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Article

Fast-Time Simulations to Study the Capacity of a Traffic Network Aimed at Urban Air Mobility

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Abstract: This article investigates viable solutions to implement an Urban Air Mobility network in Milan, Italy, and analyzes its influence on the airspace capacity. The network comprises eight vertiports for passenger transport among two main airports in the area and the city using electric vertical take-off and landing aircraft (eVTOLs). A Fast-Time Simulation (FTS) model with the software AirTOp (Air Traffic Optimization) allowed the evaluation of the ideal capacity of the network by varying two configurations, which differ from each other in terms of the number of Final Approach and Takeoff areas (FATOs). The results show how it is possible to reach high hourly capacities (in the order of one hundred), thus allowing the use of the service for about 4% of the total passengers passing through the two airports during the reference day chosen for this study. However, the results are ideal due to the strong idealism of the system, which overlooks several factors, and they should be considered as the maximum limit that can be obtained. Despite this, the method presented in this article can also be adapted for other urban areas with high population densities. In addition, the use of a simulation tool of this type allows, in addition to a numerical analysis, a qualitative analysis of the network behavior in terms of traffic, thus highlighting the criticalities of the proposed systems.

Keywords: Urban Air Mobility; capacity; aerotaxi; airspace structure; airspace design; U-Space; Fast-Time simulations; vertiports

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1. Introduction

In recent years, the technological development in the field of electrification, automation, and vertical take-off and landing (VTOL) led to innovative goods and passenger air transport models within cities through the use of Unmanned Aerial Vehicles (UAVs) or drones [1,2]. The substantial number of investments and the continuous development and updating of the regulatory framework led to the prediction that by 2050, there will be about 160,000 drones operating in these commercial operations [3]. Using drones will reduce congestion in city traffic, emissions of pollutants, and travel time through strategic networks between points of high interest such as airports with the city center, as well as several points within the cities themselves [4,5]. The main challenge of this new mobility is developing a complete and adequate regulatory framework to support complex operations and meet safety and quality standards [6], especially certification for stakeholders and aeronautical products [7,8]. Given the criticality of unmanned operations and the design complexity of the aircraft in these contexts, the development of regulations and standards is a complex challenge to face. The first step in the aircraft and infrastructure design for Urban Air Mobility (UAM) is defining the operational scenario and mission. The mission composition is a crucial factor [9,10] because even slight differences can lead to a significant shift in the optimal design point of the machine. Another impacting factor on the aircraft concept is noise emission [11–13], which is influenced by design parameters (e.g., speed at the tip of the rotor blades) and should be minimized [14]. This can be achieved by increasing the number of rotors to distribute the thrust, but it conflicts with the main constraint of optimizing space for urban operations. The need to achieve and balance conflicting performances in the aircraft design influences factors characterizing the mission, limiting autonomy, efficiency, flight altitudes, and the number of seats [15–17].

In recent years, several studies have been conducted about the operation of Urban Air Mobility. In particular, Lim and Hwang [18] utilize the k-means clustering method to distribute vertical take-off and landing (VTOL) stations, assessing commuter data for the Seoul metropolitan area to determine the cumulative mobility demand. They find that the stations' location affects system efficiency more than number. Efficient flight planning is crucial for safety (collision avoidance) and operating cost reduction (trajectory design) [19]. Tang et al. [20] propose a method to establish a cost-optimal trajectory before UAM vehicle departure, employing a layer-based airspace subdivision. Flight execution, achieved by navigating around obstacles and delaying departure, if necessary, noticeably reduces costs. Subsequent sensitivity studies examine the relationship between operating cost savings and additional passenger costs due to delay, emphasizing the importance of trade-offs. Maheshwari et al. [21] highlight the limitations of UAM operations, including high operating costs, depleted station capacity, and weather conditions, and explore their interdependencies. In addition, vehicle-specific parameters such as the range capacity, cruise speed, and cost of travel per passenger are vital for economically viable flight operations. Goyal et al. [22] study UAM applications across feeder services to airports, air taxi operations, and air ambulance applications, identifying potential risks and defining barriers across regulatory, weather, perception, and infrastructure domains. Technology can mitigate but does not eliminate challenges, and operations costs remain a significant barrier to entry; further studies should investigate the environmental effects [23–25]. Zhang et al. [26] studied the capacity, considering distinct types of vertiports characterized by different Final Approach and Takeoff area (FATO) management, highlighting that the best solution to maximize the capacity of the vertiport is the use of independent FATOs.

