Scalable U-Space Authorization Workflow enabling Fairness and Capacity Management

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Abstract— **To support the expected increase in drone traffic, the next phases of U-space deployment must be able to dynamically manage capacity-demand imbalances, and fairness issues in airspace access. This article discusses how these processes may be constrained by the First-Come-First-Served authorization process mandated by regulation. Alternatively, it proposes an authorization workflow that defers in time the authorization decision and provides until then a probabilistic view of the authorization result. In addition, it proposes to implement a flight prioritization system using different priority queues whose access is indirectly controlled by a new U-space service: the fairness management service. Simulation results demonstrate that the proposed mechanism is able to reduce the flight submission order impact into the final authorization success rate.**

Keywords-U-space; authorization; strategic phase; fairness; DCM

I. Introduction

Across Europe, U-space [1] services are being gradually implemented to enable drone operations [2]. Broadly, these initial deployments consist in a first set of basic services (i.e.: network identification, geo-awareness, flight authorization and traffic information services) mandated by European regulation [3]. These services and regulatory framework can support low density, low risk traffic, but further developments are needed to leverage the expected drone market. In this sense, available estimations forecast the operation of 70,000 parcel delivery drones across Europe by 2035 [4]. Traffic will especially concentrate in cities where a six-fold increase of traffic density may be expected when compared with current commercial traffic [5]. This prospective scenario hints a congested airspace, which will become a scarce, contested and valuable resource for drone operators.

In this regard, the latest version of the U-space CONOPS [6] considers the emergence of some problems so far overlooked in regulation such as fairness or congestion management. As it will be discussed in Section II, an adequate solution of these problems requires to analyze an almost global view of all concurrent flight operations affected by these problems in a given area. However, the current regulation-mandated strategic phase flight authorization process is performed flight by flight. Thus, it will be argued that an adequate solution to these problems is constrained by current regulation.

Alternatively and as a possible solution, a new authorization workflow is being proposed in the context of the SESAR 3 JU SPATIO project [7] (i.e.: u-Space sePAraTIOn management; the project covers drone separation management including the integration of Dynamic Capacity Management (DCM) in the strategic phase, the application of fairness criteria to deconflict drones and tactical conflict prediction and resolution). This article describes such proposal, consisting in the following novel contributions (presented in Sections III, IV and V):

a) An alternative authorization workflow that defers the authorization decision until sufficient information is available, enabling the implementation of congestion and fairness management techniques in a decentralized U-space deployment.
b) A probabilistic view of the authorization process to guide operators' decisions until a final authorization decision is taken.
c) An alternative prioritization scheme with multiple priority queues whose access is governed by a set of centralized rules defined by authorities.
d) The identification of a new service/functionality deployed within the Common Information Service Provider (CISP): the fairness management service, in charge of the distribution of fairness rules.

Then, Section VI will present simulation results supporting the adoption of the proposed authorization framework. Finally, Section VII will summarize the main findings and describe the next steps.

II. Analysis of the Current Regulatory Framework and Related Work

Commission Implementing Regulation 2021/664 [3] establishes the regulatory framework for the U-space across Europe. When referring to the requirements to conduct a UAS flight operation, it mandates that, before each flight, UAS operators must submit an authorization request, which is typically referred as flight plan or U-plan. Among other information, the U-plan defines the expected 4D trajectory of the drone, usually as a set of 4D volumes (as detailed in the corresponding AMC/G [8]). Based on this information, regulation 2021/664 indicates that U-space Service Providers (i.e.: USSPs) must ensure that the requested operation is free of intersection in space and time with any other concurrent operations for the U-plan to be accepted. Otherwise, the UAS operation cannot be conducted in the original form (i.e.: an authorization is not granted) and may be subjected to an alternative generation process (i.e.: deconfliction). In nominal cases, this authorization decision is to be taken immediately as the operator submits an authorization request.

Overall, the regulation establishes an exclusive use of airspace 4D volumes by each operation, which implies that several operators may compete to operate in the same airspace. Therefore, as traffic increases, it will be essential to ensure an efficient airspace usage. This will require the implementation of advanced Dynamic Capacity Management (DCM) techniques that will allow to increase drone density while maintaining safety [6]. Examples in the literature [9], [10], [11], [12] solve this problem by using mixed-integer programming techniques to optimize the number of operations on an area, acting on either all concurrent flights or batches of them. As a result, the optimal occupation scenario may require implementing changes (e.g.: time delays, altitude stratification…) in a set of operations. Therefore, it is necessary to wait until the flight picture is complete so that the demand and capacity analysis can be performed and changes to flight plans can be implemented. Trying to incorporate this requirement into the regulatory framework means that either the authorization decision is delayed until close to the instant of take-off; or that conflicting flight plans are accepted on submission and changes (or even authorization withdraws) are implemented afterwards. Both are in principle not considered in regulation.

