,599105	0,333403	NIL
Latvia	27,6	0,013438	- 0,959667	0,251725	NIL
Lithuania	43,72	0,021192	- 0,099139	0,396987	NIL
Spain-Canarias	56,74	0,017832	0,595902	0,334042	NIL
Albania	49,23	0,020896	0,194999	0,391429	NIL
Bulgaria	26,72	0,012831	- 1,006643	0,240363	NIL
Cyprus	35,08	0,018202	- 0,560365	0,340976	NIL
Croatia	44,47	0,021259	- 0,059102	0,398246	NIL
Spain	69,67	0,009314	1,286139	0,174468	NIL
France	63,61	0,013399	0,962641	0,251006	NIL
Greece	31,6	0,016122	- 0,746136	0,302009	NIL
Hungary	32,3	0,016566	- 0,708768	0,310331	NIL
Italy	80,11	0,003894	1,843453	0,072941	MHCV
Slovenia	61,84	0,014610	0,868154	0,273683	NIL
Czech Republic	42,18	0,020949	- 0,181348	0,392436	NIL
Malta	16,02	0,006133	- 1,577837	0,114897	NIL
Austria	71,48	0,008187	1,382762	0,153362	NIL
Portugal	36,97	0,019163	- 0,459472	0,358977	NIL
Bosnia and Herz.	40,68	0,020581	- 0,261422	0,385540	NIL
Romania	32,36	0,016604	- 0,705565	0,311035	NIL
Switzerland	96,88	0,000501	2,738680	0,009381	VHCV
Turkey	24,56	0,011349	- 1,121950	0,212604	NIL
Moldova	58,82	0,016588	0,706938	0,310734	NIL
North Macedonia	51,75	0,020171	0,329523	0,377860	NIL
Serbia-Montenegro	32,82	0,016889	- 0,681009	0,316376	NIL
Slovakia	51,66	0,020203	0,324719	0,378454	NIL
Armenia	29,83	0,014958	- 0,840623	0,280197	NIL
Georgia	21,12	0,009082	- 1,305586	0,170126	NIL
Morocco	39,86	0,020327	- 0,305196	0,380789	NIL
Egypt	15,4	0,005818	- 1,610934	0,108991	NIL
Belarus	43,13	0,021116	- 0,130635	0,395553	NIL

f(x)max value: 0,021297
f(z)max value: 0,398942

	n	Data share:	Spatial share:	Spatial size:
Very high critical value:	1	2,38[%]	0,37[%]	69700[km^2]
High critical value:	0	0,00[%]	0,00[%]	0[km^2]
Medium high critical value:	1	2,38[%]	3,86[%]	732000[km^2]
Not significant area:	39	92,86[%]	68,47[%]	12987700[km^2]
Medium low critical value:	1	2,38[%]	27,31[%]	5180000[km^2]
Low critical value:	0	0,00[%]	0,00[%]	0[km^2]
Very low critical value:	0	0,00[%]	0,00[%]	0[km^2]