Another important aspect of the development of UAM concerns the airspace configuration and capacity [27]. In recent years, the European Union developed the concept of U-Space, an airspace operating at very low-level (VLL) altitudes (i.e., a flight level below the minimum safety altitude of 300 m in urban and suburban areas) [5]. U-Space is a set of services designed to support the safe and efficient entry of drones into the airspace [28].

The concept developed by the FAA [29] highlights the relationship between UAM, ATM, and UTM (Uncrewed Traffic Management) in different classes of airspace. Different corridors can be used depending on the type of operation and the type of aircraft, which therefore have specific access conditions. The FAA also states that a separation service within the corridors is not necessary since the latter is guaranteed by the operational characteristics of the corridors themselves.

This article adopted the FAA concept of U-Space because it provides pre-established flight corridors based on the operation type by varying access conditions [29].

According to the FAA, there is no need for in-corridor separation as the operational characteristics of the corridors provide separation. The reduction in areas subject to noise, falling debris, and occupation of the airspace available for already operational aviation are among the advantages of this organization. However, it has disadvantages due to the possibility of ending up outside U-Space if a flight can no longer follow its flight plan. As a result, other flights could switch from instrument flight rules to visual flight rules, and an area with a high concentration of aircraft would be created, increasing the risk of collision. This suggests that, if airspace is designed by directing traffic in predetermined corridors, there will be greater predictability and organized traffic at the cost of more limited operations and suboptimal trajectories. Finally, it is important to underline that passenger transport with drones in unmanned configuration will not be possible shortly, given the absence of a framework regulating it [30]. Nevertheless, employing an on-board piloted eVTOL following visual flight rules will be possible.

This article deals with a futuristic scenario, thus assuming that it will be possible to use a substantial number of drones in unmanned configuration to transport passengers in an urban and airport context. In Italy, the National Civil Aviation Authority (Ente Nazionale per l'Aviazione Civile, ENAC) has published the 2021–2030 Strategic Development Plan for advanced air mobility [31] to start tests in some Italian cities, in anticipation of major attractive events such as the 2025 Jubilee in Rome and the 2026 Winter Olympic Games in Milan. Therefore, a "Business Plan" was developed to implement the strategic plan with over EUR 1.8 billion in investments. The plan includes tests and demonstrations to build a vehicle and construct the infrastructure at the network level for the main Italian cities. As a benefit, the added value generated will be around EUR 2.8 billion, and the new jobs will be around 50,000 workers. Very recently, ENAC has also issued the regulation for "National requirements for operations, airspace and infrastructure for aircraft with vertical take-off and landing capability" [32], in line with EASA [33].

This article presents a study to evaluate the feasibility of implementing drone operations between two Italian airports (i.e., Milan Linate, LIML, and Milan Malpensa, LIMC) and the city center, using a simulation model developed through the AirTOp application [34]. The aim is to evaluate the ideal hourly capacity of the network and the considered vertiports, accumulated delays, and formation of high-traffic intensity areas (hotspots). This article will describe the modeling process of the network simulation model and the related operational hypotheses. Based on the results, innovative solutions and potential changes to regulations and procedures will be proposed to implement the service within Milan City. The method described in this article can be adopted in any other metropolitan area, thanks to the extreme flexibility of the simulation methods.

Apart from this introductory paragraph, the rest of the document is organized as follows. Section 2 describes the simulation method used to evaluate the capacity of the airspace when drones are included. In this section, the characteristics of the studied area are also described. Section 3 describes the results. Section 4 discusses the results and their impact on the implementation of such a proposed concept with a general comparison of data. Section 5 presents conclusions and closing remarks.

2. Materials and Methods

A Fast-Time simulation model implemented in the AirTOp software [34] allowed the capacity study of a traffic network consisting of 8 interacting vertiports. The simulation models developed for this study were created with the AirTOp simulator version 5.0.0 P2. The AirTOp simulation platform is an advanced gate-to-gate simulation tool, created for the design, modeling, and simulation of air traffic, both for the evaluation of traffic management in the airport environment and en route and approach. Specific tools modeled each part of the system to simulate its activity. Therefore, the simulation model is a simplified and virtual replica of a real system and reflects a set of characteristics relevant to the set study objectives. Fast-Time simulations can be used for the following:

- To define the theoretical maximum ATC capacity of a predefined scenario and provide the elements to support the process of identifying its real capacity [35,36];
- To propose studies and analyses for the optimization of the airspace or to prepare the definition of a greater ATC capacity [37,38];
- To provide elements to evaluate the overall efficiency of the ATS network as well as to optimize its use and design [39];
- To measure the pros and cons of new operational concepts, such as Urban Air Mobility, which is the objective of this study.