A possible alternative authorization flow has been proposed by the DACUS project [13]. Within that framework, as operators submit U-plans for authorization they are considered as part of the tentative flight picture (i.e.: possible operations), but an authorization decision is not taken in that moment. Later, when the flight picture for a given time frame is considered to be complete and stable (a moment named as RTTA or Reasonable Time To Act), the batch of U-plans for that time frame is processed jointly. As a result, U-plans are fitted into the available capacity and impacted (modified) if necessary, providing a final authorization decision. This framework has been tested in a centralized deployment with a unique service analyzing all U-plans and directly implementing changes. However, it can be argued that each individual USSP is responsible for implementing changes in their own flights and thus that a decentralized alternative is required. Also, batch processing of flights can create undesirable border effects and can yield to scalability issues.

Coming back to the current regulatory framework, regulation 2021/664 lays out two different authorization priorities to deconflict concurrent operations: special operations (e.g.: police, SAR, firefighting missions… [14]) and other operations, having the first one precedence over the rest. Then, over the same priority category, a FC-FS prioritization is to be used, authorizing conflicting operations that have been submitted earlier over those that have been submitted later in time.

However, the coexistence of different types of missions and operators with different requirements can lead to inequities in airspace access [15], which has already been proved with simulations [16]. For instance, operators that can schedule their operations far in advance (e.g.: agricultural inspections) can take advantage of the regulation mandated First–Come–First–Served (FC-FS) airspace reservation scheme over other operators that cannot plan until almost last minute (e.g.: Urban Air Mobility operations). Similarly, as no usage limits are in place incumbent operators with many operations may monopolize airspace access over newcomers. In this sense, it is expected that U-space systems ensure that airspace access is “equitable and fair” for all operators [6], understanding fairness as a virtuous state in which the welfare of each operator is maximized subject to capacity constraints and the needs and limitations of all other operators [17].

Some of the proposals found in the literature for managing fairness are far from the European concept of U-space. For example, [18] defends the delimitation of portions of airspace that are allocated exclusively to operators in an auction process. Also based on an economic logic, [19] proposes to establish a pay-per-use scheme so that operators will have to pay for each flight in proportion to the airspace occupation. Closer to European regulations, the DACUS project [13] has proposed to use a virtue-point system to prioritize operations. In this system, points are awarded to those operations that contribute to the overall efficiency of the system or that have been submitted in time. Then, this per-operation score is used to decide which flights are affected when implementing deconfliction changes. The last version of the U-space CONOPS [6] embraces and extends this idea, also considering U-plan definition uncertainty or the type of mission to assign those points. In both cases, the FC-FS approach is broken (as late-filed flights might have higher priority than early-filed flights), and a deferred authorization based on the previously explained RTTA scheme is to be assumed.

In conclusion, an adequate solution to the congestion and fairness management problem entails breaking with the current authorization workflow mandated in the regulation. In this sense, it is required to delay the authorization decision until enough flights have been submitted to be able to apply fairness and capacity management criteria. Otherwise, operators would be subjected to continuous and unpredictable changes in the authorization status of the operation. The deferred authorization decision also enables the implementation of new prioritization rules among the different operators that can break the FC-FS policy as the gatekeeper of airspace access.

III. SPATIO Srategic Authorization Workflow

The objective of the proposed authorization workflow is to go beyond current regulation in order to enable congestion and fairness management. To do so, this article proposes a deferred authorization workflow that includes some differential elements when compared with existing proposals: operator involvement and certainty needs, multi-USSP environment, and scalability.

From the operator point of view, introducing new elements in the authorization process increases the uncertainty about the final authorization result and increases the probability of requiring adjustments in the U-plan. In that sense, the operator