3. European airspace spatial outliers analysis

Airspace/ANSP	Value	z-score	Wz(i)	Indicator
Portugal-S. Maria	9,52	- 1,924824	0,474190	LH
Belgium	67,79	1,185780	1,005747	HH
Germany	67,2	1,154284	0,892532	HH
Estonia	28,79	- 0,896141	0,046062	LH
Finland	54,92	0,498746	- 0,140778	HL
United Kingdom	68,03	1,198592	0,422854	HH
Netherlands	58,83	0,707472	1,073276	HH
Ireland	27,82	- 0,947922	1,198592	LH
Denmark	59,71	0,754449	0,706831	HH
Norway	43,23	- 0,125297	0,762723	LH
Poland	43,39	- 0,116755	0,277831	LH
Sweden	56,8	0,599105	0,026310	HH
Latvia	27,6	- 0,959667	- 0,131702	LL
Lithuania	43,72	- 0,099139	- 0,151988	LL
Spain-Canarias	56,74	0,595902	- 0,896497	HL
Albania	49,23	0,194999	0,186458	HH
Bulgaria	26,72	- 1,006643	- 0,585027	LL
Cyprus	35,08	- 0,560365	- 1,159673	LL
Croatia	44,47	- 0,059102	0,212081	LH
Spain	69,67	1,286139	- 0,431713	HL
France	63,61	0,962641	1,567821	HH
Greece	31,6	- 0,746136	- 0,438719	LL
Hungary	32,3	- 0,708768	0,188326	LH
Italy	80,11	1,843453	0,342572	HH
Slovenia	61,84	0,868154	0,614586	HH
Czech Republic	42,18	- 0,181348	0,686252	LH
Malta	16,02	- 1,577837	0,548659	LH
Austria	71,48	1,382762	0,862739	HH
Portugal	36,97	- 0,459472	- 0,086995	LL
Bosnia and Herz.	40,68	- 0,261422	- 0,370056	LL
Romania	32,36	- 0,705565	- 0,422371	LL
Switzerland	96,88	2,738680	1,335785	HH
Turkey	24,56	- 1,121950	- 0,891871	LL
Moldova	58,82	0,706938	- 0,705565	HL
North Macedonia	51,75	0,329523	- 0,559697	HL
Serbia-Montenegro	32,82	- 0,681009	- 0,046691	LL
Slovakia	51,66	0,324719	0,093972	HH
Armenia	29,83	- 0,840623	- 1,213768	LL
Georgia	21,12	- 1,305586	- 0,981286	LL
Morocco	39,86	- 0,305196	0,474190	LH
Egypt	15,4	- 1,610934	- 0,653250	LL
Belarus	43,13	- 0,130635	- 0,391854	LL

	n	Data share:	Spatial share:	Spatial size:
High-High value:	13	30,95[%]	21,85[%]	4145300[km^2]
High-Low value:	5	11,90[%]	14,02[%]	2659500[km^2]
Low-Low value:	14	33,33[%]	23,46[%]	4450300[km^2]
Low-High value:	10	23,81[%]	40,67[%]	7714300[km^2]

4. Neighboring samples similarity

Airspace/ANSP	(i,1)	(i,2)	(i,3)	(i,4)	(i,5)	(i,6)	(i,7)	(i,8)	(i,9)
Portugal-S. Maria	LP	LE	GC						
Belgium	LF	ED	EH	EG					
Germany	LO	EB	LK	EK	LF	EH	EP	ES	LS
Estonia	EF	EV	ES						
Finland	EE	EN	ES						
United Kingdom	EB	EK	LF	EI	EH	EN			
Netherlands	EB	EK	ED	EG					
Ireland	EG								
Denmark	ED	EH	EN	ES	EG				
Norway	EK	EF	ES	EG					
Poland	LK	ED	EY	LZ	ES	UM			
Sweden	EK	EE	EF	ED	EV	EY	EN	EP	
Latvia	EE	EY	ES	UM					
Lithuania	EV	EP	ES	UM					
Spain-Canarias	LP	AZ	GM						
Albania	LW	LG	LI	LY					
Bulgaria	LW	LG	LR	LY	LT				
Cyprus	LG	LT	HE						
Croatia	LJ	LH	LI	LY	LQ				
Spain	LF	LP	AZ	GM					
France	EB	ED	LI	LE	LS	EG			
Greece	LA	LB	LC	LW	LI	LM	LT	HE	
Hungary	LO	LD	LJ	LR	LY	LZ			
Italy	LA	LO	LD	LJ	LF	LG	LM	LY	LS
Slovenia	LO	LD	LH	LI					
Czech Republic	LO	ED	EP	LZ					
Malta	LG	LI							
Austria	LK	LJ	ED	LH	LI	LZ	LS		
Portugal	AZ	LE	GC	GM					
Bosnia and Herz.	LD	LY							
Romania	LB	LH	LU	LY					
Switzerland	LO	LF	ED	LI					
Turkey	UD	LB	LC	UG	LG				
Moldova	LR								
North Macedonia	LA	LB	LG	LY					
Serbia-Montenegro	LA	LB	LD	LW	LH	LI	LR	LQ	
Slovakia	LO	LK	LH	EP					
Armenia	UG	LT							
Georgia	UD	LT							
Morocco	LP	LE	GC						
Egypt	LC	LG							
Belarus	EV	EY	EP						