A simulation scenario is a set of elements necessary to represent the operational environment and/or the infrastructure being studied. The base scenario, for a simulation, reproduces the environment being measured in "standard conditions" such as the following:

- ICAO International standard atmosphere;
- No wind;
- Visibility conditions 1;

- Military areas not in use;
- Correct functioning of all systems;
- Air traffic control management rules and procedures agree with the operational contact point and the client.

The verification of the performance of an operational scenario is the iterative process through which the ATM system, an infrastructure, or a new operational concept can be evaluated. The verification process used is consistent with the Eurocontrol document [40], which provides for the definition of objectives; preparation of the validation plan; definition of simulation exercises; analysis of results; and development and distribution of conclusions.

The first step for defining the simulation model evaluates the existing operations in the area. For this purpose, three key elements have been considered:

Prohibited and restricted areas;

- Visual flight rule (VFR) traffic routes in and out of Airport Traffic Zones (ATZs);
- Take-off and landing procedures from/to the two airports.

Concerning Milan, Figure 1 shows two prohibited zones (i.e., P147, P259) that must not be flown over and a restricted area (R9) above the city.

Once the operational boundaries of the network have been defined, it is possible to identify the possible portion of airspace used for unmanned traffic (i.e., the U-Space). The process includes the following phases:

1. Choice of the 8 vertiport locations: The model consisted of the two airport vertiports (i.e., Milan Linate and Milan Malpensa), two vertiports located in the city center near City Life and Porta Romana, and four provincial vertiports located in Rho, Legnano, Lainate, and Busto Arsizio. No analysis regarding the construction site of the vertiport was carried out.
2. Vertiport design: Two different configurations of the network were proposed. The first one includes vertiports with a single FATO, and vertiports have two independent FATOs in the second configuration. Their layouts (e.g., car parks and taxiways) were simplified: vertiports with a single FATO have a single parking space, while vertiports with a double FATO have four parking lots, two per FATO, which manage arrivals or departures.
3. Definition of routes: Only connections between the city vertiports and the two airports have been considered, that is, no connections between city vertiports. All the waypoints and routes followed by drones have been defined. In particular, the network is characterized by two main corridors. In Figure 2 the routes followed by the drones are indicated with red lines and shows that the upper manages all flights to Malpensa, and the lower manages all flights to Linate.
4. Definition of Standard Instrument Departures (SIDs) and Standard Arrival Routes (STARs). The landing and take-off procedures of each vertiport have been defined. Concerning the one-FATO network configuration, each vertiport has a single STAR and two SIDs, the former towards the upper corridor and the latter towards the lower corridor. For the second configuration, since the two FATOs are independent, there are two STARs and two SIDs. The only exceptions are the two airport vertiports with only one SID and one STAR for both configurations.
5. Definition of safety conditions: A general horizontal separation of 0.5 NM, a separation of 60 s between two consecutive take-offs, and a final separation of 0.5 NM (i.e., take-off is possible if the incoming drone is at least 0.5 NM from the landing point) were imposed. No vertical separation was imposed because all machines fly at a 500 ft altitude according to the U-Space rules by EASA [30]. Therefore, separations at the intersections have been managed by stopping the aircraft upon departure from a vertiport if a specific portion of the corridor is occupied.
6. Choice of the machine: the simulation focused on the Volocopter Volocity, whose fundamental characteristics are in Table 1.

