Mobility Impact Assessment of Innovative Aircraft inside the European Multimodal Transport Network

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The Clean Sky Joint Technology Initiative (JTI) within the EU Horizon 2020 Framework Programme proposes to introduce new concept aircraft and rotorcraft to replace reference technology counterparts at different time scales (2020/2035/2050). An increasing global demand for efficient air mobility and transportation systems will foster the development of highly optimized transportation solutions. In a future context of advanced intermodal and multimodal transport systems, particular importance will be given by the regional connections performed by innovative aircraft able to manage trips with effective "door to door" travel time within 4 hours. The paper presents a new way of predicting the mobility impact of new aircraft configurations on the current and future European transport network. The methodology, developed in the framework of the DEPART2050 project, has been implemented to show how innovative aircraft and rotorcraft connections could coexist and improve the current and future networks of high-speed train, highways, commercial aircraft operations, quantifying the consequent benefits. A case study representing the European intermodal/multimodal network is shown in order to illustrate the potential of the methodology. A complete mobility analysis of the entire European intermodal network is presented, and the results are described in detail.

I. Nomenclature

ATS	=	Air Transport System
EU	=	European Union
GCD	=	Great Circle Distance
NA	=	New Aircraft
N_{max}	=	Maximum number of new New Aircraft routes
NGCTR	=	Next Generation Civil Tiltrotor
NUTS	=	Nomenclature of Territorial Units for Statistics
PR4	=	Population Reached in less than 4 hours
STT	=	Shortest Travel Time
TT	=	Travel Time
VTOL	=	Vertical Take-Off and Landing

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II. Introduction

Within Clean Sky 2, the project DEPART2050 (Design Evaluation and Performance Assessment of Rotorcraft Technology by 2050) has undertaken the environmental (emissions and noise) and socio-economic assessments for two fast rotorcraft technologies: the tiltrotor aircraft and the compound helicopter. The objective of the project work is to perform at airport level and at Air Transport System (ATS) level, assessments of environmental (emissions and noise) and mobility improvements that may be accrued through the introduction of these new technologies over the designated time scales. Different missions have been simulated: passenger transport, Emergency and Medical Services (EMS), Search and Rescue (SAR), ferrying to offshore Oil And Gas (OAG) rigs, and cargo transport. Preliminary mission analyses performed by J. Stevens et al. [1] reveal that considerable reductions in time and normalized CO_2 emissions can be found for fast rotorcraft relative to conventional helicopters. Moreover, in passenger transport missions, relevant reductions in total travel time are found especially when compared to other means of transportation, such as road, rail and conventional air transport. In fact, such innovative aircraft, as they can operate from shorter runways, will enable the utilization of smaller airports and optimally located heliports. Past research [2],[3] suggests that the introduction of VTOL services in civil aviation could provide a valid solution to air and ground congestion and has the potential of reducing delays at busy airports: in fact, "tiltrotor aircrafts are among the technologies that could improve passenger mobility at large terminals and in the most crowded intercity corridors"[4] .

Mobility improvements are highly mission and location-dependent: for this reason, a more general network modelling approach is needed to quantify the benefits given by integrating new aircraft (NA) inside the current European passenger transport scenario. A literature review on air transport network modelling can be found in Zanin and Lillo [5], whereas an interesting worldwide study on the air transport network by Allroggen et al. [6] proposes a new metric for air transport connectivity, able to quantify local network issues and performance.

However, mobility benefits cannot be analyzed considering air transport alone: in fact, if the new aircraft may sometimes be a valid alternative to conventional aviation, most of the time it will be integrated inside traditional air routes, resulting in a better travel solution with respect to ground transport. Sun et al. [7] implemented a door-to-door travel time estimation framework, aiming to analyze the potential competitiveness of on-demand air taxis in Europe with respect to existing transport modes: car, railway and scheduled air transport. A similar method has been used also by Grimme et al. [8] in a study focused on Germany, in which they analyzed the potential use of a hybrid-electrical regional aircraft for regional air transport services from smaller airfields. Both these studies analyze the problem of the introduction of a NA from a domination standpoint, i.e., they predict which is the distance range where the NA mode will be winning against competing modes. Neither of these studies deals with the potential combination of modes, apart from the air network: access and egress times from relevant cities to their nearest airport are taken into account in the air transport mode, constituting a first basic intermodal/multimodal passenger transport (car+airplane).

Nevertheless, intermodal transport analysis studies [9],[10] demonstrated the importance of mobility assessments carried out on a fully integrated transport network. This is even more important following the goal established by ACARE (Advisory Council for Aviation Research and Innovation in Europe) of achieving, by 2050, 90% of intra-European door-to-door journeys within 4 hours [11], a topic which has been furtherly treated by Grimme and Maertens [12]. For this reason, the European Commission supported the development of TRIMODE [13],[14], a model which integrates a fully comprehensive European intermodal transport network, representing in detail all transport movements on all freight and passenger modes at a NUTS 3 zonal scale.

The current paper presents the methodology developed to assess the mobility benefits arising after the introduction of a new aircraft or rotorcraft network inside the current European intermodal transport network. A new modeling tool, the EMMA (*European Multimodal Mobility Analysis*) code, has been implemented to calculate the best intermodal transport combination, minimizing travel time, which is needed to reach location B from location A. This has been achieved by modelling the network as a graph, as suggested in [15], in order to solve the shortest path mathematical problem with the Dijkstra algorithm [16].

The implemented methodology allows to simulate the networks of various transportation modes and integrate them with a new one, dedicated to the specific aircraft under analysis. The models, for the moment able to cover the European countries, use the data related to current road, rail and air connections (2019).

The EMMA code presents various innovative capabilities: firstly, it tackles the NA mobility impact problem considering the overall transport network, not only the air traffic network. This is of prior importance because small and regional aircrafts are often in direct competition with efficient ground transport systems; not considering these infrastructures would lead to incomplete and inaccurate deductions. Furthermore, it includes a quick way to rank the best routes that should be added to the baseline network, based on a few aircraft high level requirements. Thanks to the use of innovative aircrafts and rotorcrafts capable of VTOL (vertical take-off and landing) characteristics, even heliports and smaller airports, which currently do not have regular scheduled flights, could become viable nodes of the new network. For this reason, a complete list of European minor airfields has been included in order to account for new promising routes; it is therefore possible to select a subset by filtering the airports based on a limited number of parameters (such as runway length, surface type, etc.).

The whole analysis is focused on optimizing connections by minimizing shortest travel time (STT) from origin to destination, allowing intermodal transport changes: this is done selecting the most suitable transport mode combination (road, rail, air). Connection, node and network performance metrics will be proposed and discussed. Other factors, such as fare prices and comfort are not considered and should be modelled in future developments.