Airspace/ANSP	(i,1)	(i,2)	(i,3)	(i,4)	(i,5)	(i,6)	(i,7)	(i,8)	(i,9)	r[%]
Portugal-S. Maria	0,26	0,14	0,17							0,19
Belgium	0,94	0,99	0,87	1,00						0,95
Germany	0,94	0,99	0,63	0,89	0,95	0,88	0,65	0,85	0,69	0,83
Estonia	0,52	0,96	0,51							0,66
Finland	0,52	0,79	0,97							0,76
United Kingdom	1,00	0,88	0,94	0,41	0,86	0,64				0,79
Netherlands	0,87	0,99	0,88	0,86						0,90
Ireland	0,41									0,41
Denmark	0,89	0,99	0,72	0,95	0,88					0,89
Norway	0,72	0,79	0,76	0,64						0,73
Poland	0,97	0,65	0,99	0,84	0,76	0,99				0,87
Sweden	0,95	0,51	0,97	0,85	0,49	0,77	0,76	0,76		0,76
Latvia	0,96	0,63	0,49	0,64						0,68
Lithuania	0,63	0,99	0,77	0,99						0,84
Spain-Canarias	0,65	0,17	0,70							0,51
Albania	0,95	0,64	0,61	0,67						0,72
Bulgaria	0,52	0,85	0,83	0,81	0,92					0,78
Cyprus	0,90	0,70	0,44							0,68
Croatia	0,72	0,73	0,56	0,74	0,91					0,73
Spain	0,91	0,53	0,14	0,57						0,54
France	0,94	0,95	0,79	0,91	0,66	0,94				0,86
Greece	0,64	0,85	0,90	0,61	0,39	0,51	0,78	0,49		0,65
Hungary	0,45	0,73	0,52	1,00	0,98	0,63				0,72
Italy	0,61	0,89	0,56	0,77	0,79	0,39	0,20	0,41	0,83	0,61
Slovenia	0,87	0,72	0,52	0,77						0,72
Czech Republic	0,59	0,63	0,97	0,82						0,75
Malta	0,51	0,20								0,35
Austria	0,59	0,87	0,94	0,45	0,89	0,72	0,74			0,74
Portugal	0,26	0,53	0,65	0,93						0,59
Bosnia and Herz.	0,91	0,81								0,86
Romania	0,83	1,00	0,55	0,99						0,84
Switzerland	0,74	0,66	0,69	0,83						0,73
Turkey	0,82	0,92	0,70	0,86	0,78					0,82
Moldova	0,55									0,55
North Macedonia	0,95	0,52	0,61	0,63						0,68
Serbia-Montenegro	0,67	0,81	0,74	0,63	0,98	0,41	0,99	0,81		0,75
Slovakia	0,72	0,82	0,63	0,84						0,75
Armenia	0,71	0,82								0,77
Georgia	0,71	0,86								0,78
Morocco	0,93	0,57	0,70							0,73
Egypt	0,44	0,49								0,46
Belarus	0,64	0,99	0,99							0,87
Average neighbouring samples similarity:										0,71

Appendix 4. Cost-efficiency based airspace defragmentation assessment results preview

Overview of the research results:

