Delays caused by ATFM measures in 2007 amounted to 21.5M minutes, causing an estimated cost of €1,300M to the users [8].

C. User Driven Prioritisation Process (UDPP)

Nowadays in real-time operations, Air Traffic Management provides services on a "First come, first served" basis without real reference to maintaining airline schedules. This minimizes the possibilities to help airspace users and airport operators managing punctuality performance. This contrasts with the commercial airline sector which is very competitive. It is therefore essential for airlines to construct their individual schedules to satisfy their selected market, resulting in their competing needs not necessarily being aligned with some notion of overall network optimisation.

Airspace users among themselves can recommend to the Network Management a priority order for flights affected by delays caused by an unexpected reduction of capacity, and more generally any kind of measures such as cancellation or re-routing. The airspace users will respond in a collaborative manner to the Network Management with a demand that best matches the available capacity. UDPP requires the cooperative action of a group of actors with diverse objectives and incentives determining their behaviour.

1) Constraints for UDPP.

In the future, airspace should have sufficient capacity to cope with demand in normal circumstances. Nevertheless, there will be more airports which will be working at maximum capacity for significant periods of the day. Most delay allocation will be the result of scheduling such airports close to their capacity limits and delay management at such airports will be a daily activity.

The key aspects of UDPP are to achieve an effective balance between the overall Network efficiency/stability and the diversity of user requirements and to assure an impartial perspective, balancing the various and potentially conflicting requirements and keeping the overall performance requirements and access right as a guiding principle.

2) Degrees of Freedom Left.

Prioritisation will be needed in case of disruptions of the network and at congested airports. The airspace users will be able to trade slots, if they individually agree to do so, based on agreements and rules that are transparent to the other actors. The process will be monitored by the Network Management function in order to make sure that an acceptable solution is available in due time and that all concerned parties are aware of any adverse network wide effects that may develop.

A delay management function will be implemented at network level to assist airspace users in the UDPP process. Consequently, the users will make their prioritisation according to the UDPP process. The Network Management function will assess the impact of the UDPP proposal on network stability or will also call a Collaborative Decision Making (CDM) process to agree an alternative solution in order to minimise the impact of the users' proposal on the network stability.

When runway slots are known, delay will be allocated by users working collaboratively according to their own priorities (UDPP). The network management function is independent and will assure the overall efficiency of the system and may act as decider of last resort if parties fail to agree.

There is another aspect to be considered when prioritizing: the degrees of freedom left. This means that although the main objective of UDPP is to assist airspace users' needs, there will be some predominant ATM measures that will not allow the prioritization of some of these airspace user preferences.

3) Future Implementation of UDPP concept.

Within SESAR JU framework, the possible implementations of UDPP will be analysed and validated under Project 7.6.4 scope, along three main steps:

a) Step 1: Time based operations.

The main change introduced with regards to today's departure slot based process is the shift to the management of arrival times at the congested point/area. UDPP will be first used to address reduced airports capacity, with a primary focus on departure congestion (local demand management). The collaborative decision making process will mainly rely on the existing system using current techniques adapted to System Wide Information Management (SWIM) compliant information sharing.

b) Step 2: Trajectory based operations.

The scope of UDPP is progressively extended to the full 4D management and prioritisation of business/mission trajectories. However the collaborative process remains limited to important mismatch between the network capacity and the demand to ensure that procedures are available to maintain safe operations, to minimize the impact on the demand and to allow for a smooth recovery. This intermediate step will use ground-ground limited SWIM services enabling a mixed mode of information sharing both current techniques and SWIM capabilities.

c) Step 3: Performance based operations

The third step addresses the final UDPP implementation. The scope of the collaborative process is progressively extended to operations in nominal conditions giving airspace users the ability to manage any demand/capacity imbalance according to their business objectives and performance requirements. The Regional Network Manager is the last resort broker ensuring the stability of the whole network. The process is supported by full SWIM-enabled information sharing for the collaborative planning services.

Live trials experiments will be used to assess operational requirements related to Step 1 and Fast time simulation and modelling tools will be used to validate the concept in Step 2 and Step3.