At the moment, the EMMA code works on the European network, but it can also be expanded for worldwide analysis purposes. The model, visible in Figure 1, works by integrating a geography module, where the network locations are selected, and various travel time matrices, related to the different transport modes: road, rail, air, and NA mode. The NA network is built by simulating the NA on the selected routes using a dedicated flight route model.

III. The EMMA model description

Predicting how the introduction of a new aircraft (NA) may impact on the future European transport network is a difficult and complex task. The difficulties in solving this mathematical problem are the following:

- Existence of a large number of variables;
- Transport mode choice depends on human decisions;
- Travel time is a statistical quantity, not a deterministic quantity;
- Large data is required for model validation.

Despite these difficulties, it is possible to build up a simplified model capable of giving reasonable indications, by making the following assumptions:

- Each trip leg from point A to point B is uniquely characterized by its shortest travel time (STT) value, an approach followed also by Grimme and Pabst [17]: one single value, the minimum possible. Reality is instead affected by traffic, airplane or train connection delays, different coincidence times, all introducing variability in travel time, which in fact is a distribution with an associated probability. In EMMA, this variability is neglected.
- For each trip connection the passengers choose the best intermodal combination which minimizes STT. Each transport mode change carries a penalization due to a fixed time wait for the mode exchange; the wait time assumptions will be better explained in the following paragraphs and are visible in Table 1.

The EMMA model is, to the authors' knowledge, the first attempt to provide a quantitative method to measure the impact of NA introduction on a full intermodal transport scenario The goal of EMMA is to assess whether the introduction of a NA can produce quantifiable benefits for the European network, in a specific time scale; in addition, it should be capable of discovering the routes providing the highest benefits to the network. The EMMA model works by integrating different submodules, described below.

A. Geography module

The EMMA model requires to define a discretization of the space to be analyzed in order to build the intermodal transport network. NUTS 3 regions belonging to EU and other European countries have been chosen as they are characterized by a good level of detail for the purpose of our study. NUTS (Nomenclature of Territorial Units for Statistics) is a European geocode standard for referencing the subdivisions of countries for statistical purposes, established by Eurostat in 1988. The smallest regional discretisation level for which population data are publicly available is NUTS 3 level (corresponding approximately to US counties): access to population data for the 2000-2018 period is available consulting the Eurostat database [18].

In the geography module, a total of 1399 NUTS 3 regions belonging to EU and other partner countries (i.e. Switzerland, Norway, etc.) are analyzed. Figure 2 highlights how this territorial subdivision is carried out. For the network to be built, however, it is necessary to choose for each NUTS 3 region a unique geographical point that represents it; for practical reasons it was decided to use the most important (populous) city center of a region as the node of the network; a similar approach was employed by Grimme et al. [17].

In addition to city nodes, there are also airport and train station nodes; for simplicity the train station nodes coincide exactly with the city center nodes. The European network considered involves 1399 cities in 34 countries (the chosen nodes are visible in Figure 2) and more than 4500 existing airports and heliports of the most different sizes, from the smallest heliport up to big international airports.

A network can be mathematically represented by a graph: this equivalence permits to use the algorithms derived from graph theory. Cities and airports represent the graph nodes, and they are connected by edges; each edge connection is characterized by an edge weight, which in our model is represented by travel time (TT). Two nodes can have more than one edge connecting them, each of which is representative of a different transport mode. Each transport mode network can be viewed as a separate subgraph; merging all the mode subgraphs allows to build the complete intermodal network. A practical example of network subgraph can be observed in Figure 3.

In the following paragraphs, a description on how to calculate the node-to-node edge weights, represented by travel time (TT), will be illustrated for all the three abovementioned transport modes.

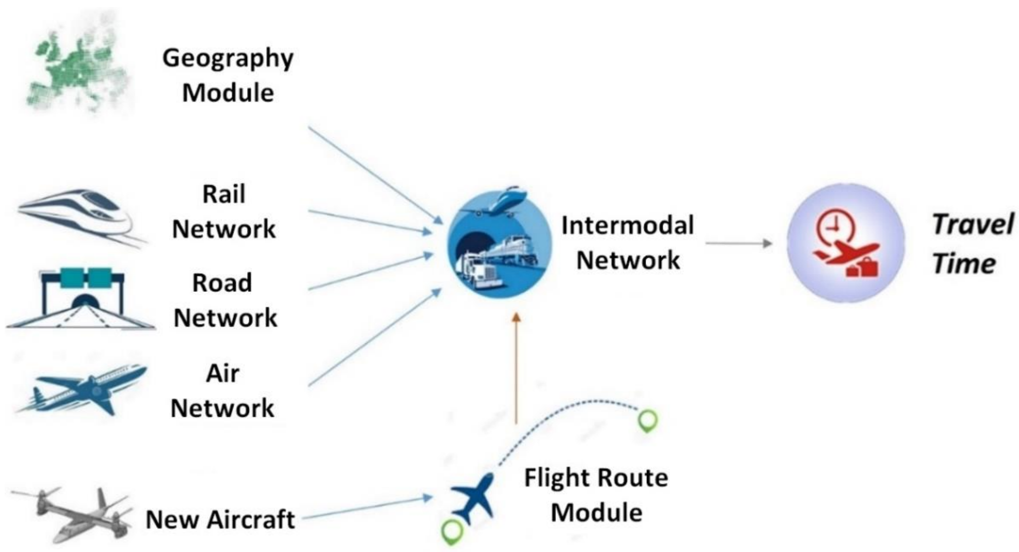

Figure 1. Structure of the EMMA mobility analysis tool.

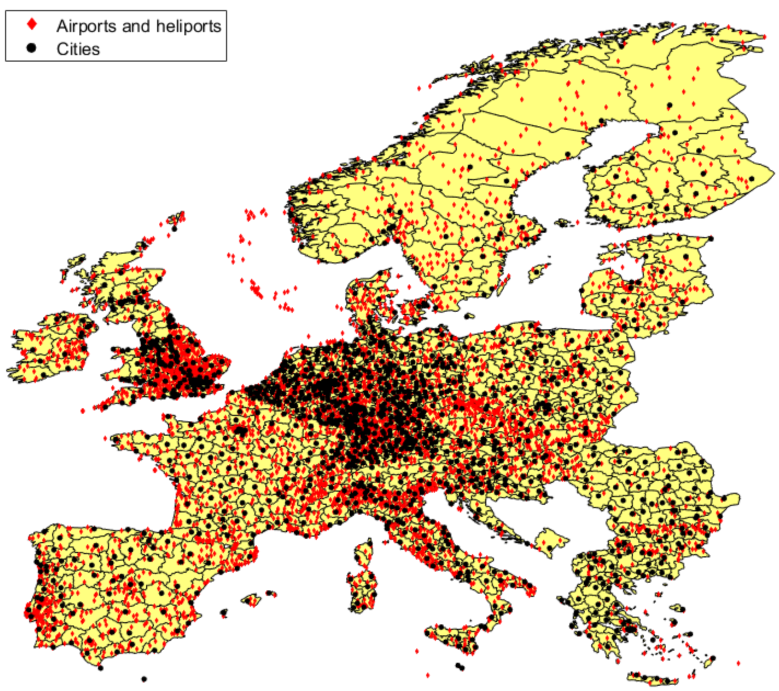

Figure 2. NUTS 3 regional subdivision: NUTS 3 cities and airports/heliports represent the nodes of the EU intermodal network.