	Data share	Spatial share
1. European airspace clustering analysis		
1.1. Non-clustered airspace area:	59,52[%]	65,84[%]
1.2. Clustered airspace area:	40,48[%]	34,16[%]
2. European airspace critical areas analysis		
2.1. Very high critical value:	2,38[%]	0,37[%]
2.2. High critical value:	0,00[%]	0,00[%]
2.3. Medium high critical value:	2,38[%]	3,86[%]
2.4. Not significant area:	92,86[%]	68,47[%]
2.5. Medium low critical value:	2,38[%]	27,31[%]
2.6. Low critical value:	0,00[%]	0,00[%]
2.7. Very low critical value:	0,00[%]	0,00[%]
3. European airspace spatial outliers analysis		
3.1. High-High value:	30,95[%]	21,85[%]
3.2. High-Low value:	11,90[%]	14,02[%]
3.3. Low-Low value:	33,33[%]	23,46[%]
3.4. Low-High value:	23,81[%]	40,67[%]

1. European airspace clustering analysis

Airspace/ANSP	n.ANSPs	Value	LISA I(i)	GISA I(i)	E(i)
Portugal-S. Maria	3	9,52	- 0,899611	0,275931	- 0,0243902
Belgium	4	67,79	1,171807	0,275931	- 0,0243902
Germany	9	67,2	1,010187	0,275931	- 0,0243902
Estonia	3	28,79	- 0,029701	0,275931	- 0,0243902
Finland	3	54,92	- 0,075496	0,275931	- 0,0243902
United Kingdom	6	68,03	0,488599	0,275931	- 0,0243902
Netherlands	4	58,83	0,740838	0,275931	- 0,0243902
Ireland	1	27,82	- 1,148205	0,275931	- 0,0243902
Denmark	5	59,71	0,517448	0,275931	- 0,0243902
Norway	4	43,23	- 0,104894	0,275931	- 0,0243902
Poland	6	43,39	- 0,034719	0,275931	- 0,0243902
Sweden	8	56,8	0,007459	0,275931	- 0,0243902
Latvia	4	27,6	0,142584	0,275931	- 0,0243902
Lithuania	4	43,72	0,018831	0,275931	- 0,0243902
Spain-Canarias	3	56,74	- 0,534020	0,275931	- 0,0243902
Albania	4	49,23	0,031575	0,275931	- 0,0243902
Bulgaria	5	26,72	0,615567	0,275931	- 0,0243902
Cyprus	3	45,83202	0,000071	0,275931	- 0,0243902
Croatia	5	44,47	- 0,014550	0,275931	- 0,0243902
Spain	4	69,67	- 0,571106	0,275931	- 0,0243902
France	6	63,61	1,486237	0,275931	- 0,0243902
Greece	8	31,6	0,291442	0,275931	- 0,0243902
Hungary	6	32,3	- 0,127154	0,275931	- 0,0243902
Italy	9	80,11	0,606473	0,275931	- 0,0243902
Slovenia	4	61,84	0,517442	0,275931	- 0,0243902
Czech Republic	4	42,18	- 0,132176	0,275931	- 0,0243902
Malta	2	16,02	- 0,858014	0,275931	- 0,0243902
Austria	7	71,48	1,171434	0,275931	- 0,0243902
Portugal	4	36,97	0,047994	0,275931	- 0,0243902
Bosnia and Herz.	2	40,68	0,106372	0,275931	- 0,0243902
Romania	4	32,36	0,316032	0,275931	- 0,0243902
Switzerland	4	96,88	3,630598	0,275931	- 0,0243902
Turkey	5	24,56	0,904910	0,275931	- 0,0243902
Moldova	1	58,82	- 0,502471	0,275931	- 0,0243902
North Macedonia	4	51,75	- 0,182499	0,275931	- 0,0243902
Serbia-Montenegro	8	32,82	0,042252	0,275931	- 0,0243902
Slovakia	4	51,66	0,025172	0,275931	- 0,0243902
Armenia	2	29,83	1,056676	0,275931	- 0,0243902
Georgia	2	21,12	1,322723	0,275931	- 0,0243902
Morocco	3	39,86	- 0,147977	0,275931	- 0,0243902
Egypt	2	15,4	0,622000	0,275931	- 0,0243902
Belarus	3	43,13	0,058968	0,275931	- 0,0243902
Data set arithmetic mean:		45,83	0,275931		
Standard deviation value:		18,66	0,096717		