IV. Complexity Metrics and Indicators: A Literature Review

A. *How does the Network Affects Behaviour?*

It might sound obvious that there is a connection between topology and transport function in complex networks. The intricacy of unveiling it relies on discerning between which functionalities or behaviours in a complex network are linked to the network structural properties and which ones are due to the routing rules. The attempts to investigate this issue are focussed on relatively simple networks, from which conclusions can be identified more easily. Once these patterns are captured, similar behaviours in more intricate networks can be sought.

In [9] and [1] the congestion at node level (presence of queue) is correlated with the betweenness centrality. This is a topological property of a node i defined as the average number of times that a random walk between any pair of nodes of the network passes through i. The strong correlation links this random betweenness and the average of particles received by a node in case of random diffusion taking place.

In [9] the global structure of the air transport network is analysed, finding that is a scale-free, small-world network, but with anomalous values of centrality. These anomalies arise because of the multi-community structure of the network. The communities cannot be explained solely based on geographical constraints, but also geopolitical considerations have to be taken into account.

The ‘‘systems’’ analysis of the structure of the worldwide air transportation network carried out in [1] unveils that the network is a small-world network in which the number of nonstop connections from a given city and the number of shortest paths going through a given city have distributions that are scale-free. The nodes with more connections are not always the most central in the network. The work hypothesizes that the origin of such behaviour is the multi-community structure of the network. The analysis of the community structure allows identifying the most efficient ways to engineer the structure of the nodes, by detecting which ones are poorly connected. Cities that connect different communities play a disproportionate role in important dynamic processes such as propagation. While most of the nodes (95%) are peripheral; that is, the vast majority of their connections are within their own communities, nodes that connect different communities are typically hubs within their own community, although not necessarily global hubs. The existence of network-specific roles points to the more general question of what evolutionary constraints and pressures determine the topology of complex networks and of how the presence or absence of specific roles affects the performance of these networks.

The scale-free feature is key for improving the network functional robustness from a macroscopic point of view. Statistically, the probability that a hub node is impacted by random perturbations is the same that for a non-hub one, for which external perturbations or unexpected events impacting the performance of the node’s elements do not imply that the network structure is affected so severely [15] and [16]. However, the error tolerance comes at the expense of attack survivability. The topological weaknesses are linked to the inhomogeneous connectivity of these networks, a feature that could be exploited by those seeking to damage these systems.

Reference [17] establishes correlation between reliability and topology for electricity networks. Some topological features that are found to increase with the fragility of the network are the deviation from a random graph null model degree distribution, the increased preponderance of star and triangle motifs in spite of linear ones and the inhomogeneous patch size distribution. Evidences analysed show an increased fragility when the topology of the network deviates from a random one, maybe in search of a higher interconnectedness. On a topological basis, favouring the connectivity and interconnectedness, though originally intended to avoid interruptions in power service, would difficult, at the same time, the islanding of disturbances.

B. *Dynamic Indicators for Managing Complex Networks*

The behaviour of a complex network is very hard to predict, even if it stick to rigid local rules and no disturbances (noise) are in place, since very often the outcomes of ruling depends on the dynamics/ history of previous decisions. How to avoid the triggering of global cascades of “contaminations” (being epidemic diseases or overloads at nodes) is a matter of much study.

One of pioneering books on complex networks approaches the discussion of the appearance of cascades [10]. The propagation of undesired disruptions is linked to the existence of percolating clusters. Taking as example a network of individuals of two types (vulnerable and stable) and the transmission of information, Watts describes how an innovation can only spread if the initial innovator is connected to at least one early adopter. If the innovation hits a vulnerable cluster (one containing potential adopters) and this cluster happens to percolate throughout the network, then the innovation will trigger a global cascade. The potential occurrence of global cascades can be predicted from the existence in the network of percolating vulnerable clusters. As one of the conclusions included in the book, Watts highlights that real-world complex systems are both robust and fragile at the same time. They are robust because they have to survive in the real world and, if not able to withstand shocks, they would have either to be re-designed or evolved. But the cascade model shows also that every complex system has a weak point, which if struck can provoke even collapse of the system. Usually the weakness is quickly fixed once identified, but as it is demonstrated, that does not remove the fundamental fragility of a complex system, and the weakness will most probably only be moved to another part of the system.

