Methodologies for the initial design studies of an innovative community-friendly miniliner

To cite this article: Lorenzo Trainelli *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1024** 012109

10th EASN 2020 IOP Publishing
IOP Conf. Series: Materials Science and Engineering 1024 (2021) 012109 doi:10.1088/1757-899X/1024/1/012109

Methodologies for the initial design studies of an innovative community-friendly miniliner

Lorenzo Trainelli, Carlo E.D. Riboldi, Alberto Rolando, Francesco Salucci

Department of Aerospace Science and Technology, Politecnico di Milano, Milan, 20156, Italy

E-mail: `lorenzo.trainelli@polimi.it`

Abstract. The present paper illustrates some of the strategies adopted to set the top-level aircraft requirements for an innovative near-zero emission miniliner. This novel 19-seater is conceived to provide a micro-feeder service, devised to exploit the existing European network of small local airports and airfields as feeders to hubs, as well as an intercity service to enhance connections between destinations that are not served by efficient ground transportation. First, a survey of the current network of airports and airfields is carried out and the existing ground transportation is analysed. Secondly, the potential demand for the microfeeder and intercity services is estimated based on the assessment of the time advantage between ground based means of transport and the miniliner option. Application examples in different geographic contexts provide useful information for the definition of crucial design requirements such as payload, range, runway length, and cruising airspeed.

1. Introduction

The UNIFIER19 "Community Friendly Miniliner" project is a research effort in response to the Clean Sky call H2020-CS2-CFP09-2018-02, focused on the conceptual design of a near-zero emission CS23 commuter aircraft conceived for the enhancement of the mobility of European citizens. This type of vehicle, capable to exploit the potential of the wide European small airport network, is seen as a key enabler of the Flightpath 2050 vision, including the ambitious policy of a 4-hour door-to-door travel duration for virtually all destinations in the EU [1]. This design activity involves several highly innovative aspects [2, 3, 4, 5], stemming from the ambition to achieve an environmentally-friendly and, at the same time, cost-effective solution for short haul regional transportation [6, 7, 8]. This brings into play dedicated market studies envisioning future services for hub-feeding (*microfeeder* role) and intercity commuting (*intercity* role) based on the UNIFIER19 aircraft, i.e. the miniliner. As this market segment is not yet developed, a fundamental preparatory task involves the estimation of the potential passenger demand. This is considered crucial to the sensible determination of some of the most important top-level aircraft design requirements, such as payload, range, takeoff and landing distances, cruising airspeed.

2. Aerodrome studies

The starting point for the estimation of the potential demand for a miniliner service is the assessment of the existing and potential aerodrome infrastructures in a geographical area of interest. Based on the current European scenario, three types of aerodromes are identified (Table 1):

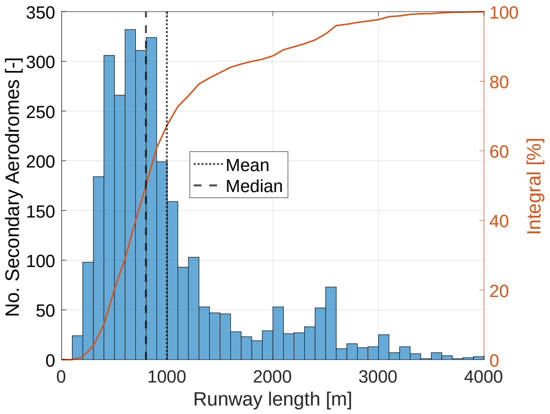


Figure 1: Runway length distribution of European secondary aerodromes

Table 1: Survey of airports and airfields in Europe

Group	Type	Description	Quantity
Hubs	Hubs	$\geq$ 5M pax/year	69
Secondary aerodromes	Secondary airports	< 5M pax/year	1928
	Airfields	no ICAO code	1101
Total			3098

(i) **Major airports**, which are most typically adopted as hubs, support a volume above 5,000,000 passengers per year.

(ii) **Secondary airports**, which are below such threshold.

(iii) **Airfields**, by far the majority of aerodrome infrastructures in any European country, which are mainly used for sport and leisure flight. Airfields do not feature an ICAO code.