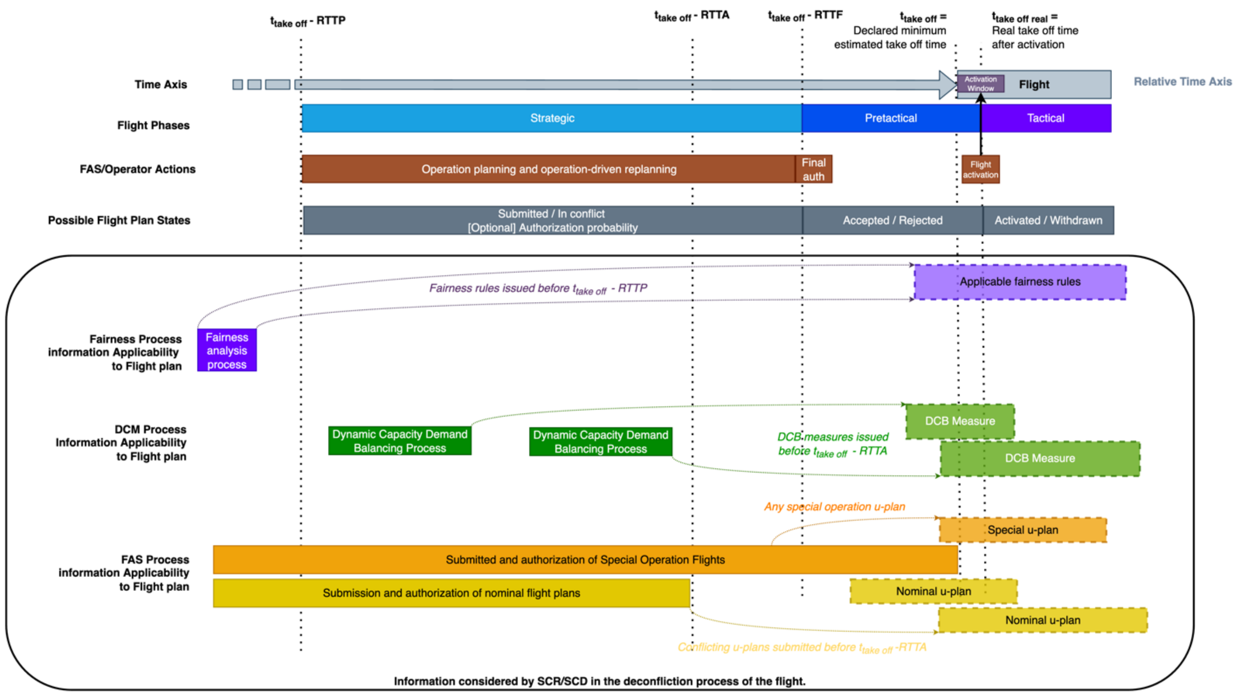

Figure 1. Phases and times within the authorization process.

must be promptly informed of any status change affecting its U-plan, even providing estimates or predictions on the final authorization result. Also, the number of changes required in the operation should be reduced and be made with sufficient time. In any case, operators must be included in the authorization decision loop, participating in the alternative generation process, and taking the final decision concerning their own U-plan changes (which may be assisted by an automated process). This is necessary because it is the operator who knows the details of the mission to be performed, its operational constraints and business logic.

Considering USSPs requirements, even if some U-space functions may be performed by the CISP (e.g.: DCM service), USSPs are responsible of managing their own flights: authorization decision, conflict resolution… Therefore, the proposed authorization workflow must be distributable in a multi-USSP environment. In fact, different USSPs may provide differential value by applying different conflict resolution and traffic sharing algorithms. Finally, to ensure scalability and stability, batch-based calculations should be avoided in favor of asynchronous interactions between the various parties involved in the authorization process.

Based on these requirements, the proposed authorization workflow can be understood as a distributed process (as shown in the lower half of Figure 1) in which a set of temporally decoupled services (e.g.: fairness management, DCM) asynchronously provide constraints to the flight authorization process. Constraints (e.g.: traffic balancing, named DCB, measures) dynamically shape how traffic should ultimately behave in an area so that operators modify their initial operations to meet capacity/demand or other requirements. Also, traffic prioritization strategies (which will be denoted fairness rules) can be generated to break the FC-FS approach. Encoding the result of these processes as constraints allows that regardless of how they are generated (centralized or decentralized), USSPs can apply them autonomously, considering each flight plan independently. For this to work, restrictions must be generated continuously over time, but far in advance so that the process is stable, and operators can react to them. Also, they will be only applicable to a subset of flights within the time applicability window of each measure. This way, analysis slots or batches are avoided reducing the impact of possible border effects.

From a single U-plan perspective (as shown in the upper half of Figure 1), the proposed authorization workflow defers the authorization decision in time so that the FC-FS approach is broken, and dynamic constraints can be computed and applied. Thus, a U-plan lifecycle can be divided in three different phases that are relative to the time instant where each operation begins: strategic phase, pre-tactical phase and tactical phase. Within each phase, different information (i.e.: constraints generated by the asynchronous processes) is required to assess the U-plan authorization status. Also, different involvement is expected from the operator throughout the life cycle of a U-plan.

Temporally describing the proposed phases, flights are not to be submitted a given amount of time before the operation starts. This amount of time is denoted here as the Reasonable Time To Plan (RTTP) interval. It determines the start of the operation's strategic phase relative to the expected flight take-off time. Before this milestone is reached, long-term constraints based on historical data (e.g.: computation of fairness rules) are to be asynchronously computed and available to be used during the strategic phase.