B. Road network

The car network nodes are represented by the complete set of NUTS 3 cities, whereas edge weights are represented by the TT values calculated using the Openstreetmap routing service [19]. This service uses average travel times depending on the road type, without accounting for traffic; differences in TT estimation between Openstreetmap and Google Maps have been found lower than 10%. The car network is given as input to the EMMA tool: each NUTS 3 city is connected to all the others (1399X1399 matrix, with empty diagonal), and TT is calculated in both directions for every city pair.

C. Railway network

The train network nodes are all the NUTS 3 cities and the TT values between nodes are obtained from a web service that provides train timetables, Eurail [20]. The calculated time is computed based on the existing real connections (2019); if there are more options with different travel times, the one that provides the minimum time is chosen. For the limited number of NUTS 3 cities that do not have a train station, travel time by car is added to reach the nearest train station. Unlike the car network, where the net travel time is considered, for the train mode an additional waiting time is inserted at the departure station and a waiting time at the arrival station, which will add up to form the total time. The waiting times are defined in Table 1.

D. Scheduled air transport network

This network is actually the union of two distinct networks:

- Airport network (airplane flight mode): it is composed by all the EU airports having scheduled flights as nodes. Airport network time is computed as the sum of flight time, waiting time at origin airport, waiting time at destination airport and connection time (only in case of indirect flights).
- City-airport connection network (car mode): its origin nodes are NUTS 3 cities, and its arrival nodes the airports. In order to avoid unnecessary network complexity, only a fraction of the possible city-airport connections is considered: an airport proximity time filter is used to cut every city-airport connection characterized by a connection time over a specified threshold. The travel time is calculated in the same way as the road network.

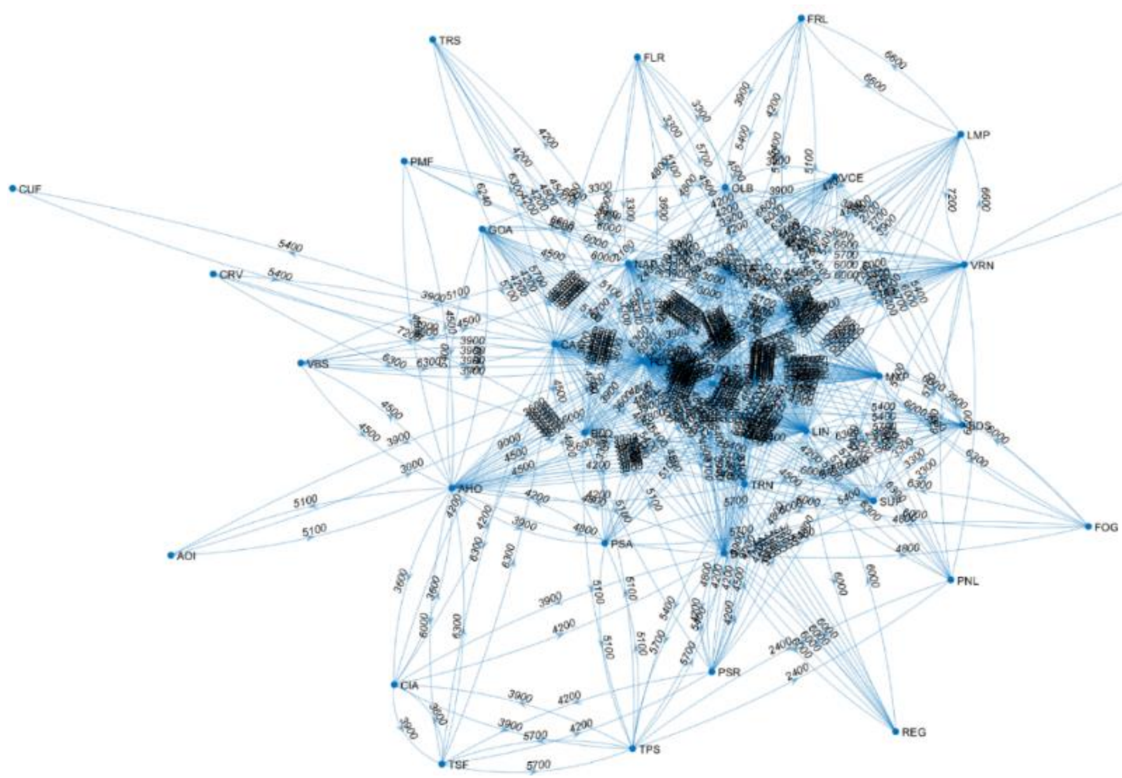

Figure 3. Italian airport network subgraph: TT is the edge weight (in seconds).

E. Intermodal network.

The union of the car, train and air transport networks, transformed into a single large graph, allows to create the *baseline intermodal network*, or simply *baseline network*. The goal of the intermodal network construction is to calculate the shortest travel time (STT) needed to reach location B from location A, along with the information of the employed combination of transport modes. STT can be calculated using the well-known Dijkstra algorithm [16], which is commonly used to find the shortest path between nodes in a graph.

The EU intermodal network implemented inside the EMMA code is composed of more than 3 million edge paths. It is possible to construct a matrix containing all the 1399X1399 city pair travel times and to store, for each pair, the transport mode combination which realizes that specific travel time (trip data). In Table 1 the different waiting and connection times employed in the model are listed for different transport modes.

Table 1. Network waiting and connection times assumed in the model.

Airport proximity time filter	180 min
Big airport waiting time	60 min before departure, 30 min after arrival
Heliport/Small airport waiting time	20 min before departure, 10 min after arrival
Train station waiting time	15 min before departure, 10 min after arrival
Aircraft connection time	45 min
Train connection time	15 min

F. Flight route module

A flight path model is necessary for the estimation of travel time of the new aircraft (NA) for each mission. The typical NA mission can be simplified in the following phases: warm-up, take-off, climb, cruise, descent, landing, idle. The travel time related to some of these phases can be considered fixed (warm-up, idle, take-off and landing), while the duration of others will vary depending on route distance (cruise, climb, descent). An example of mission profile for a generic regional aircraft is visible in Table 2. Regional aircraft example: input data needed to simulate NA missions.Table 2 and Figure 4: for shorter missions it makes sense to choose a lower cruise altitude (and maybe speed) with respect to longer missions, optimizing operational performance. In order to estimate the travel time, it is thus necessary to know the duration of each phase as a function of distance. This is a mandatory input to be inserted in the model.