The set of secondary airports and airfields, collectively referred to as Secondary Aerodromes (SA) is the asset that may be exploited by the miniliner transport network. The existing SAs with runways longer than 100 m have been identified through an analysis of the European data available on `openAIP.net` [9] considering EU27 countries. Data about passenger traffic was taken from Eurostat published information [10].

A total of 3,029 SA were taken into account. The runway length distribution of the selected SAs is shown in Figure 1. The average runway length is 996 m, with minimum and maximum values at 108 m and 4,000 m, respectively. The shape of the distribution shows a marked asymmetry, with many runways shorter than the mean value. The median value is, in fact, 798 m, while the standard deviation is 698 m. The red curve in Figure 1, representing the integral of the runway length distribution, helps further understanding of the situation. It interesting to note that runways 600 m or longer represent 75% of the total, 800 m or longer 50%, and 1,000 m up capture 35%. Of all SAs, 44% have either concrete or asphalt runways, while 48% feature a grassy surface. Other types of surfaces are gravel, soil and sand, which together account for less than 3% of the total. For a few aerodromes, no precise data are available.

Another interesting aspect of making use of SAs is the distance s_{SA} between any of them and the nearest one. Due to the very fine grid of existing SAs, considering only runways longer than 800 m (1376 SAs: 1,214 airports and 200 airfields), the mean value of s_{SA} is 66 km, while the median value is 40 km. Even more interestingly, 80% of SAs have another SA within 75 km range. This result may imply the need for short diversion distances for the miniliner.

3. Analysis of ground transportation

An analysis of the existing European ground transportation system was carried out. The goals were the identification of possible transport mode competitors for the miniliner services and the evaluation of the *ground transportation efficiency* on a local territorial basis, in order to provide information for the areas where a miniliner service can be more competitive and time-efficient. To do so, Eurostat data [11] were analysed, leading to the mapping of Europe with respect to the density of the ground transportation infrastructures. The total length of motorways and railways

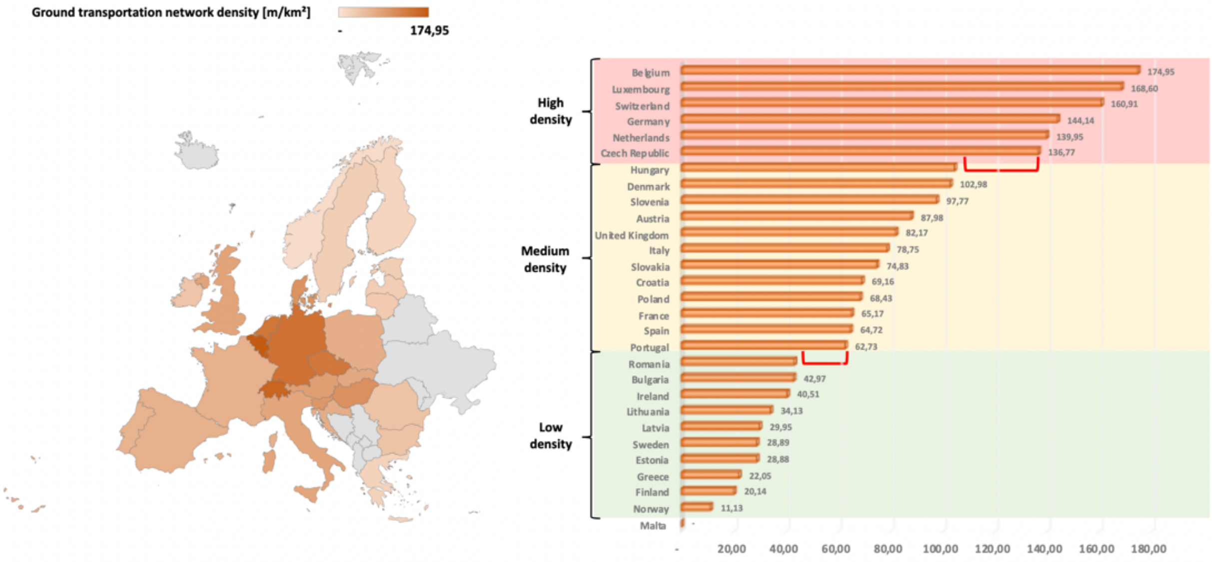


Figure 2: Ground transportation network density map in Europe (left) and related country clustering (right)

measured in m divided by the country area in km was used to derive the ground transportation efficiency, as the overall ground network density. Figure 2 shows the distribution of such index across European countries. As reported, the maximum values are reached in Central Europe, with a peak in Belgium, while minimum values are found especially in North-Easternmost and South-Easternmost countries.