Within the strategic phase, the operation planning process can be started at any time. As the operator submits a flight authorization request (U-plan), it is registered into the U-space system (and shared with all USSPs) and assessed for conflicts with preexisting traffic and constraints. In keeping with the objective of always providing information to the operator, it is notified if the U-plan conforms with current traffic and constraints (i.e.: *submitted* state is assigned) or not (i.e.: *in-conflict* state assigned). The *submitted* state should not be considered as a definitive authorization but as an informative status for the user indicating that, if the restrictions (i.e.: U-plans, DCB measures…) are not changed, the flight will be finally authorized. The *in-conflict* state means that the flight is still under consideration but that it will need deconfliction to be authorized if no further changes in traffic or constraints appear.

In parallel, other flights may be submitted and the DCM process is continuously assessing the demand-capacity balance and issuing capacity constraints when hotspots have been detected. Thus, new traffic or constraints may lead to a change of a U-plan from submitted to in-conflict state. Meanwhile, some examples of events making an in-conflict U-plan move to a submitted state would be the resubmission of an amended U-plan without conflicts, or, much more unfrequently, the withdrawing of a conflicting U-plan by its own operator, or the removal of preexisting constrains.

As an added-value informative tool for operators until a definitive authorization result is taken, USSPs can provide operators with predictive information on the final authorization result based on current and historical patterns. This information, which can be termed as "*authorization probability*", is an estimate on how probable it is that a submitted flight is finally authorized. It provides a plausibility measure of the U-plan status, informing the operator how much it may be affected by future flight plans or DCB measures. For clarity, this magnitude can be a categoric variable related to probability intervals (e.g.: low, medium, high probability). The operator can use this information to start preparing the flight in case of a high authorization probability, initiate a deconfliction process to increase the probability or even desist from performing the flight well in advance in case of a very low authorization probability.

As the strategic phases progresses, the Reasonable Time To Act (RTTA) interval determines how far in advance the flight picture is considered as almost complete and when applicable DCB measures should have been already generated by the DCM process. At $t_{take\ off}$-RTTA, the set of restrictions and possible conflicts to be considered in the deconfliction process of a given U-plan is frozen. New DCB measures issued after this instant are not considered in this flight. Similarly, any new possibly conflicting U-plan is of lower priority than the current U-plan and thus not considered in deconfliction (except for special operation flights). Therefore, this enables opening a short non-dynamic replanning window in which the operator can adapt, if needed, the operation to avoid conflicts and constraints.

Then, the Reasonable Time To Freeze (RTTF) interval determines how far in advance a final authorization decision should be taken after the re-planning window. At $t_{take\ off}$-RTTF, if no conflict is found in the amended operation (only considering the set of applicable flights, UAS zones, applicable constraints…), the operation is *accepted*. Afterwards, the flight cannot suffer any additional changes except for non-nominal situations, starting the pre-tactical phase. If conflicts are still found, the operation is *withdrawn*.

Finally, at the pre-tactical phase, an activation window opens close to the estimated take off time. Within it, it is possible to request the activation/clearance of the authorization, starting the tactical phase.

From the U-space services point of view, the proposed flow allows to temporally decouple the authorization workflow from other additional computations that generate restrictions on free flight. Moreover, by deferring the authorization process, it allows to break with the FC-FS logic as detailed in the next section. Furthermore, it also enables cleanly distributing the U-space authorization and strategic deconfliction processes into different USSPs.

IV. Spatio Fairness Management Proposal

Regarding fairness management, the proposal is to partially break the FC-FS approach and adopt a multi-queue authorization framework where each queue would correspond to a different priority during the authorization process. This is possible thanks to the previously described deferred authorization workflow. The objective is to provide an authorization infrastructure that is flexible and supports different fairness notions that may be regulated by policymakers.

To do so, it is proposed to embrace the two regulation-mandated priorities but extend the nominal case (i.e.: non-special) to include additional priority categories. As a result, a series of priority categories with decreasing priority should be adopted, each corresponding to an independent authorization virtual queue:

- Special operations - [SO].
- Nominal priority 1 - [N1].
- Nominal priority 2 - [N2].
- …

Then, as U-plans are submitted, the USSP is responsible of checking in which priority queue the flight is to be entered according to a set of fairness rules. These rules act as gatekeepers of each priority queue and serve to implement the fairness strategy mandated by regulators. Strategies may be static or change dynamically over time as the traffic picture evolves. In both cases, rules need to be common for all USSPs, so they share a fully synchronized view on the virtual priority queues. Thereby, the need for a new U-space service, namely U-space Fairness Management Service, is identified. This service, whose interactions are depicted in Figure 2, will be charged of dynamically computing fairness rules and of distributing them between USSPs.