Wind speed is not taken into account in flight route model simulations. When considering aggregate travel time calculations - which is the main objective of this study - the wind effect on time is expected to be neutral, since the percentage of flights with favorable and opposite winds should be similar.

Any changes in flight parameters happening in real cases, such as changes in speed and altitude due to unpredictable causes (meteorological conditions, engine malfunctions, etc.) are not simulated.

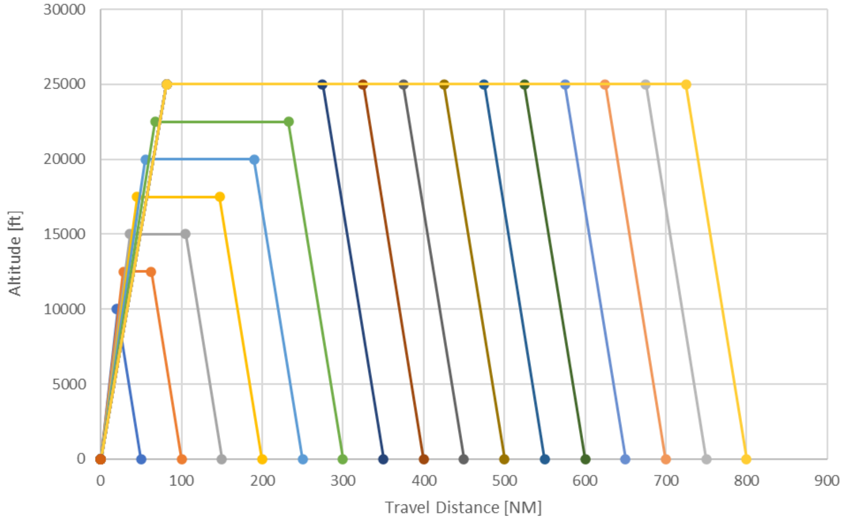

Figure 4. Regional aircraft mission profile: climb, cruise and descent altitudes as a function of distance.

Table 2. Regional aircraft example: input data needed to simulate NA missions.

PARAMETERS		WARM-UP	TAKE-OFF	CLIMB		CRUISE		DESCENT		LANDING	IDLE
Distance [NM]	Max altitude [ft]	Time [min]	Time [min]	Horizontal Speed [kCAS]	Vertical Speed [ft/min]	Horizontal Speed [kCAS]	Vertical Speed [ft/min]	Horizontal Speed [kCAS]	Vertical Speed [ft/min]	Time [min]	Time [min]
50	10000	3	1.5	270	2125	290	0	270	-1500	2	1
100	12500	3	1.5	270	2000	295	0	270	-1500	2	1
150	15000	3	1.5	270	1875	300	0	270	-1500	2	1
200	17500	3	1.5	270	1750	300	0	270	-1500	2	1
250	20000	3	1.5	270	1625	300	0	270	-1500	2	1
300	22500	3	1.5	270	1500	295	0	270	-1500	2	1
350	25000	3	1.5	270	1375	290	0	270	-1500	2	1
400	25000	3	1.5	270	1375	290	0	270	-1500	2	1
450	25000	3	1.5	270	1375	290	0	270	-1500	2	1
500	25000	3	1.5	270	1375	290	0	270	-1500	2	1
550	25000	3	1.5	270	1375	290	0	270	-1500	2	1
600	25000	3	1.5	270	1375	290	0	270	-1500	2	1
650	25000	3	1.5	270	1375	290	0	270	-1500	2	1
700	25000	3	1.5	270	1375	290	0	270	-1500	2	1
750	25000	3	1.5	270	1375	290	0	270	-1500	2	1
800	25000	3	1.5	270	1375	290	0	270	-1500	2	1

G. New aircraft network

It is necessary to know the new aircraft routes and performance data to employ the Flight Route Model and determine the travel time spent by the NA in each individual route. By making a comparison between the *baseline network* and the *improved network* including NA routes it is possible to quantify the potential contribution of the new aircraft mode to the performance improvement of the entire intermodal network.

In addition to NA mission data, two additional aircraft parameters are of major importance in determining network improvements: the maximum range and the minimum runway length to achieve a safe take-off. In fact, the possibility of using heliports and small airports (with short runways), which may not currently have scheduled flights, could bring relevant advantages in a future transport scenario. For this reason, a list of all available EU airports has been downloaded from the Eurostat website and has been integrated with data related to runway length. The choice of the airports on which to operate the new aircraft depends mainly on these parameters and drives the choice of the nodes of the new aircraft network. The flight route module, on the other hand, allows to calculate the travel times of the new network: the connections will be limited by the maximum range of the aircraft, thus reducing the number of total possible connections between airports.

The choice of the airports/heliports on which to operate the NA drives the choice of the nodes of the new aircraft mode network. The problem arises on how to determine which are the NA routes that should be added to the baseline network. It is clear that adding all possible routes would not be achievable in practice (the number of possible airport combinations is too high). Inside the EMMA code an optimization procedure has been implemented in which it is possible to define a maximum number of new roundtrip NA routes and the algorithm chooses the routes which provide the highest benefits to the overall network. The result can be achieved with the following steps:

1) Calculate STT values for the *baseline network*.
2) Generate a network containing all feasible airport connections for the NA. It is necessary to know some basic characteristics of the NA to determine the set of airports on which it can operate. The union of this network with the *baseline network* gives rise to a new network, hereinafter referred to as the *complete network*.
3) Compare STT matrices of the *baseline network* and the *complete network* and classify the NUTS 3 city pairs according to the maximum reduction in STT or other chosen performance metrics.
4) Choose the maximum number of new routes N_{max}, which are supposed to be operated by the NA.
5) Identify the first N_{max} pairs of NUTS 3 cities that produced the best results, depending on the chosen performance metric.
6) For each NUTS 3 pair identified, analyze the travel data to determine which pair of airports was used and insert the route in a list containing the optimal routes.
7) Generate a NA network with the best routes found in step 6 and add it to the *baseline network* to obtain the *improved network*.

Since the improvements impact not only on the chosen city pairs, but also on the entire intermodal network, this process does not ensure to obtain the best possible solution from a network point of view; however, it certainly finds a solution to the problem reasonably next to the optimum. By this way it is possible to quantify the potential NA contribution to performance improvement of the entire intermodal network.

The routes can be ranked based on different network performance metrics, explained in the following section. These metrics can be used to compare the *baseline* and *improved* networks, at both connection and node levels.

IV. Mobility impact metrics

Several mobility impact metrics can be employed to understand transport network performance at both connection and node level: they permit to quantify performance benefits related to NA introduction. In the following section, these metrics will be used to measure the impact of a specified NA on the *EU baseline intermodal network*.