This analysis leads to the general classification of European countries highlighted in Figure 2. As apparent, the wide differences in the ground transportation efficiency values found across Europe yield the possibility of a clustering in three subsets. In fact, discrete jumps (marked in red in the figure) are found between the values for Romania and Portugal, and for Hungary and the Czech Republic. This inspires the definition of three subsets with high, medium, and low ground transportation efficiency. This study is considered preliminary to the analysis of selected cases seen as representative of the different conditions encountered in the three country subsets.

4. Potential demand estimation methodology

On the basis of the known the aerodrome infrastructure, a vast number of routes may be traced connecting all locations. It is clearly crucial to be able to adequately downselect possibly interesting routes from such a large set. For this market study, a selection is enforced according to a time-saving criterion: the air routes which guarantee a minimum time advantage with respect to the car alternative are considered, while the others are discarded. Air route distances have been calculated by referring to orthodromic distances, whereas car travel distances and times have been gathered through HERE Maps APIs [12].

4.1. Identification of route catchment areas

For a microfeeder service, the travel time is retrieved as the sum of the time needed to reach a SA from the considered municipal area t^{T-S} using land-based means and the travel time of an airline flight to the hub t^{mf}. The latter is clearly a function of the flight performance characteristics of an assumed aircraft, and is obtained as

$$t^{mf} = t^a + t^c, \tag{1}$$

where t^a is a constant term gathering fixed airport-related time durations: check-in, turnaround, taxi, etc., while block cruise duration t^c depends on the trip distance and cruising speed.

For the intercity service, the travel time is given by the time needed to reach the nearest SA (S_1) from the departure town T_1, $t^{T_1-S_1}$, using land-based means, the miniliner travel time, t^{mf}, and the time to go by car/train/bus from the arrival SA (S_2) to the destination town T_2, $t^{S_2-T_2}$.

Given the previous travel time definitions, the catchment area for a miniliner route is defined based on the positive evaluation of the following constraints, stated here for the microfeeder case:

$$\begin{cases} \frac{t^{T-H}}{t^{T-S}+t^{mf}} \geq k \\ t^{T-H} - \left(t^{T-S} + t^{mf}\right) \geq t_{ref} \end{cases}, \qquad \begin{cases} \frac{t^{T-H}}{t^{T-S}+t^{mf}} \geq k \\ t^{T-H} - \left(t^{T-S} + t^{mf}\right) \geq t_{ref} \end{cases} \tag{2}$$

where k represents an imposed time advantage of the novel miniliner-based transport solution with respect to the usual, purely ground-based one, while t_{ref} is a minimum time difference.

4.2. Microfeeder potential demand estimation algorithm

4.2.1. Route function The application of Eqs. (2) to all considered municipal areas and aerodromes allows defining a number of connections between hubs and SAs, representing a potential traffic demand. This can be expressed in terms of the total number of passengers P_i with an advantage in reaching the i-th hub via the miniliner service. However, this data, based only on demography (geographic distribution of the population), may be not be sensitive enough to the potential travel interest of the local population. As a second factor, the local distribution of wealth, represented by the national gross domestic product (GDP), is thus considered. Therefore, for the pair represented by the i-th hub and the j-th SA, the corresponding route is associated to a demographic level D_{ij}, bound to the population size, and to an economic index G_{ij}, based on the GDP distribution, to represent the propensity to travel of the population associated to the route. Based on these parameters, it is possible to define the route value function $F_s\left(i,j\right)$ as

$$F_s\left(i,j\right) = \alpha \, \frac{D_{ij} - \min_{j \in H} D_{ij}}{\max_{j \in H} D_{ij} - \min_{j \in H} D_{ij}} + \left(1-\alpha\right) \frac{G_{ij} - \min_{j \in H} G_{ij}}{\max_{j \in H} G_{ij} - \min_{j \in H} G_{ij}} \tag{3}$$

where H represents the set of all hubs, and α is a tuning parameter defining the relative relevance of the economic aspect, with respect to a purely demographic datum.