In order to ease interoperability between USSPs, fairness rules should be defined in a simple way. Also, explainability is required for operators. Therefore, we propose to encode fairness rules as the maximum number of simultaneous U-plans (i.e.: flown concurrently with the submitted flight) each operator can have in a priority queue. This means that USSPs must check for other submitted U-plans of the same operator, to be flown at the same time, and verify if the maximum capacity of each queue has been exceeded. An incoming U-plan is to be entered to the queue of higher priority for which the operator has not exceeded the allocated capacity.

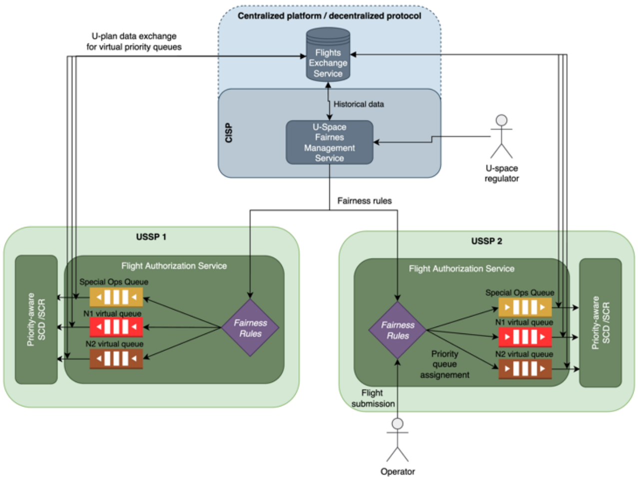

Figure 2. Fairness Management Service role and multi priority flight authorization scheme.

This proposal only describes an enabling framework to manage fairness. Thus, further work is required on how to compute the maximum number of flights per queue to ensure equitable airspace access. A discussion on this topic can be found in [17], fairness rules may be related to the type of operation, the demand of each operator, the available capacity... For validation purposes and as a first step, the following fairness rules will be used in this article:

- For simplicity, only two priority queues are considered: N1 and N2.
- The maximum number of flights per operator in priority N1 is related to the overall available capacity (which should have been estimated during the U-space Airspace Risk Assessment process) and the number of U-space operators:

$$flights\ N1 = \left| \frac{capacity\ [n^{\underline{o}}\ simultaneous\ flights]}{n^{\underline{o}}\ operators} \right|$$

  This way, available capacity is distributed uniformly between all operators so that all of them have an equal chance of accessing to the N1 priority queue.
- An unlimited number of flights by operator in N2 to ensure that remaining capacity can be used.

These fairness rules aim to avoid that an operator that sends all flights well in advance has assigned a high priority for all of them, thus partially breaking the FC-FS order. In addition, since the number of flights in the N1 queue is restricted, it prevents one operator from monopolizing the airspace, promoting operators with fewer flights.

Once a U-plan has been submitted to one of the priority queues, it is possible to easily check for conflicts while also considering the priority. In this sense, given a flight in a queue, only those flights in the same queue or queues with higher priority will be considered as possible conflicting flights to authorize it. That means that if two flights are simultaneously submitted in categories N1 and N2 and are competing to operate in the same 4D-volume, N1 flight shall be first considered for authorization. Within a single category, a FC-FS prioritization is used.

To perform U-plan deconfliction within a FC-FS authorization workflow, only the authorized flights' information was shared between USSPs. However, in order to enable both deferred authorization and fairness management, information of all submitted U-plans, independently of their state, must be shared between USSPs. Also, the priority queue each U-plan has been entered is to be shared together with the 4D representation of U-plans. This information can be shared either through a indirect exchange service mechanism (e.g.: via centralized platform) or with direct USSP communication mechanism (e.g.: InterUSS [20]).

Overall, the proposed multi-priority queues controlled by fairness rules aim to be a first simple approach to allow studying different airspace fairness strategies.

V. Dynamic Capacity Management Integration

The proposed authorization workflow also enables to integrate DCM, understood as a continuous, centralized process that analyzes the demand-capacity situation and asynchronously proposes (ideally in a proactive way) constraints to solve imbalances. Measures can restrict the airspace occupation in an area (e.g.: maximum occupied capacity per flight, maximum number of flights in an area) or propose organization structures (e.g.: layering) to increase capacity. In any case, the measures are understood as restrictions that affect certain flight plans. Therefore, they can be applied independently by each USSP on its own U-plans, without requiring synchronous coordination between USSPs and enabling the operators' feedback in their implementation to each U-plan. Possible second-order effects in their implementation (i.e.: amended U-plans creating new hotspots) can be mitigated by issuing them far in advance, providing wide application areas or designing measures that do not increase the U-plan initial envelope (e.g.: reducing take-off time window).