A. Connection metrics

Connection shortest travel time (STT): it is the shortest travel time possible necessary to connect location A and location B, achieved with one or a combination of more transport modes. As example in Figure 5 we plot connection STT for the NUTS 3 region coded AT333: it is Osttirol, a highly mountainous district in in Austria. All the EU regions are colored based on the STT needed for a passenger to reach them from AT333. Typically, mountain regions require a high amount of time in car connections, especially due to slow roads. Trips towards the middle of Europe present STT of more than 6 hours, corresponding to a low average travel speed. The maximum STT encountered is approximately 12 hours: examples are trips from Osttirol to Arctic regions, the Shetland Islands, Western Ireland. This plot is particularly useful to identify individual connection anomalies between two specified regions.

Connection speed. For a particular connection between locations A and B, it is the great circle distance (GCD) between A and B divided by STT. Note that the real distance travelled is different from the GCD. It also accounts for all the waiting and connection times in changing different transport modes.

Connection efficiency. It is defined as the ratio between a specific connection speed and the network mean speed, computed as a function of distance (using a moving average): its value can be higher than 1. It is a relative measure, so knowledge of the *baseline network* performance as a function of distance is needed (calculated by EMMA). In Figure 6 connection efficiencies between AT333 and the rest of Europe are plotted. It is clear that AT333 is characterized by some connectivity issues: for most of the EU destinations efficiency is between 0.6 and 0.8, which means that for the particular connection distance, connection speed is 20%-40% lower than the EU average. This plot is particularly useful to identify interesting deviations from the average connection speed.

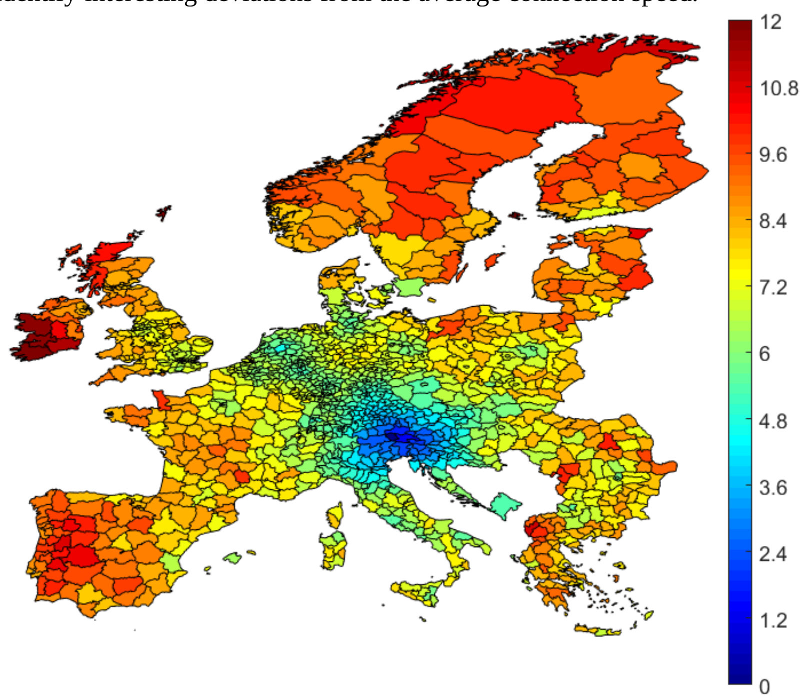

Figure 5. AT333 connection STT [hours] in the *baseline EU intermodal network*.

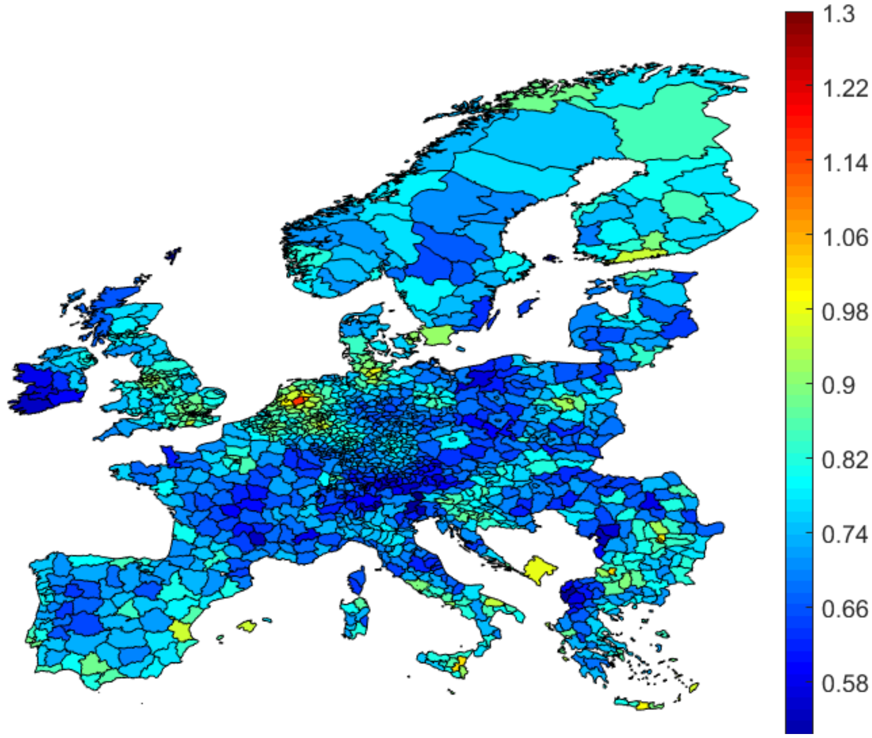

Figure 6. AT333 connection efficiency in the *baseline EU intermodal network*.

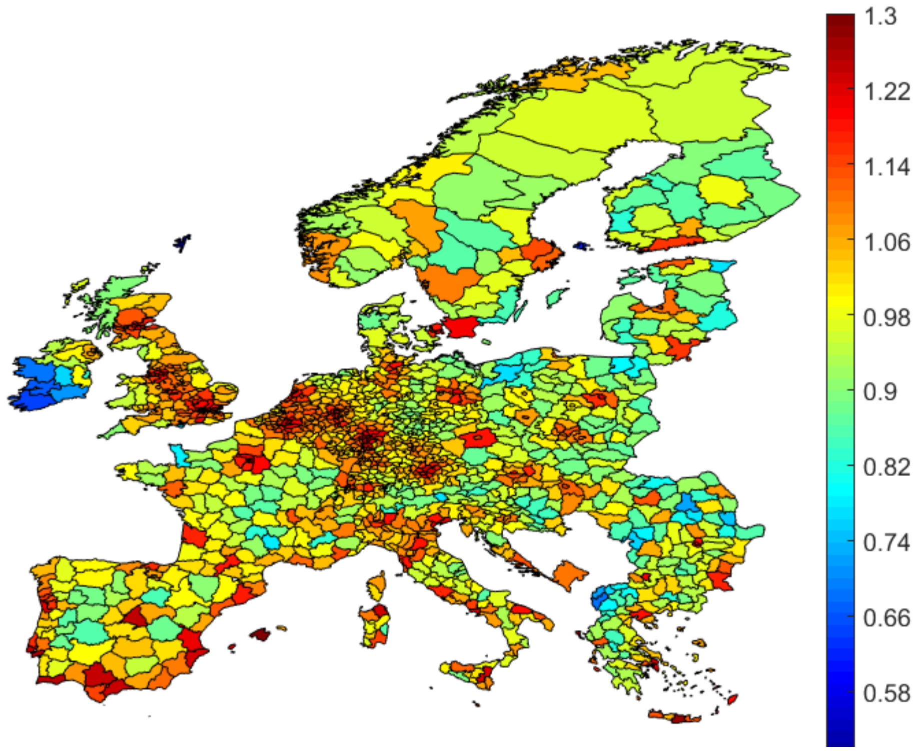

Figure 7. Node connection efficiency for the *baseline EU intermodal network*.