4.2.2. Hub feeding demand The analysis of the traffic potential of the connection routes must match with the actual feeding needs of the hubs. This can be quantified through the variables P_i^{arr} and P_i^{dep}, retrieved from publicly available databases and representing the number of passengers arriving and departing hourly from the i-th hub, respectively. In order to obtain a match between the actual airport needs and the potential traffic quota pertaining to each route connecting the i-th hub with secondary clusters, the following algorithm is proposed.

The values P_i^{arr} and P_i^{dep} are normalised by the population corresponding to the area connected to the considered hub, N, generating the following indices:

$$O_i = \frac{P_i^{arr}}{N}, \qquad D_i = \frac{P_i^{dep}}{N}, \tag{4}$$

where the values of O_i and D_i represent the hourly number of passengers generated and attracted by the i-th hub, respectively. Next, the route value functions for all hub-SA pairs are normalised with respect to the sum of the route function values over the number of SAs, yielding

$$\varphi\left(i,j\right) = \frac{F_s(i,j)}{\sum_{j \in S} F_s(i,j)}, \tag{5}$$

where S represents the SA set. Finally, the hourly rate of generated (input) traffic on the routes from all hubs to a SA and the hourly traffic rate input on the route from the j-th SA to the hubs are defined as

$$o_j = \sum_{i \in H} \varphi(j,i)\, D_i, \qquad d_j = \sum_{i \in H} \varphi(i,j)\, O_i. \tag{6}$$

The potential hourly demand of the route from the i-th hub to the j-th SA is $G_{ji} = \varphi(j,i)\, D_i$, whereas the dual value from SA to hub is $g_{ij} = \varphi(i,j)\, O_i$. Both G_{ij} and g_{ji} are potential traffic demand parameters and are usually functions of the time in the day, as daily airport passenger flow in hubs typically features traffic peaks.

4.3. Intercity potential demand estimation algorithm

For the potential demand estimation in the intercity case a wholly different approach was needed. To estimate the number of people interested in travelling between two towns, statistic data about commuters were used. In particular, periodical censuses usually provide *matrices of commuting habits*, estimating the number of people that commute daily for work or study reasons. The total traffic flow can be arranged in the form of a typical Origin-Destination (OD) matrix $G = (g_{ij})$, where g_{ij} represents the commuter flow for the (i,j) route from the i-th origin to the j-th destination. It is interesting to note that commuter traffic flow is bidirectional, i.e. those who travel one way in the morning will travel back in the afternoon. Thus, the afternoon OD matrix is simply the transpose of the morning OD matrix.

5. Potential demand estimation studies

The methodology described above has been applied to the study of a number of cases, in order to verify its capabilities to provide useful data for market studies dedicated to the design of a 19-passenger miniliner, targeted in the UNIFIER19 project. In order to derive useful information on the effect of some of the top-level aircraft requirements (TLAR) on the demand-capturing capability of microfeeder and intercity services, parametric studies have been performed.

Here, results are shown as obtained by considering ranges of variation for the design values of the following performance parameters:

- Trip distance: from 100 to 300 km (microfeeder) and 600 km (intercity) with 50 km step increments (5 and 11 cases).
- Cruising speed: 200 ± 50 KTAS (3 cases).
- Takeoff and landing distances: 800 ± 200 m (3 cases).

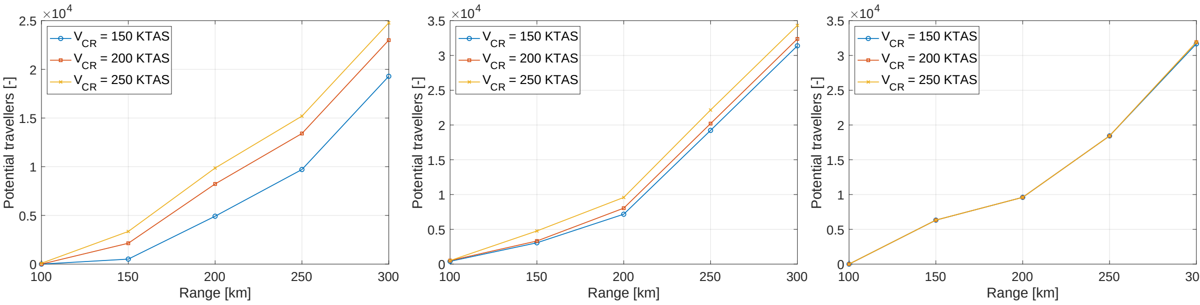
Cruising altitude is assumed at 4,000 ft. This is possibly reduced in case the trip is so short that the climb phase ends before reaching cruising altitude. Other mission profile parameters include optimal climb at a rate of climb of 500 ft/min and descent at cruising airspeed at a rate of descent of 250 ft/min.