VI. Validation

To demonstrate that the proposed deferred authorization workflow is a valid approach enabling fairness management, a set of simulation scenarios have been carried out. In this sense, subsection A describes the experimental setup used to conduct the experiments. Then, subsection B presents the results of an experiment that analyzes fairness implications of operators with different flight submission time patterns (scenario 1). Finally, subsection C presents a similar analysis but considering the effect of operators with a heterogeneous number of submitted flights (scenario 2).

A. *Experimental setup*

The validation is supported by an accelerated-time, agent-based simulator that models the U-space strategic phase. In it, the proposed authorization framework has been implemented, as well as the current regulation-mandated FC-FS approach, that will be used as a baseline for comparison. This simulator mimics the interactions and structure of the real U-space ecosystem, considering the behavior of operators, USSPs and a centralized CISP.

For each scenario, 32 operators are modelled with different behaviors (i.e.: flight submission time patterns or number of submitted U-plans). Each operator submits a set of U-plans to the U-space system for approval. Traffic for each operator is randomly generated in accordance to the operator selected behavior (e.g: which determines when they are submitted) and using the authors' previous work in [21]. Although other types of operations could be considered, all operators perform linear flights at constant height, between two random waypoints within an area under study. The considered area has a maximum estimated capacity of 100 simultaneous flights. Take off times of simulated flights are uniformly distributed in 24 hours, and submission times for each flight are randomly selected following the operator behavior.

For each scenario, 30 scenario runs (i.e.: different realizations of the scenario generation process for the same input parameters) are generated to perform Montecarlo simulation. At the beginning of each simulation run, the presented fairness rules (i.e.: maximum number of flights per operator and priority queue) are encoded into the simulated CISP, which distributes them into the different USSPs through the simulated Fairness Management Service. As the simulation progresses, operators timely submit their operations to their assigned USSPs for authorization. When running the simulator with the proposed authorization workflow, USSPs enters each flight into the corresponding priority queue according to the fairness rules. Later in time, at the $t_{take\ off}$-RTTF of each flight, a final authorization decision is taken based on all the available information. Alternatively, if the simulator is run using the FC-FS mode, an authorization decision is immediately obtained. In both cases, at the end of the simulation process, the results are recorded for later analysis and comparison.

B. *Experimental scenario 1. Submission time analysis.*

This validation scenario seeks to test whether the proposed mechanism reduces the dependence between the U-plan authorization probability (i.e.: defined as the ratio between the number of authorized flights and the number of submitted flights) and the U-plan submission time (i.e.: how far before takeoff the operator submits the operation). To test this, in each run, two types of operator behaviors are simultaneously simulated, each submitting 150 flights:

- 16 early-submission operators, who submit their U-plans far in advance: 14 to 24 hours before the take-off time.
- 16 late-submission operators, who submit their U-plans close to the take-off time: 4 to 14 hours before the flight.