B. Node metrics

Node shortest travel time (STT): once location A is chosen, it is the sum of all STT from location A to all the possible remaining locations.

Node efficiency. It is calculated as the average of the connection efficiencies of all the routes leaving a particular node. It is a relative measure, so knowledge of the baseline network performance as a function of distance is needed (calculated by EMMA). Figure 7 illustrates how node efficiency, which is distance-independent, is a valid measure of intermodal connectivity: the most populated cities are usually well connected, as expected. Remote regions, instead, score lower efficiency values: AT333, our previous example, shows a node efficiency around 0.7, confirming that an average trip starting from Osttirol is 30% slower on average with respect to the rest of Europe.

Population reached in less than 4 hours (PR4). It is the amount of the total population that can be reached, from a particular location, in less than 4 hours, assuming the shortest travel time itinerary. This metric was proposed by Leipold et al. [21] following the 2050 goal set by the EU to achieve 90% of total intra-European door-to-door journeys in less than 4 hours [11]. In order to compute PR4, population values related to the whole set of NUTS 3 regions must be known; in EMMA these data are retrieved from Eurostat [18]. Figure 9 in the next section provides the plot related to PR4 in the *baseline EU network*.

V. Case Study: Next Generation Civil Tilt-Rotor

The Next Generation Civil Tilt-Rotor (NGCTR) is Leonardo Helicopter's (LH) Clean Sky 2 (CS2) Fast Rotorcraft candidate. The NGCTR Technology Demonstrator (NGCTR-TD) will be built and used to optimize the design and demonstrate through flight several innovative technologies, among which the five pillars depicted in the chart below. The configuration will go beyond current state-of-the-art architectures of this type of aircraft, exploiting the results of Clean Sky Green RotorCraft (GRC) and earlier research programs (i.e. Friendcopter, ERICA and NICETRIP). Demonstration activities will aim at validating its architecture, technologies/systems and operational concepts.

NextGenCTR Conceptual aircraft (NGCTR-2023,) is also being developed under CS2 following the work done in Clean Sky in order to predict/analyse the impact of NGCTR-TD innovative technologies on a future tiltrotor product.

Figure 8: CS2 FRC proposed NGCTR concept.

NGCTR-2023 is planned to have a passenger seating capacity of 20-25 people, which is much larger than the nine-seat AW609 tiltrotor. NGCTR-2023 will incorporate the five key major enabling technologies that are being trialled on the Next Generation Technology Demonstrator NGCTR-TD:

1) Split gearbox drivetrain concept and non-tilting engine installation;
2) Advance flight control architecture (modular and scalable flight control system);
3) Advanced wing architecture;

4) Efficient nacelle architecture;
5) Optimised tail configuration.

Any design issues highlighted during the NGCTR-TD flight and wind tunnel testing programme will be assessed, re-designed and applied in principle to NGCTR-2023. NGCTR-2023's typical cruising altitude is up to 25000 ft, whereas the typical cruising speed is up to 250 kts, although details may vary depending on mission range.

In order to understand the benefits given by the NGCTR for passenger transport at the EU network level, it is possible to run a simulation with the EMMA code. This analysis has been carried out on the European Union and three additional countries, for which transport data are available: Norway, Switzerland and the UK, accounting for 1399 NUTS 3 regions. The employed methodology can be summarized as follows:

1) Calculation of the performance parameters related to the baseline network, considering car, train, and airplane modes;
2) Choice of the network optimization parameter: in the current case population reached in less than 4 hours (PR4) is selected;
3) Choice of the number of new NGCTR routes, composing the NGCTR network, which are added to the baseline network to build the *improved network*;
4) Calculation of the intermodal STT values and performance parameters of the improved network.

Firstly, it is interesting to have a look at the current PR4 levels in Europe, which are visible in Figure 9. For each NUTS 3 region, a unique value of PR4 is estimated by summing up all the populations belonging to the regions which can be reached in less than 4 hours. It is clear that regions that are highly populated present higher values of PR4, and also geographical position plays a really important role. NUTS 3 regions in the middle of Europe are surrounded by areas which are highly populated and therefore are able to reach a higher population in a lower travel time. Big cities also score higher levels of PR4, because they have quick access to airports, permitting to reach other big and highly populated cities. Peripheral and remote regions of Europe score the lowest values: Scandinavian regions near the Arctic circle, some Baltic regions, but also isolated islands. Some regions of Sardinia, for example, present internal connection problems: travel times of up to 2.5 hours to reach the nearest airport drastically decrease the PR4 value. Shetland Islands are an extreme example: since no scheduled flights are available there, according to our data, the only connection with the nearest airport is by ferryboat in 8 hours, and therefore the PR4 value approaches zero.

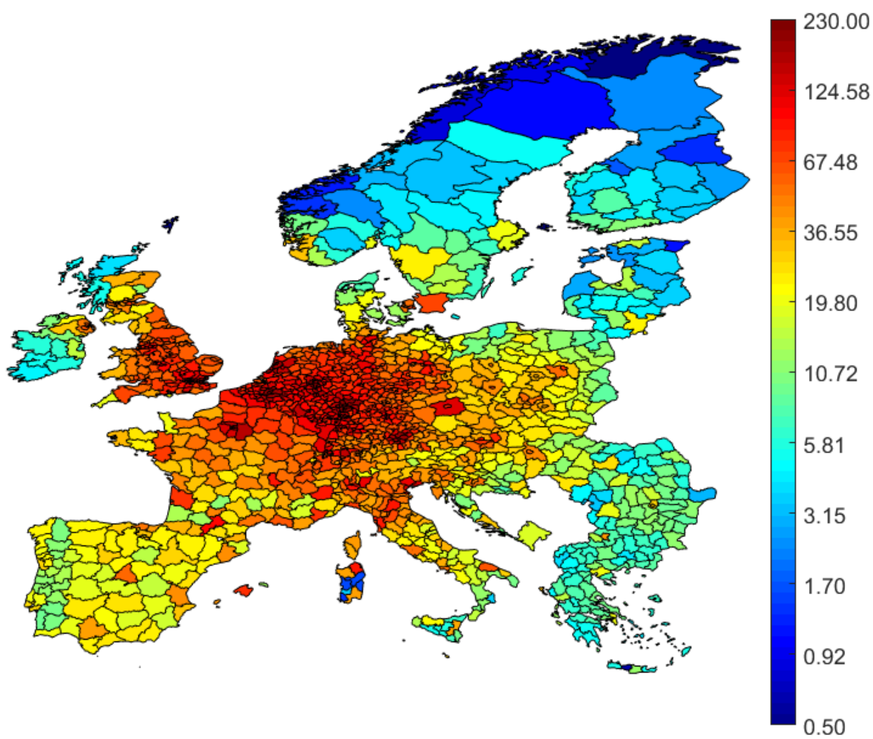

Figure 9: PR4 (in millions) for the EU baseline network.