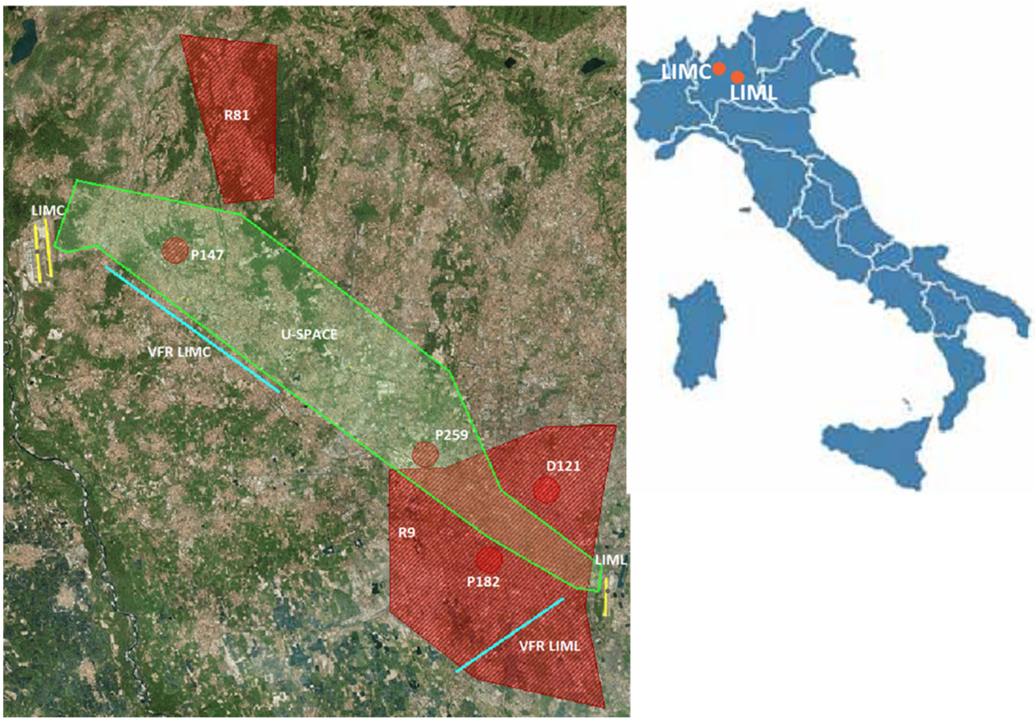

Figure 1. Prohibited zones and restricted areas above the city of Milan.

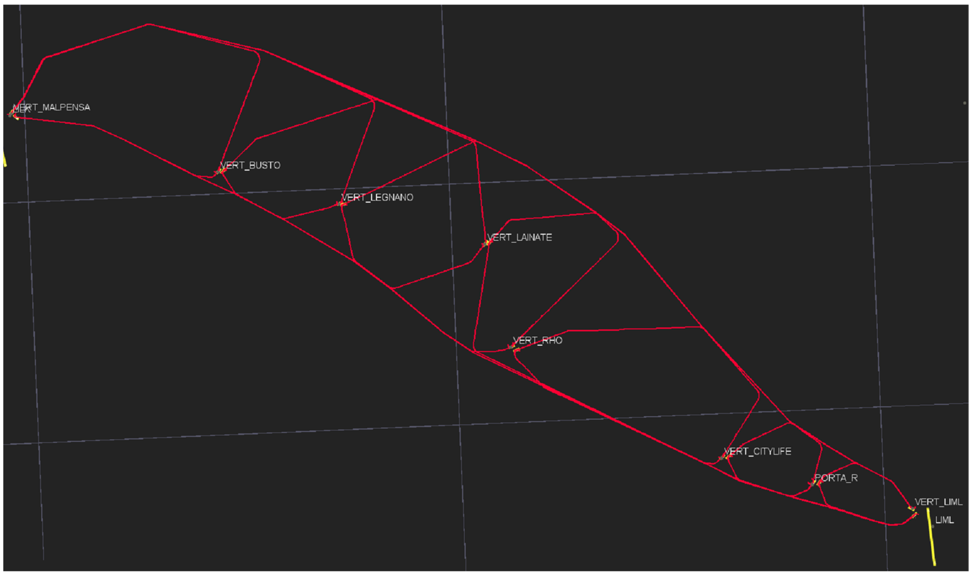

Figure 2. Vertiport route network.

Table 1. Characteristics of Volocopter Volocity.

Characteristic	Value
Number of passengers	1 + 1 pilot
Operating empty weight (OEW)	700 kg
Maximum take-off weight (MTOW)	900 kg
Climb rate	590 ft/min
Descent rate	400 ft/min
Cruise speed	50 kts

7. Traffic generation: A capacity study using simulation models involves the generation of baseline traffic, which increases until system saturation. This traffic was generated from the monitored value of passengers through the two airports on 26 June 2023, which showed an above-average number of movements and limited delays. The traffic data analyzed were extracted from the Aeronautical Information Regulation and Control cycles provided by Eurocontrol. In particular, five time slots with a constant level of traffic between 07:00 and 21:00 were considered. Figure 3 shows the values of each hourly range, so the number of passengers monitored between 20:00 and 21:00 is included in the x-value of 20.

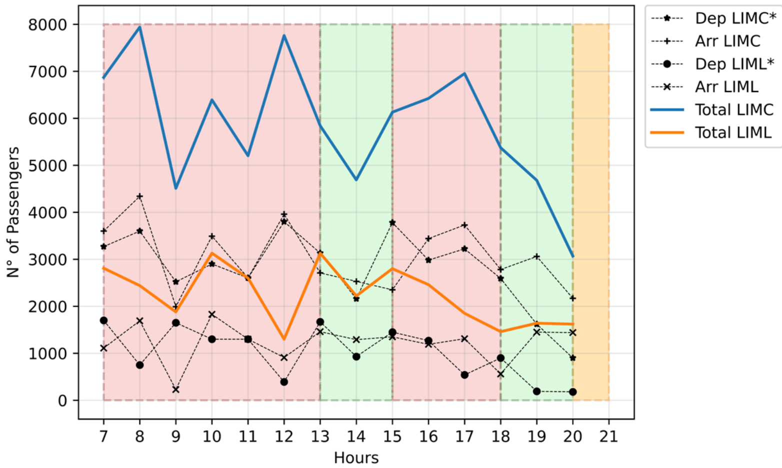

Figure 3. Hourly number of passengers at the two airports. (* values referring to departures two hours later).