Dynamic robustness is monitored in [11] to provide indications on the actions that can be performed in a network in order to decrease undesired effects. Robustness, as defined for the study of the impact of structure on the network behaviour, is defined as the ability of a network to avoid cascading of overloads failures when a fraction of its constituents is damaged. The dynamic robustness is then introduced to study the impact of dynamics on the behaviour. The damage or malfunction (degraded capacity) of a single node can trigger a cascade. The question discussed in [11] is the identification of the possible operational strategies to prevent the cascade from propagating through the entire network. In [12] the "strategy of defence" is based on the selective further removal of nodes having small load and edges having large excess of load, right after the initial attack or failure and before the propagation of the cascade. In [13], instead of permanently removing the overloaded nodes to prevent propagation of overloads, the diffusion through these nodes is degraded.

The network critical load, defined as the particle density beyond which jamming at the nodes appears, is used in [9] as an indicator of the influence of network routing rules on behaviour. Congestion awareness is introduced in the diffusion rules of the particles in the network: particles are randomly assigned origin and destination nodes, and the routing rule for the particle to be moved to the next location in its way from origin to destination is based on the local information about congestion degree of neighbours, i.e. the queue lengths of the neighbouring nodes. The routing rules are varied between random diffusion and rigid congestion-gradient driven flows. The main result shown with the theoretical models used, is the existence of an optimum value of the congestion awareness parameter, both for random and for scale-free networks: the network critical load increases when a small amount of local congestion awareness is present in the routing rules, but it decreases as the routing rules become too rigid. The result reveals the existence of "stubs" acting as traps for the particles: low degree nodes connected to hubs with long queues.

For the correct reading of these conclusions, it must be highlighted that the routing rules used a purely local congestion-awareness parameter. In this line, other significant result shown by the authors of the model is that, regardless of the network topology, the critical load decreases as the number of nodes increases: in large networks with routing based on local information jamming at nodes appears unavoidable.

Within the air transport domain, the reorganisation of the airlines route networks is another field of study for improving the performance of the network. Reference [14] proposes a complex network approach to the matter. The work is based on the premise that the two main categories of airline route networks, point-to-point and hub-and-spoke, are examples of small-world and scale-free networks respectively, and so the related studies from complex networks domain are applicable for the study of airline route networks. The paper focuses therefore on measuring airline route related indicators such as the average shortest flight distance of an airline route network and the airline network robustness against closure of airport(s) and/or route segment(s).

V. Preliminary Set of Scenarios

With a view on the challenge of improving the efficiency of the European air transport system, and trying to anticipate the impact at network level, a list of criteria is included here as potentially beneficial in the context of European ATM. Implementation and simulation of the resulting routing rules and combinations of them in the network will provide feedback on the possible consequences in terms of network stability and performance.

Criteria should take into account the following scenarios:

- Giving priority to flights with higher number of passengers with connecting flights, or with higher ratio "number of passengers with connecting flights" / "total number of passengers". When using this criterion, a number of sub-criteria can be also applied:
    - For those passengers with connecting flights, the time buffer for transfer at the transfer airport must be maximised, therefore trying to give priority to flights with passengers for whom a minimum delay would imply the consumption of the transfer buffer and, ultimately, missing the connecting flight;
    - In the same line, looking upstream could unveil that final destination (that of the connecting flight) is a poorly connected airport. This would imply that those passengers missing the connecting flight will probably have to wait until the day after to find another option for reaching final destination.
- Criteria for passengers with connecting flights are also applicable to cargo connections for cargo flights. Here, besides, another factor is called into play: perishable cargo, for which a delay in delivery will mean a dramatic loss of value. An example are daily newspapers;
- Service quality commitments of airlines depend on the particular business model of each aircraft operator. Diverse models can be implemented, assigning higher priorities to flights with certain characteristics pre-defined by the company. An example is the number of business passengers on board;
- The previous criterion links with the establishment of global scoring criteria for flights, where prioritised lists issued within each company are further filtered taking into account the cost that delay would imply for each type of operator;
- Looking at limiting the propagation of delays, flights going to less congested airports should be given priority. Otherwise, overloads will follow and stacks will give raise to the appearance of delays yet at new network locations;
- Dependencies between flights through the use of the same aircraft are source of much reactionary delays.