From a quantitative standpoint, the best performing regions in Central Europe present values of PR4 between 100 and 230 million people, which for the selected countries account between 20% and 45% of the whole population (a little more than 500 million). This is quite far from the established ACARE goal which aims at completing 90% of door-to-door travels in the EU in less than 4 hours by 2050.
The current PR4 situation in the EU has been analyzed; now the beneficial impact on PR4 of introducing new NGCTR routes will be assessed, to understand how the intermodal transport scenario may change.
In order to calculate the NGCTR network it is necessary to define the tiltrotor maximum range, which is chosen to be 600 NM. Since a VTOL aircraft can operate even in the absence of a runway, the whole set of European airports (from very small to big) and heliports has been used to build the NGCTR network.
From a practical point of view, only a small fraction of the total possible airport combinations will be operated by a NGCTR in the next future. It was therefore decided to simulate two different European scenarios:

- 1000 new NGCTR routes, visible in Figure 10
- 5000 new NGCTR routes, visible in Figure 11

The performance parameter chosen to find the best new routes is, as discussed before, PR4. The code ranks all the feasible new routes based on the increase of overall European PR4 and adds the ones having the highest beneficial impact. The percentage increase in PR4 for each NUTS 3 region, achieved with the introduction of the new routes can be observed in Figure 12 (1000 new routes) and Figure 13 (5000 new routes).
From the abovementioned figures, some interesting considerations can be made:

1) To optimize PR4 the algorithm is favouring spoke-hub connections, which help to achieve a higher connectivity between a metropolis and its peripheral regions. This boosts the PR4 values of the peripheral regions, because a quick access to a large international airport permits to reach other big European cities in less than 4 hours.
2) The maximum PR4 gains are encountered in those regions which are directly connected to a metropolis with a new NGCTR route. In practice, this means that AHF services would play an important role in PR4 maximization inside Europe. The big cities instead, do not experience big percentage increases because they are already well connected with scheduled airplane routes. To improve visualization capability, the legend in the figures is limited at 100% PR4 increase. However, much higher gains are possible, since deep red regions correspond to increments equal or higher than 100%. As an example, in the 1000 new routes case the maximum PR4 gain is about 1440% for the ITG2A region of Sardinia; in the 5000 new routes case an astonishing 17280% is reached in the FI200 Finnish region corresponding to the Aland Islands, in the middle of the Baltic sea. Obviously, these regions in the baseline network are poorly connected, so it is easy to achieve high gains in the improved network once a connection with a big city is established.
3) The number of routes highly affects the PR4 increase. With 1000 new routes, more than 100% gains are found only in some isolated regions; with 5000 new routes, these gains are more evenly distributed around Europe.

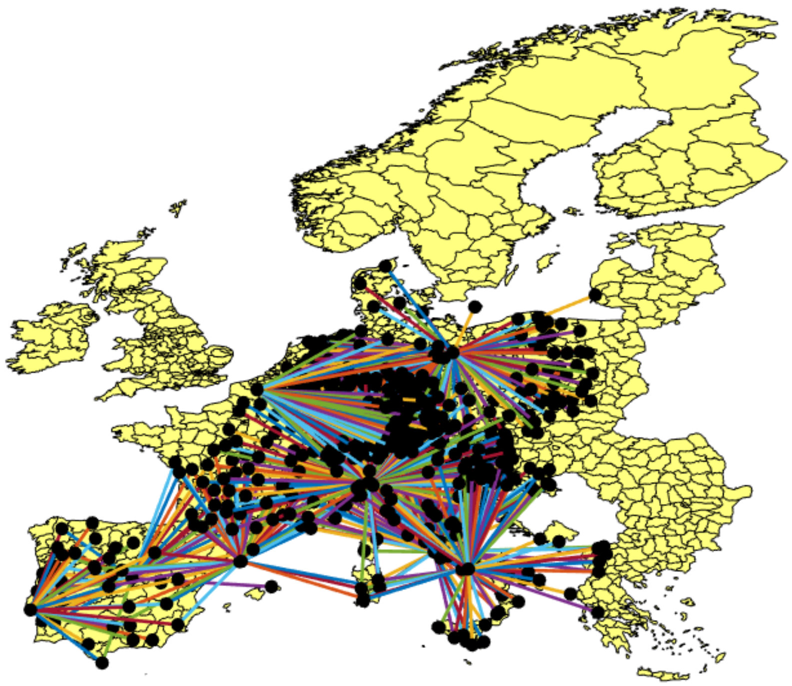

Figure 10. New NGCTR routes chosen to maximize PR4 (1000 new routes case).

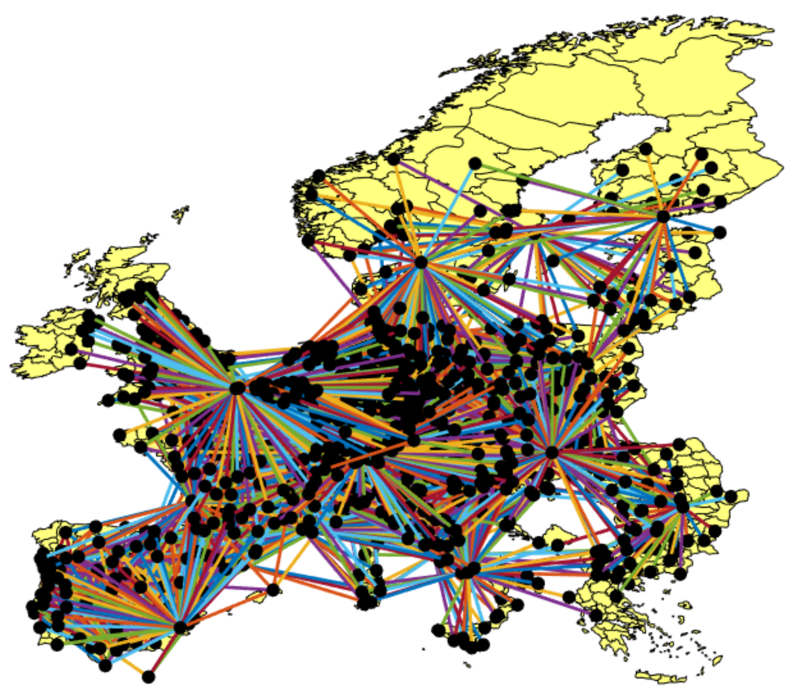

Figure 11. New NGCTR routes chosen to maximize PR4 (5000 new routes case).