It has been assumed that only a very limited percentage of airport passengers will use UAM (up to 2%), since it is a mode of transport that can be chosen by business and first-class passengers. Starting from these hypotheses, the flights have been scheduled considering a trend similar to that of the movements recorded in the airports.

Table 2 lists the hourly number of movements (arrivals + departures) of the two airports for each time slot. The total daily movements are therefore equal to 460. The traffic has been divided so that the following are true:

- The four provincial vertiports are always connected with the two airports;
- The City Life vertiport mainly serves the Malpensa vertiport;
- The Porta Romana vertiport mainly serves the Linate vertiport.

Table 2. Hourly number of movements (arrivals + departures) in LIML and LIMC.

Time Slot	Hourly Number of Movements	
	Vertiport LIML	Vertiport LIMC
07:00–13:00	14	22
13:00–15:00	12	16
15:00–18:00	14	22
18:00–20:00	12	16
20:00–21:00	10	14

The capacity saturation of a system is reached when a saturation trigger is exceeded. The average delay per aircraft was considered a trigger in this study. It usually consists of three components:

- Ground delay: associated with ground handling and measured from when the aircraft leaves the parking lot until it reaches the waiting point or the queue for entry to the runway begins [41];
- Runway delay: Associated with the phase before departure since the aircraft reaches the waiting point or the queue beginning until take-off. This delay component depends on the runway timing management in terms of separations and procedures and is not affected by events inside the parking lots [42,43];
- Sequencing delay: associated with events during flight (e.g., the entry into hold circuits, course changes, changes in altitude and speed, and vectoring) [44,45].

In this study, only the runway delay has been considered because it was assumed that the land side is simplified with an infinite parking capacity and that there are no elements that cause further delays once the aircraft is en route. Two consecutive drone takeoffs have a time separation of 1 min, which corresponds to a 0.5 NM spatial horizontal separation, and it is assumed that this distance is always respected during the flight. The maximum delay has been set at 10 min, which is less than the maximum delay considered at the airport level (15 min) to take into account the very short range and urban service of the flights. The average delay D_m is calculated according to Equation (1):

$$D_m = \frac{D_t}{TD + LO} \tag{1}$$

where TD is the number of landings, LO is the number of takeoffs, and D_t is the total delay accumulated during an hour in a vertiport.

System saturation occurs when one of the vertiports turns out to be saturated [46]. Once the saturation trigger has been identified, it is necessary to understand the characteristics of the network capacity [47,48]. Figure 4 explains the measurement of arrivals and departures for a single vertiport and its final capacity evaluation. As a result, i × j simulations are conducted, where i is the number of variants (traffic increments) and j is the number of simulations performed for each variant differing for flight schedules to generate randomness in the system [49]. Randomness is automatically applied by AirTOp varying by a few minutes (before or after) the scheduled flights generated on the base scenario by the software itself. The FTS model records, for each vertiport, how many take-offs and landings occur in an hour, considering ten-minute steps. The simulation results are filtered to eliminate all the hourly arrival–departure pairs that exceed the saturation triggers.