The countermeasure could be giving priority to flights with the higher number of rotations upstream;

- An airline at its hub airport usually has at its disposal aircraft for replacement in case the arrival of the previous rotation of a departing aircraft is delayed for any reason. Therefore, penalising flights heading to their airline hub might not be so critical in terms of delay propagation;
- The possibility of using secondary airports in combination with surface transport should be taken into account when congestion is also affecting destination airport, as a way to restrain delay propagation and to timely deliver cargo or passengers to their destination.

VI. Expected Outcomes and SESAR Research Questions Addressed

The research proposed by NEWO project within SESAR WP-E scope will identify and evaluate new operational solutions for flight prioritization rules in case of severe capacity shortfalls affecting departures at airports.

This main objective responds to the interest of the airspace users in applying their own priorities, based upon a CDM approach, during periods of capacity shortfall. In the absence of any external event affecting the capacity of the Air Transport elements, flights are usually handled on a first come first served basis. In case of severe capacity shortfalls affecting departures, departure flights can be prioritised according to pre-defined rules/ criteria. The criteria for building the departure queue (either first come first served or prioritisation) might be necessary in case of disruptions in the network and at congested airports within the context of a congested network. It will be the responsibility of the airspace users (mainly airlines) to respond in a collaborative manner with a demand that best matches the available capacity. This is known as the User Driven Prioritisation (UDPP) Process. It is also foreseen that the UDPP process is supported by a catalogue of pre-defined strategies.

The success of this operative is linked to the evaluation of the set of airline operational strategies and potential solutions in support of the UDPP. A pre-assessment of the potential impact that diverse prioritisation rules would have on the network performance and stability is needed, capturing any adverse network-wide effects that their application may develop.

Expected outcome of the study are the probabilities and consequences in terms of operational performance (predictability, capacity, and efficiency), of the introduction of innovative and business preferred local operational approaches. In the ATM system, all players are concerned with minimising the impact in terms of potential operational, economic or environmental penalties derived from the implementation of local strategies with negative global consequences. Even if a certain local solution seems optimal for the individual operator applying it, the reactionary effects can mean, at the end of the day, performance degradation in the network that revert in cost-inefficiencies for the operator. Moreover, today's strategies might not be optimal for tomorrow's network. The behaviour of a congested air traffic network is still an open issue within the field of air traffic management. In highly congested networks, sub-optimal behaviours may emerge, such as bunching, deadlocks, delays, or too long recovery times, which may spread across the network and hinder its performance. The assessment, previous to SESAR implementation phase, of the impact of these strategies, allows setting additional measures that enable tackling in the most beneficial way with the possible emerging behaviours generated by the congestion of the network at the horizon 2020+.

The NEWO project is part of the SESAR WP-E, dedicated to long term innovative research of air transport. Research included in WP-E is focussed on investigating promising ideas that could bring improvements to the air transport system beyond the SESAR timeframe. As a catalyst of European research capability, WP-E addressed the unveiling of system interrelations and dependencies by looking at the air transport from innovative perspectives. NEWO contributes to two of the four research themes proposed within WP-E:

- Mastering Complex Systems safely. Complexity science can help understanding the behaviour of the ATM complex system. The air traffic system contains a huge number of elements and agents that interact, in many situations nonlinearly, giving rise to degraded behaviours of parts of the network or of the whole network. NEWO applies the complexity prism to air transport network modelling, further developing and exploring the potential of the ATM-NEMMO modelling framework which incorporates schemes from the complexity science. The approach puts effort on global modelling to capture the nonlinear coupling effects and emergent behaviour.
- Economics and Performance. As it is stated in the Economics and Performance Theme, users will increasingly require that charges are based on quality of service provision, measured by such elements as capacity and delay, and therefore costs. The impact of certain prioritisation rules on departure delays and capacity are some of the issues that will be deeply addressed in the project.

Within the main addressed WP-E theme Mastering Complex Systems safely, NEWO project cover the following topics:

- Intelligent modelling: Investigate the modelling of the ATM system of systems using methods and tools from the science of complexity, with models able to capture its changing, dynamic and evolutionary behaviour.
- Emergent behaviour: Use any results to better understand emergent properties such as delay, predictability and safety.

- Non-determinism: Investigate the impact of uncertainty on overall system behaviour.

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