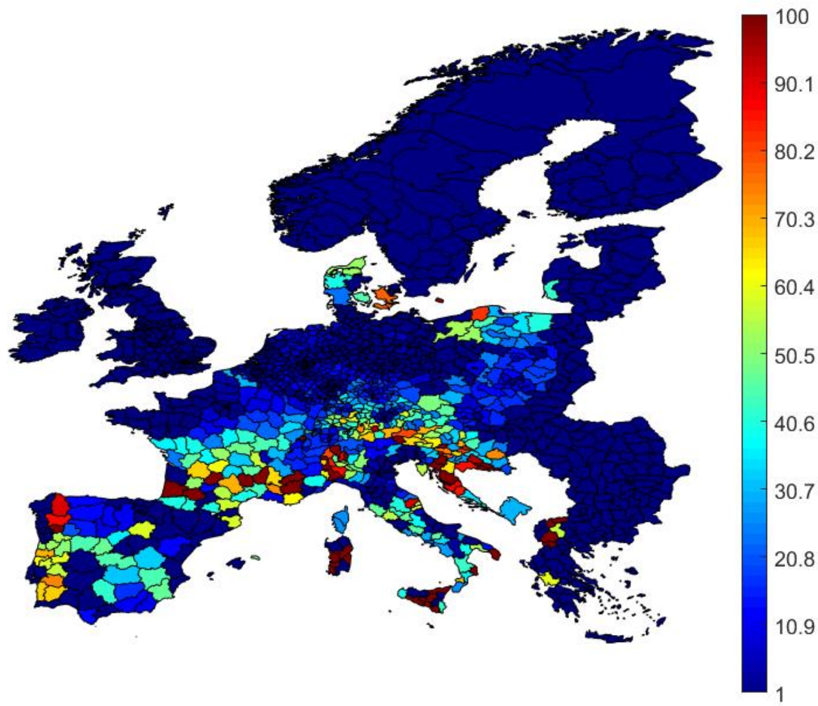

Figure 12. PR4 increase [%] with respect to the baseline network (1000 routes).

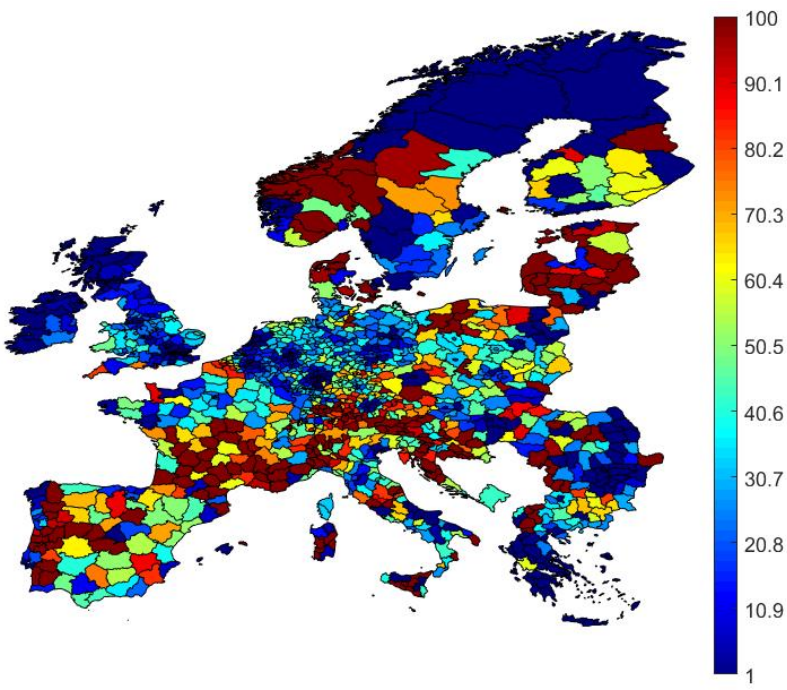

Figure 13. PR4 increase [%] with respect to the baseline network (5000 routes).

VI. Conclusions and Future Work

The introduction of a new aircraft, Leonardo's NGCTR tiltrotor, has shown to improve mobility performance of the EU intermodal network: in fact, the introduction of new NGCTR routes has reduced the travel times, increasing PR4, towards a big set of regions. Remote, peripheral, and poorly connected regions achieve the highest gains in PR4, which are found to be often much higher than 100%. The improvements depend strongly on the number of new NGCTR routes generated; however, PR4 values increase less than linearly with the number of new routes. From an overall intermodal network perspective, it is estimated that in the *baseline network* an EU citizen on average is able to reach 62.36 million EU people in less than 4 hours. With the introduction of 1000 NGCTR routes the average PR4 value is 67.45 million, corresponding to an 8% increase. With the introduction of 5000 NGCTR routes, instead, the average PR4 value is 78.74 million, corresponding to a 26% increment with respect to the baseline.

The methodology developed inside the EMMA code allows to model, by overlapping, different transport mode networks, considering the evolution of the existing ones and the addition of the specifically developed new aircraft network. The modelled European intermodal network makes it possible to estimate network performance on nearly 2 million trips over a network connected by about 3 million edges with a small computational effort (minutes). The EMMA code optimizes the future intermodal network to estimate:

- how many new connections should be added versus an initial situation to reach a defined intermodal network improvement;
- which node and connection performance gains could be obtained;
- the sensitivity of the network to parameter changes.

These data can be usefully employed as a valid support in evaluating a first set of high-level requirements to define new aircraft configurations by performing future network scenarios prediction. The next steps are the following:

- improve the accuracy of the present models evaluating their robustness to small TT variations;
- broaden the geographic area towards markets not yet considered (both mature and emerging economies);
- enhance the overall time gain in a green perspective, elaborating network performance metrics accounting also for environmental goals (CO2 per passenger, etc.).

Acknowledgments

This work has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme, grant agreement No. 776900. The authors would like to acknowledge Wolfgang Grimme and Alf Junior from DLR for the precious help on intermodal network modelling. In addition, they want to express their gratitude to Carmine Fiorillo, Filippo Lo Cicero, Giovanni Troiano and Antonino Dipeso from Leonardo Aircraft for the valuable help in data gathering and modeling suggestions. A special thank goes also to Giorgio Vicenzotti, Andrea Artioli and Michele Arra from Leonardo Helicopters for their effort in reviewing the current manuscript in record time.

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