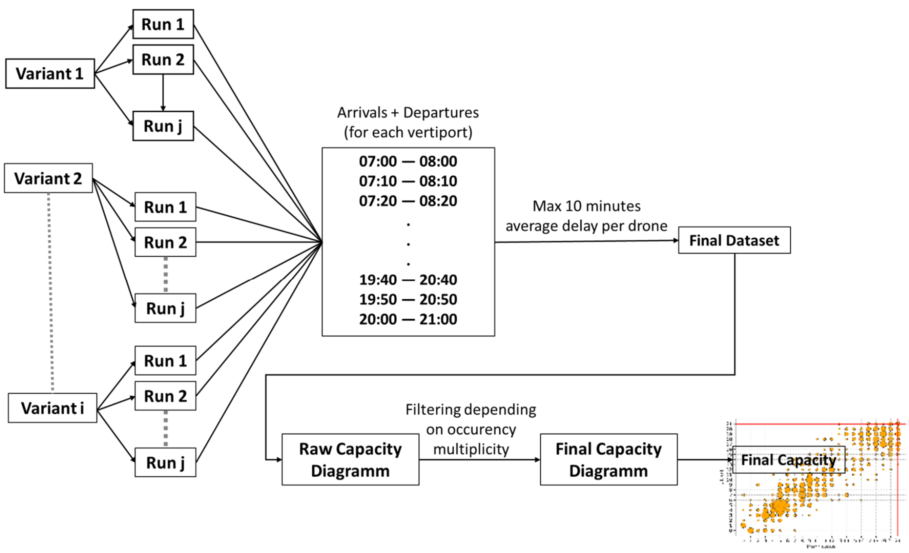

Figure 4. Capacity calculation for a single vertiport.

3. Results

For each network configuration, the base traffic was increased by 160% and 300%, respectively, in 10% steps, reaching a maximum of 1196 daily flights for the first configuration and 1840 daily flights for the second configuration. Since each variant simulation is carried out five times, 85 simulations were carried out for the first configuration and 55 simulations for the second configuration. Figure 5 shows the number of simulated total movements the two airport vertiports can handle daily.

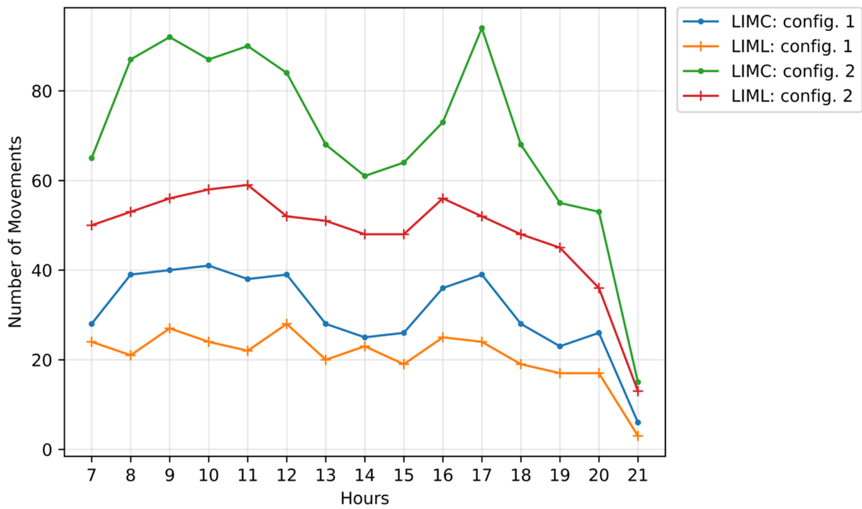

Figure 5. Aerodromes' vertiport total movements.

The curves in Figure 5 reproduce a trend similar to the passenger traffic in Figure 3. By unpacking these trends into departures (Figure 6) and arrivals (Figure 7), the departures and arrivals distribution is uniform for both configurations of LIML, while the trend fluctuates in both configurations of LIMC.

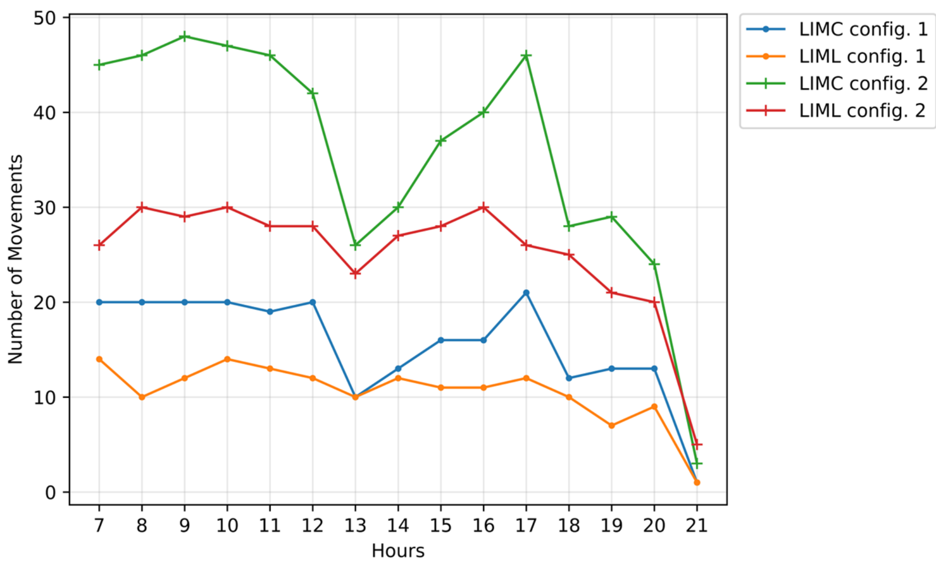

Figure 6. Aerodromes' vertiport departures.