The size threshold for towns considered in the analysis is 20,000 inhabitants. The constant part of the total travel time t^a is set to 40 min. The parameters defining the time advantage in Eqs. (2) are set as $k = 1.3$ and $t_{ref} = 30$ min.

5.1. Microfeeder service

Three case studies are presented in the following, all related to a possible feeding service for a single hub. These have been chosen as representative examples of the different conditions encountered across the European countries with respect to their ground transportation efficiency. Therefore, one case per each of the subsets identified in Section 3 was considered:

(i) High ground transportation efficiency: Brussels Zaventem Airport (ICAO code: EBBR), Belgium.



(a) EBBR (b) LIPZ (c) EVRA

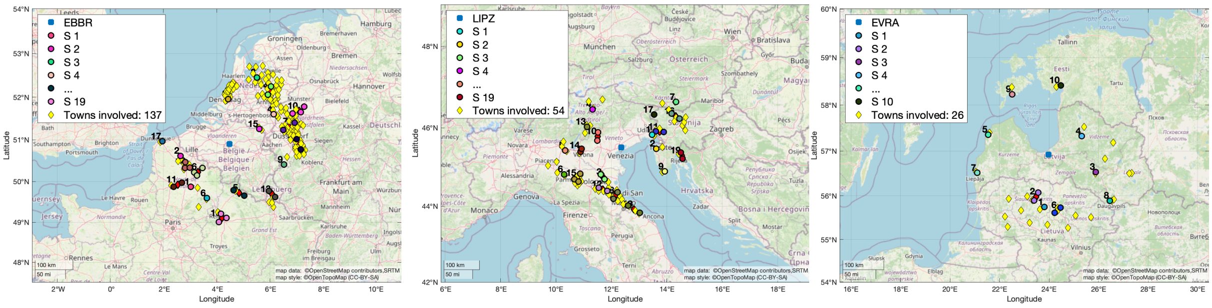
Figure 3: Potential demand estimation results for a microfeeder service to EBBR, LIPZ and EVRA in the case of 800 m long runways for secondary aerodromes

(ii) Medium ground transportation efficiency: Venice Marco Polo Airport (ICAO code: LIPZ), Italy.

(iii) Low ground transportation efficiency: Riga Airport (ICAO code: EVRA), Latvia.

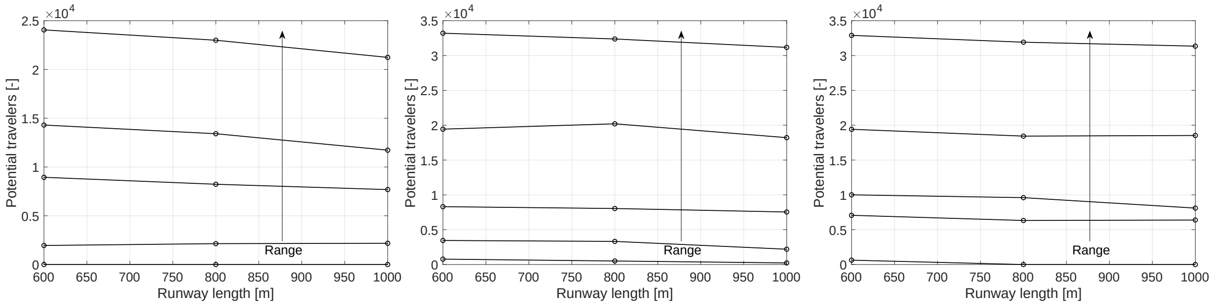
Neighbouring countries were also included in the analysis.