*n.ANSPs - Number of neighbouring Air Navigation Service Providers (ANSPs)
*LISA - Local Indicator of Spatial Autocorrelation
*GISA - Global Indicator of Spatial Autocorrelation

Global Moran's I results summary

Moran's Index (I):	0,27593
Expected Index E(I):	- 0,02439
Variance Var[I]:	348,22640
z-score value:	3,10515
p-value:	0,00094

Input data frequency distribution table:

k	h	f	fi
1	9,520000 - 24,080000	4	0,09524
2	24,080000 - 38,640000	11	0,26190
3	38,640000 - 53,200000	12	0,28571
4	53,200000 - 67,760000	9	0,21429
5	67,760000 - 82,320000	5	0,11905
6	82,320000 - 96,880000	1	0,02381

LISA frequency distribution table:

k	h	f	fi
1	(- 1,148205) - (- 0,351737)	6	0,14286
2	(- 0,351737) - 0,444730	21	0,50000
3	0,444730 - 1,241197	12	0,28571
4	1,241197 - 2,037664	2	0,04762
5	2,037664 - 2,834131	0	0,00000
6	2,834131 - 3,630598	1	0,02381

Critical value frequency distribution table:

k	h	f	fi
1	< (-2,58)	0	0,00000
2	(-2,58) - (-1,96)	0	0,00000
3	(-1,96) - (-1,65)	1	0,02381
4	(-1,65) - 1,65	39	0,92857
5	1,65 - 1,96	1	0,02381
6	1,96 - 2,58	0	0,00000
7	> 2,58	1	0,02381

Neighbouring values frequency distribution table:

k	h	f	fi
1	(- 1,232161) - (- 0,766777)	5	0,11905
2	(- 0,766777) - (- 0,301394)	9	0,21429
3	(- 0,301394) - 0,163990	8	0,19048
4	0,163990 - 0,629374	10	0,23810
5	0,629374 - 1,094758	7	0,16667
6	1,094758 - 1,560141	3	0,07143

2. European airspace focal areas analysis

Airspace/ANSP	Value	f(x)	z-score	f(z)	Indicator
Portugal-S. Maria	9,52	0,003219	- 1,945956	0,060066	MLCV
Belgium	67,79	0,010699	1,176628	0,199655	NIL
Germany	67,2	0,011099	1,145011	0,207119	NIL
Estonia	28,79	0,014088	- 0,913311	0,262893	NIL
Finland	54,92	0,018988	0,486948	0,354340	NIL
United Kingdom	68,03	0,010538	1,189490	0,196640	NIL
Netherlands	58,83	0,016774	0,696478	0,313023	NIL
Ireland	27,82	0,013417	- 0,965292	0,250366	NIL
Denmark	59,71	0,016214	0,743636	0,302572	NIL
Norway	43,23	0,021172	- 0,139498	0,395079	NIL
Poland	43,39	0,021196	- 0,130924	0,395538	NIL
Sweden	56,8	0,017988	0,587694	0,335669	NIL
Latvia	27,6	0,013264	- 0,977081	0,247515	NIL
Lithuania	43,72	0,021242	- 0,113240	0,396393	NIL
Spain-Canarias	56,74	0,018022	0,584479	0,336302	NIL
Albania	49,23	0,021027	0,182031	0,392387	NIL
Bulgaria	26,72	0,012653	- 1,024239	0,236107	NIL
Cyprus	45,83202	0,021379	- 0,000060	0,398942	NIL
Croatia	44,47	0,021322	- 0,073048	0,397879	NIL
Spain	69,67	0,009455	1,277374	0,176439	NIL
France	63,61	0,013581	0,952630	0,253424	NIL
Greece	31,6	0,015983	- 0,762729	0,298252	NIL
Hungary	32,3	0,016435	- 0,725217	0,306693	NIL
Italy	80,11	0,003957	1,836835	0,073835	MHCV
Slovenia	61,84	0,014798	0,857779	0,276145	NIL
Czech Republic	42,18	0,020973	- 0,195765	0,391371	NIL
Malta	16,02	0,005967	- 1,597633	0,111341	NIL
Austria	71,48	0,008314	1,374369	0,155147	NIL
Portugal	36,97	0,019098	- 0,474960	0,356389	NIL
Bosnia and Herz.	40,68	0,020579	- 0,276148	0,384017	NIL
Romania	32,36	0,016473	- 0,722001	0,307407	NIL
Switzerland	96,88	0,000507	2,735509	0,009462	VHCV
Turkey	24,56	0,011163	- 1,139989	0,208310	NIL
Moldova	58,82	0,016781	0,695942	0,313140	NIL
North Macedonia	51,75	0,020331	0,317074	0,379384	NIL
Serbia-Montenegro	32,82	0,016764	- 0,697351	0,312832	NIL
Slovakia	51,66	0,020361	0,312251	0,379960	NIL
Armenia	29,83	0,014801	- 0,857580	0,276192	NIL
Georgia	21,12	0,008895	- 1,324333	0,165983	NIL
Morocco	39,86	0,020311	- 0,320090	0,379020	NIL
Egypt	15,4	0,005655	- 1,630857	0,105527	NIL
Belarus	43,13	0,021155	- 0,144857	0,394779	NIL