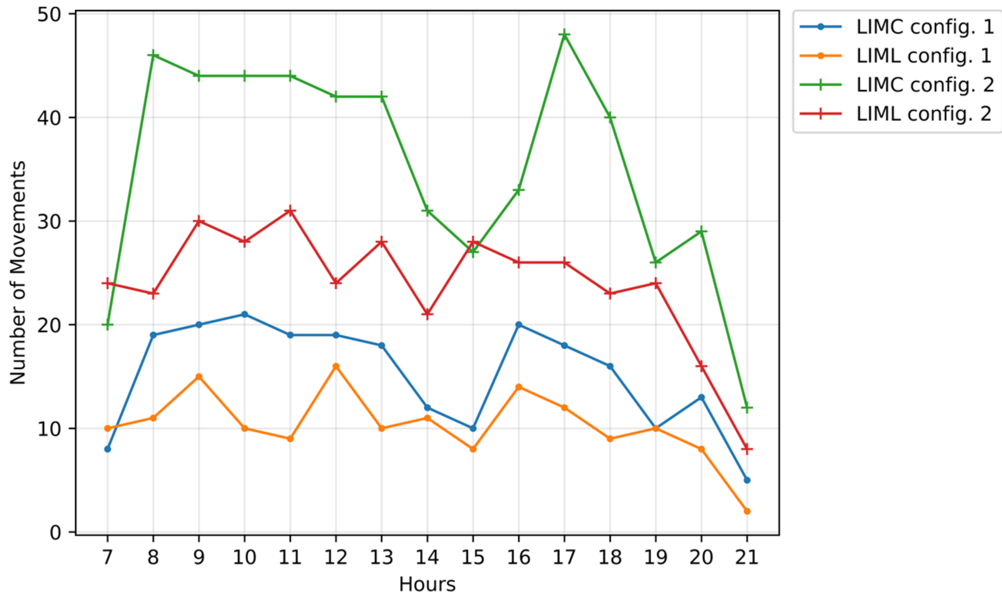

Figure 7. Aerodromes' vertiport arrivals.

This is because the lower corridor to LIML is occupied by traffic from LIMC, thus not allowing a correct distribution of departures to Linate. The peaks in arrivals to LIML are concentrated at specific times when traffic from LIMC does not influence departures from provincial vertiports. On the other hand, this issue is not in the arrivals at LIMC vertiport since the upper corridor is less busy due to the lower number of departures from LIML. Moreover, the distance of the vertiports from the upper corridor, and therefore the length of the SIDs, is much greater than the lower corridor, thus leading to a better management of separations. The analysis of the delays in Figures 8 and 9 highlights that for both configurations, the average delay per cumulative aircraft of all vertiports is predominantly dependent on drones with a flight plan to the south (i.e., to Linate).

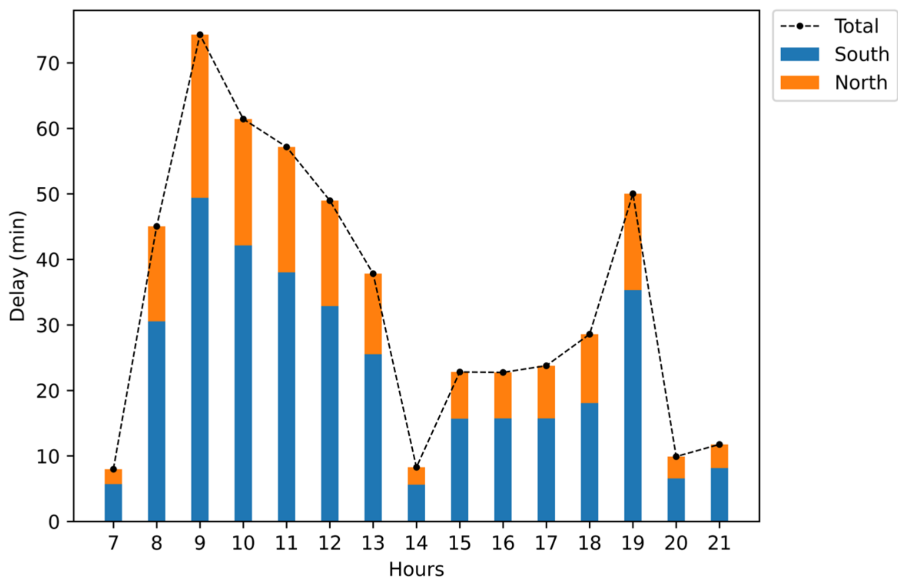

Figure 8. Configuration 1: total average delay per cumulative aircraft of all vertiports per direction.