The graphs in Figure 3 refer to the case of selecting a maximum takeoff and landing distance of 800 m (a 'light' STOL case) for all the three scenarios, showing the potential passenger demand associated to the generated route networks. All quantities are displayed as functions of the range and parametrised with respect to cruising speed. It is apparent that in the EBBR and LIPZ case (Figures 3a and 3b) the potential demand that may be captured has a higher-than-linear rise with the increase of maximum trip distance, while the increase is significant, but less marked, in dependence of cruising speed. On the other hand, in Figure 3c for EVRA, the rise in the potential demand looks roughly linear with the increase of maximum trip distance. Moreover, EVRA results look insensitive to the value of cruising speed. This is clearly related to the low efficiency of ground transportation in the regions surrounding the hub under scrutiny, together with the relative sparsity of towns reaching the assumed threshold size. The values of the potential travellers for EVRA are comparably higher with respect to the EBBR and LIPZ cases at medium values of the trip distance, and approximately the same at higher distance. Also, as a result of the high efficiency of ground transportation in the regions surrounding EBBR and LIPZ, the lower values for the trip distance provide poor results (vanishing at 100 km), since



(a) EBBR (b) LIPZ (c) EVRA

Figure 4: Distribution of towns and secondary aerodromes involved in a microfeeder service to EBBR, LIPZ and EVRA in the case of 800 m long runways for secondary aerodromes and a cruising speed of 200 KTAS



(a) EBBR (b) LIPZ (c) EVRA

Figure 5: Potential demand estimation results for a microfeeder service to EBBR, LIPZ and EVRA at 200 KTAS cruising speed

the miniliner service cannot compete with alternative ground-based travel means. For the same case of picking SAs with 800 m long runways or more, Figure 4 shows the number and location of the towns and involved aerodromes when the maximum trip distance is 200 km.

Graphs in Figure 5 show the variation of potential travellers as functions of runway length and trip distance, with 200 KTAS cruising speed. Relatively small changes are observed in the potential demand with respect to runway length. The potential demand for LIPZ at 250 km trip distance seems to slightly increase when using 800 m runways or longer. This is possibly due to a better ground connection for SAs with a longer runway than for those with a shorter one.

5.2. *Intercity service*

The Italian case is assumed for the analysis of the intercity service. A *matrix of commuting habits* is included in the census of the Italian national institute of statistics (ISTAT), and updated every 10 years. In particular, this work is based on the commuting matrix G from the 15th population and housing census from 2011 [13].

The travelling demand of Italian commuters is presented in Figures 6 and 7 as a function of trip distance, cruising speed and runway length. Figure 8 depicts a related network map. The amount of potential commuters, clearly flattens towards a constant value, saturating around 300÷350 km trip distance. Significant variations with cruising speed and runway length are observed. For instance, looking at the 350 km value, a cruising speed increment of 50 and 100 kn from 150 KTAS increases the number of passengers by 26% and 57%, respectively. The effect of runway length is similar: the number of potential commuters rises by 68% using 600 m long runways, and 28% using 800 m long runways, with respect to the 1,000 m case.

Conclusion

A key-element in understanding the applicability and profitability of a novel near-zero emission miniliner is the quantitative analysis of the air transport network it can support. This community-friendly aircraft, specifically designed for passenger transportation on short and very-short haul routes, is specifically conceived to be used in the roles of hub *microfeeder* and *intercity* liner. Therefore, market studies dedicated to these two service options are necessary to guide the determination of the aircraft design requirements. However, both air transportation segments are not yet developed and predictions concerning future market opportunities are needed.

The present study briefly illustrates some of the methods deployed to this goal. The existing system of secondary aerodromes in Europe was analyzed considering runway length, surface type and geographic distribution, showing its potential in supporting a diffuse regional network. This database has been used to provide a set of possible routes for which the travelling demand has

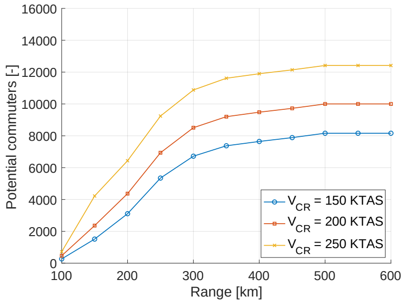


Figure 6: Potential demand estimation for an intercity service in Italy: Variation with respect to cruising speed using runways longer than 800 m