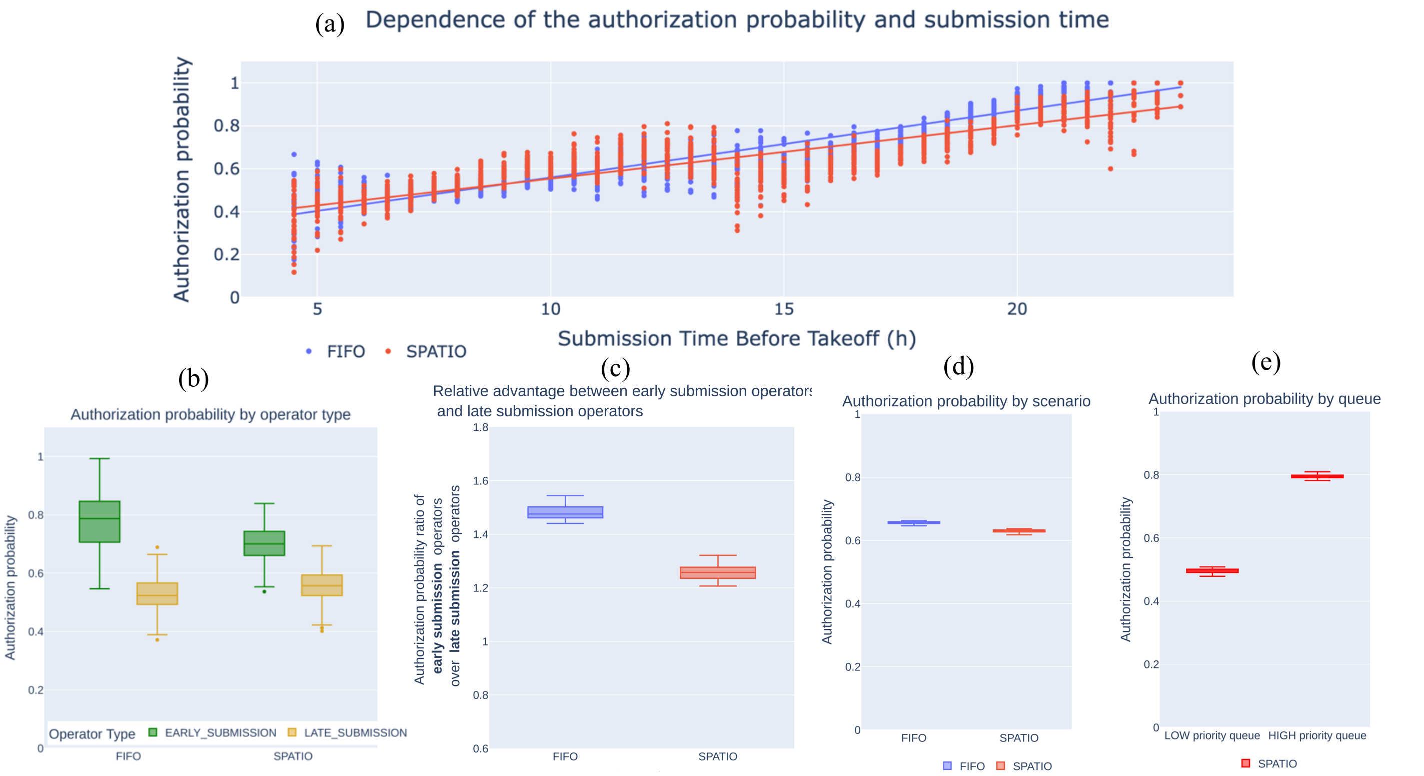

Figure 3. Results obtained for experimental scenario 1 which analyses fairness issues related to the U-plan submission times.

Results for this scenario are shown in Figure 3. The subfigure (a) is a scatter plot relating how likely it is that a flight will be authorized based on how far in advance it has been submitted for authorization. As expected, when using the FC-FS logic (also known as FIFO, depicted in blue) there is a strong linear dependence (*Pearson* coefficient of 0.88), so that those operators who send their operations earlier get to fly a greater number of times. This statement is also supported by subfigures (b) and (c). In subfigure (b), the flight authorization rates of the two operator behaviors are analyzed separately. Thus, early filler operators (in green) obtain a higher authorization success in most cases. The advantage obtained by these operators is depicted in subfigure (c) which indicates that in the FC-FS case they manage to approve on median 1.47 times more flights than late submission operators.

In turn, the proposed deferred authorization and priority queuing approach manages to slightly reduce this dependency as shown in the red data series (tagged SPATIO) of Figure 3(a). In this case, the Pearson correlation coefficient is reduced to 0.75 and, in addition, the slope of the regression line fitted to the data is clearly reduced. Therefore, we can derive that the dependence on the time of submission is partially reduced. Indeed, if Figure 3(b) is analyzed, it can be noted how the overall authorization probabilities of early filler operators have been lowered. This is quantified in Figure 3(c) where the relative advantage of both operator groups has been reduced to a median value of 1.25. Moreover, it manages to mitigate the time dependency without affecting significantly the overall authorization rate, as demonstrated in subfigure 3(d), which compares the total authorization rate for the FIFO and SPATIO scenarios.

Finally, subfigure (e) compares the authorization probabilities of flights submitted in each priority queue. Predictably, flights that are submitted in the N1 queue (denoted high priority) obtain a statistically significant improvement over those submitted in the N2 queue (denoted low priority).

In sum, this scenario allows to conclude that the proposed authorization mechanism is feasible and allows to reduce the fairness concerns related to the submission time of flight plans. It is expected that a more detailed study of how to limit the number of flights per queue for each operator based on historical behavioral data (i.e. more complex fairness rules) would allow an improvement of the results.

C. Experimental scenario 2. Number of flights analysis.

The second validation scenario seeks to analyze the fairness effects related to the number of flights submitted by each operator. For this purpose, operators with two different sizes have been simulated:

- 16 small operators, each submitting 100 flights.
- 16 large operators, each submitting 400 flights.

The time submission behavior of both groups is the same, eliminating this variable from the analysis.