f(x)max value: 0,021379
f(z)max value: 0,398942

	n	Data share:	Spatial share:	Spatial size:
Very high critical value:	1	2,38[%]	0,37[%]	69700[km^2]
High critical value:	0	0,00[%]	0,00[%]	0[km^2]
Medium high critical value:	1	2,38[%]	3,86[%]	732000[km^2]
Not significant area:	39	92,86[%]	68,47[%]	12987700[km^2]
Medium low critical value:	1	2,38[%]	27,31[%]	5180000[km^2]
Low critical value:	0	0,00[%]	0,00[%]	0[km^2]
Very low critical value:	0	0,00[%]	0,00[%]	0[km^2]

3. European airspace spatial outliers analysis

Airspace/ANSP	Value	z-score	Wz(i)	Indicator
Portugal-S. Maria	9,52	- 1,945956	0,462298	LH
Belgium	67,79	1,176628	0,995902	HH
Germany	67,2	1,145011	0,882251	HH
Estonia	28,79	- 0,913311	0,032520	LH
Finland	54,92	0,486948	- 0,155038	HL
United Kingdom	68,03	1,189490	0,410764	HH
Netherlands	58,83	0,696478	1,063691	HH
Ireland	27,82	- 0,965292	1,189490	LH
Denmark	59,71	0,743636	0,695835	HH
Norway	43,23	- 0,139498	0,751942	LH
Poland	43,39	- 0,130924	0,265182	LH
Sweden	56,8	0,587694	0,012693	HH
Latvia	27,6	- 0,977081	- 0,145928	LL
Lithuania	43,72	- 0,113240	- 0,166292	LL
Spain-Canarias	56,74	0,584479	- 0,913669	HL
Albania	49,23	0,182031	0,173457	HH
Bulgaria	26,72	- 1,024239	- 0,600999	LL
Cyprus	45,83202	- 0,000060	- 1,177858	LL
Croatia	44,47	- 0,073048	0,199180	LH
Spain	69,67	1,277374	- 0,447094	HL
France	63,61	0,952630	1,560141	HH
Greece	31,6	- 0,762729	- 0,382105	LL
Hungary	32,3	- 0,725217	0,175333	LH
Italy	80,11	1,836835	0,330173	HH
Slovenia	61,84	0,857779	0,603235	HH
Czech Republic	42,18	- 0,195765	0,675177	LH
Malta	16,02	- 1,597633	0,537053	LH
Austria	71,48	1,374369	0,852343	HH
Portugal	36,97	- 0,474960	- 0,101048	LL
Bosnia and Herz.	40,68	- 0,276148	- 0,385200	LL
Romania	32,36	- 0,722001	- 0,437716	LL
Switzerland	96,88	2,735509	1,327211	HH
Turkey	24,56	- 1,139989	- 0,793788	LL
Moldova	58,82	0,695942	- 0,722001	HL
North Macedonia	51,75	0,317074	- 0,575572	HL
Serbia-Montenegro	32,82	- 0,697351	- 0,060589	LL
Slovakia	51,66	0,312251	0,080616	HH
Armenia	29,83	- 0,857580	- 1,232161	LL
Georgia	21,12	- 1,324333	- 0,998785	LL
Morocco	39,86	- 0,320090	0,462298	LH
Egypt	15,4	- 1,630857	- 0,381394	LL
Belarus	43,13	- 0,144857	- 0,407081	LL