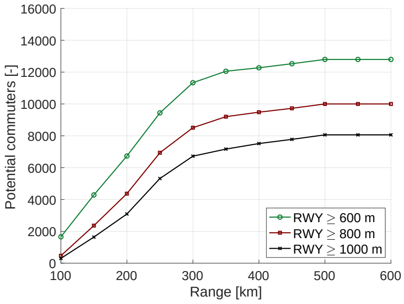


Figure 7: Potential demand estimation for an intercity service in Italy: Variation with respect to runway length at 200 KTAS cruising speed

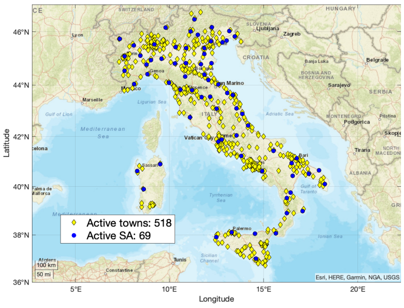


Figure 8: Distribution of towns and secondary aerodromes (SAs) involved in an intercity service in Italy with a range of 350 km, runways longer than 800 m and 200 KTAS cruising speed

been estimated. This process relies on the assessment of a definite advantage for travellers when using the miniliner instead of cars or trains, in terms of time saving, as this is assumed of crucial importance. The method is currently being extended to take into account further aspects of the travellers' motivation in choosing for flying with the miniliner, such as cost and comfort.

Application studies highlight the importance of primary aircraft performance of range, takeoff/landing distances, and cruising speed in the ability to capture the travel needs of potential customers. These results are currently being exploited in the definition of the top-level aircraft requirements for the design of the UNIFIER19 miniliner, which aims at contributing to a drastic enhancement of the mobility of European citizens, while pursuing environmental sustainability.

References

[1] Darecki M, Edelstenne C, Enders T, Fernandez E, Hartman P, Herteman J P, Kerkloh M, King I, Ky P, Mathieu M *et al.* 2011 *Off. Eur*

[2] Riboldi C E D 2018 *Aerospace Science and Technology* **81** 14–31 ISSN 12709638 URL `https://linkinghub.elsevier.com/retrieve/pii/S1270963818304322`

[3] Riboldi C E D, Trainelli L and Biondani F 2020 *Journal of Aerospace Engineering* **33** 04020031 ISSN 1943-5525 publisher: American Society of Civil Engineers URL `https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29AS.1943-5525.0001144`

[4] Riboldi C E D, Trainelli L, Mariani L, Rolando A and Salucci F 01 Jan 2020 *Noise Mapping* **7** 35 – 56 URL `https://www.degruyter.com/view/journals/noise/7/1/article-p35.xml`

[5] Riboldi C E D, Gualdoni F and Trainelli L 2018 *Transportation Research Procedia* **29** 376 – 389 ISSN 2352-1465 aerospace Europe CEAS 2017 Conference URL `http://www.sciencedirect.com/science/article/pii/S2352146518300383`

[6] Salucci F, Trainelli L, Faranda R and Longo M 2019 *2019 IEEE Milan PowerTech* pp 1–5

[7] Salucci F, Riboldi C E D, Trainelli L and Rolando A 2020 *1st Aerospace Europe Conference (AEC 2020)*

[8] Riboldi C E D, Bigoni F, Salucci F, Rolando A and Trainelli L 2019 (AIDAA) pp 1001–1008 ISBN 978-88-943960-1-0 accepted: 2019-09-25T11:35:31Z URL `https://re.public.polimi.it/handle/11311/1105676#.Xtim-sbOPE4`

[9] openAIP - Worldwide aviation database | openAIP URL `http://openaip.net/`

[10] Airport traffic data by reporting airport and airlines - Eurostat URL `https://ec.europa.eu/eurostat/web/products-datasets/-/avia_tf _apal`

[11] Regional gross domestic product by NUTS 2 regions - million EUR - Eurostat URL `https://ec.europa.eu/eurostat/web/products-datasets/-/tgs00003`

[12] Data - Eurostat URL `https://ec.europa.eu/eurostat/web/rural-development/data`

[13] Matrici di contiguità, distanza e pendolarismo URL `https://www.istat.it/it/archivio/157423`