In this case, results are shown in Figure 4. Subfigure (b) compares the authorization rate obtained for each operator group for both the FC-FS and the SPATIO proposals. Focusing on the FC-FS case, it can be seen how both cohorts obtain similar authorization rates. This is logical since in the FC-FS case each flight plan is analyzed independently at submission. However, in absolute terms (the number of approved flights is shown in subfigure (a)), this means that the operators submitting the largest number of flights monopolize the airspace, preventing minor operators from flying.

To ensure competition between operators, the proposed fairness logic could be implemented. By uniformly limiting the number of flight plans in the N1 priority queue, a competitive advantage can be given to small operators, who get to introduce a higher percentage of their flights in this category. This effect is demonstrated in subfigure (b) where it can be seen that in the SPATIO case the probability of authorization increases for operators with few flights and decreases for operators with many flights. In fact, on median, the flights authorization rate of small operators is 1.23 times the one large operators (subfigure (c)). This implies that while larger operators continue to fly a greater number of flights, smaller operators increase the percentage of flights they can operate. Thus, results support that the proposed multi priority queue approach can easily implement different fairness strategies.

VII. Conclusion and Next Steps

Prospective drone traffic analysis foresee a significant increase in unmanned flights in the coming years. As a result,

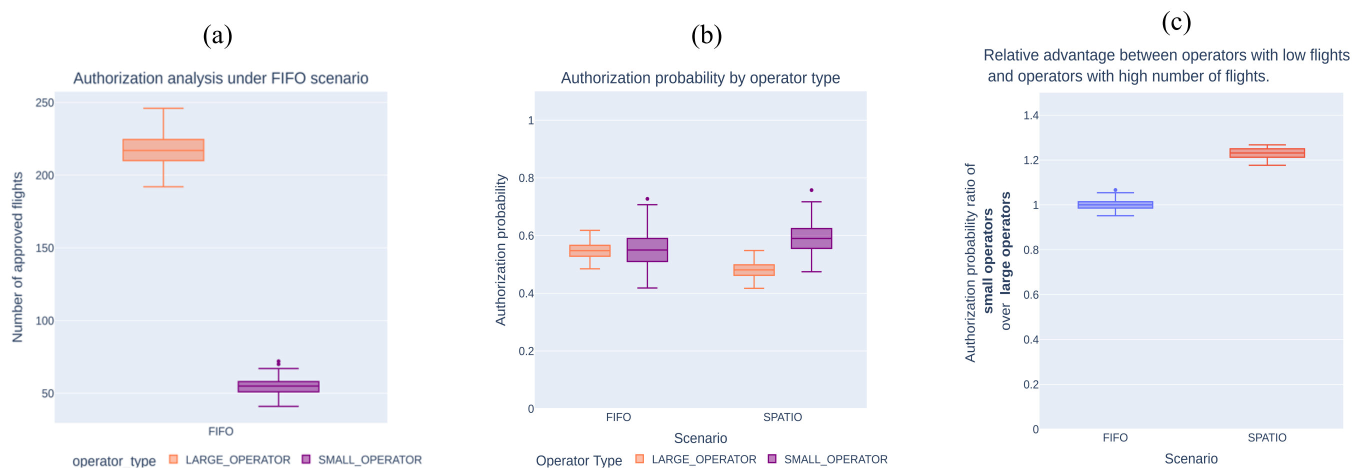

Figure 4. Results obtained for experimental scenario 2, which analyses fairness issues related to the number of submitted flights.

congestion problems are expected to arise, particularly in cities where the highest traffic density is projected. However, the current U-space regulatory framework disregards associated problems such as dynamic capacity management or fairness in airspace access. Although there are some related studies in the literature, there is no proposal that articulates a new authorization process that enables solving these problems while maintaining the distributed nature of U-space.

This article, within the framework of the SPATIO project, has described an alternative authorization flow that lays the groundwork for the integration of DCM and fairness management. In particular, it has proposed to defer the final authorization of the flight plan through an authorization workflow that is independent for each U-plan and based on asynchronous constraints and interactions. As a result, it is possible to break with the FC-FS order and manage capacity in a distributed U-space environment. Regarding fairness, the article has proposed a flight prioritization system based on different queues controlled with simple fairness rules managed from a new U-space service: the Fairness Management service. These simple rules allow to control the capacity of each queue per operator and reduce the dependency between the flight authorization rate and the submission time.

The proposal has been partially validated by simulation experiments that show that it is feasible and that it allows tackling the fairness problem. Although limited fairness rules have been used, an enabling mechanism has been put in place that allows fairness rules to be improved in the future to ensure proper fairness management. Other future work includes the integration and testing of DCM techniques within the proposed authorization framework and conducting actual tests with operators to assess their satisfaction with the mechanism.

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