	n	Data share:	Spatial share:	Spatial size:
High-High value:	13	30,95[%]	21,85[%]	4145300[km^2]
High-Low value:	5	11,90[%]	14,02[%]	2659500[km^2]
Low-Low value:	14	33,33[%]	23,46[%]	4450300[km^2]
Low-High value:	10	23,81[%]	40,67[%]	7714300[km^2]

4. Neighbouring samples similarity

Airspace/ANSP	(i,1)	(i,2)	(i,3)	(i,4)	(i,5)	(i,6)	(i,7)	(i,8)	(i,9)
Portugal-S. Maria	LP	LE	GC						
Belgium	LF	ED	EH	EG					
Germany	LO	EB	LK	EK	LF	EH	EP	ES	LS
Estonia	EF	EV	ES						
Finland	EE	EN	ES						
United Kingdom	EB	EK	LF	EI	EH	EN			
Netherlands	EB	EK	ED	EG					
Ireland	EG								
Denmark	ED	EH	EN	ES	EG				
Norway	EK	EF	ES	EG					
Poland	LK	ED	EY	LZ	ES	UM			
Sweden	EK	EE	EF	ED	EV	EY	EN	EP	
Latvia	EE	EY	ES	UM					
Lithuania	EV	EP	ES	UM					
Spain-Canarias	LP	AZ	GM						
Albania	LW	LG	LI	LY					
Bulgaria	LW	LG	LR	LY	LT				
Cyprus	LG	LT	HE						
Croatia	LJ	LH	LI	LY	LQ				
Spain	LF	LP	AZ	GM					
France	EB	ED	LI	LE	LS	EG			
Greece	LA	LB	LC	LW	LI	LM	LT	HE	
Hungary	LO	LD	LJ	LR	LY	LZ			
Italy	LA	LO	LD	LJ	LF	LG	LM	LY	LS
Slovenia	LO	LD	LH	LI					
Czech Republic	LO	ED	EP	LZ					
Malta	LG	LI							
Austria	LK	LJ	ED	LH	LI	LZ	LS		
Portugal	AZ	LE	GC	GM					
Bosnia and Herz.	LD	LY							
Romania	LB	LH	LU	LY					
Switzerland	LO	LF	ED	LI					
Turkey	UD	LB	LC	UG	LG				
Moldova	LR								
North Macedonia	LA	LB	LG	LY					
Serbia-Montenegro	LA	LB	LD	LW	LH	LI	LR	LQ	
Slovakia	LO	LK	LH	EP					
Armenia	UG	LT							
Georgia	UD	LT							
Morocco	LP	LE	GC						
Egypt	LC	LG							
Belarus	EV	EY	EP						

Airspace/ANSP	(i,1)	(i,2)	(i,3)	(i,4)	(i,5)	(i,6)	(i,7)	(i,8)	(i,9)	r[%]
Portugal-S. Maria	0,26	0,14	0,17							0,19
Belgium	0,94	0,99	0,87	1,00						0,95
Germany	0,94	0,99	0,63	0,89	0,95	0,88	0,65	0,85	0,69	0,83
Estonia	0,52	0,96	0,51							0,66
Finland	0,52	0,79	0,97							0,76
United Kingdom	1,00	0,88	0,94	0,41	0,86	0,64				0,79
Netherlands	0,87	0,99	0,88	0,86						0,90
Ireland	0,41									0,41
Denmark	0,89	0,99	0,72	0,95	0,88					0,89
Norway	0,72	0,79	0,76	0,64						0,73
Poland	0,97	0,65	0,99	0,84	0,76	0,99				0,87
Sweden	0,95	0,51	0,97	0,85	0,49	0,77	0,76	0,76		0,76
Latvia	0,96	0,63	0,49	0,64						0,68
Lithuania	0,63	0,99	0,77	0,99						0,84
Spain-Canarias	0,65	0,17	0,70							0,51
Albania	0,95	0,64	0,61	0,67						0,72
Bulgaria	0,52	0,85	0,83	0,81	0,92					0,78
Cyprus	0,69	0,54	0,34							0,52
Croatia	0,72	0,73	0,56	0,74	0,91					0,73
Spain	0,91	0,53	0,14	0,57						0,54
France	0,94	0,95	0,79	0,91	0,66	0,94				0,86
Greece	0,64	0,85	0,69	0,61	0,39	0,51	0,78	0,49		0,62
Hungary	0,45	0,73	0,52	1,00	0,98	0,63				0,72
Italy	0,61	0,89	0,56	0,77	0,79	0,39	0,20	0,41	0,83	0,61
Slovenia	0,87	0,72	0,52	0,77						0,72
Czech Republic	0,59	0,63	0,97	0,82						0,75
Malta	0,51	0,20								0,35
Austria	0,59	0,87	0,94	0,45	0,89	0,72	0,74			0,74
Portugal	0,26	0,53	0,65	0,93						0,59
Bosnia and Herz.	0,91	0,81								0,86
Romania	0,83	1,00	0,55	0,99						0,84
Switzerland	0,74	0,66	0,69	0,83						0,73
Turkey	0,82	0,92	0,54	0,86	0,78					0,78
Moldova	0,55									0,55
North Macedonia	0,95	0,52	0,61	0,63						0,68
Serbia-Montenegro	0,67	0,81	0,74	0,63	0,98	0,41	0,99	0,81		0,75
Slovakia	0,72	0,82	0,63	0,84						0,75
Armenia	0,71	0,82								0,77
Georgia	0,71	0,86								0,78
Morocco	0,93	0,57	0,70							0,73
Egypt	0,34	0,49								0,41
Belarus	0,64	0,99	0,99							0,87
Average neighbouring samples similarity:										0,70

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Zvonimir Rezo was born on 19th September 1994 in Makarska, Republic of Croatia. He grew up in Dubrovnik, Republic of Croatia, where he finished primary and secondary education. In 2013, he enrolled to the Faculty of Transport and Traffic Sciences of the University of Zagreb. In 2016, he received a Bachelor’s degree and in 2018 a Master’s degree in the field of Air Transport Engineering. In the same year and at same Faculty he enrolled to postgraduate doctoral studies. His main area of research interest is strategic planning and development of the Air Traffic Management system. During the Bachelor's, Master's and Doctoral degree studies he had studied abroad for some time. During the Bachelor's studies, he spent a semester studying at the Faculty of Operation and Economics of Transport and Communications, Žilina, Slovak Republic. During the Master's studies, he spent a semester studying and later an additional semester working as a visiting researcher at the Faculty of Civil, Constructional and Environmental Engineering of “La Sapienza” University of Rome, Rome, Republic of Italy. In 2020, he was reappointed as a visiting researcher in Rome. In 2019, he was employed as an expert associate at the Traffic Institute of Croatian Academy of Sciences and Arts in Zagreb, Republic of Croatia. In the same year, he worked as external associate on a research project conducted by the Department of Air Transport of Faculty of Transport and Traffic Sciences. Back in 2016, he was awarded the Dean's Award “Cum Laude” of the Faculty of Traffic and Transport Sciences of University of Zagreb, whereas in 2018 he received the Rector’s Award of the University of Zagreb in the category of the best individual scientific research papers. At the time of writing, he is the first author of twenty research papers published within scientific journals and conference proceedings and a few more papers under review:

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