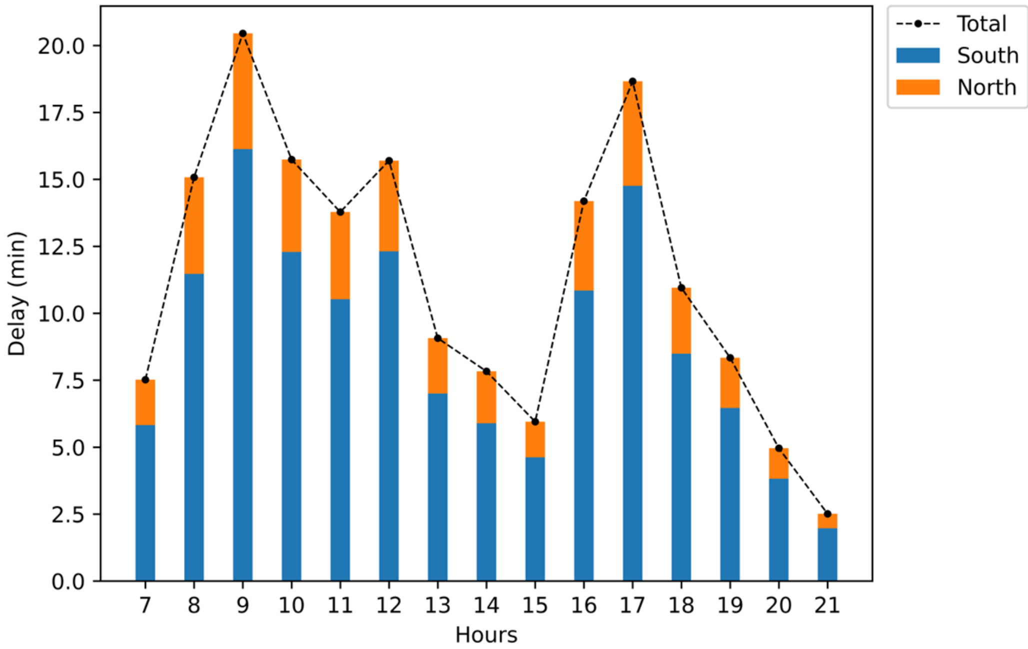

Figure 9. Configuration 2: total average delay per cumulative aircraft of all vertiports per direction.

In the first configuration, the delay is greater than in the second configuration. In Figure 10, the average delay per aircraft of each vertiport is much higher than the saturation trigger of ten minutes in the case of the first configuration for all provincial vertiports.

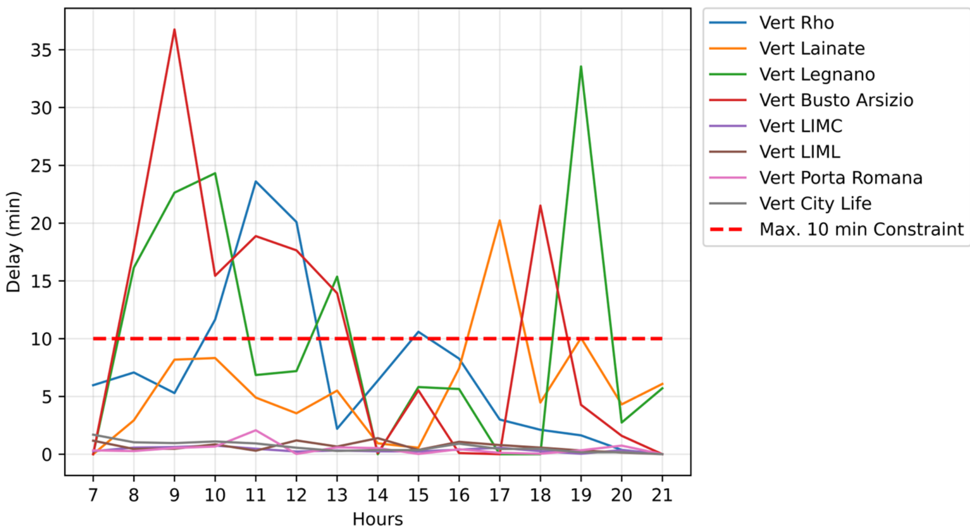

Figure 10. Configuration 1: average delay per aircraft.

Conversely, the delays are much lower in configuration 2 (Figure 11), and only the Legnano vertiport reaches the saturation trigger.

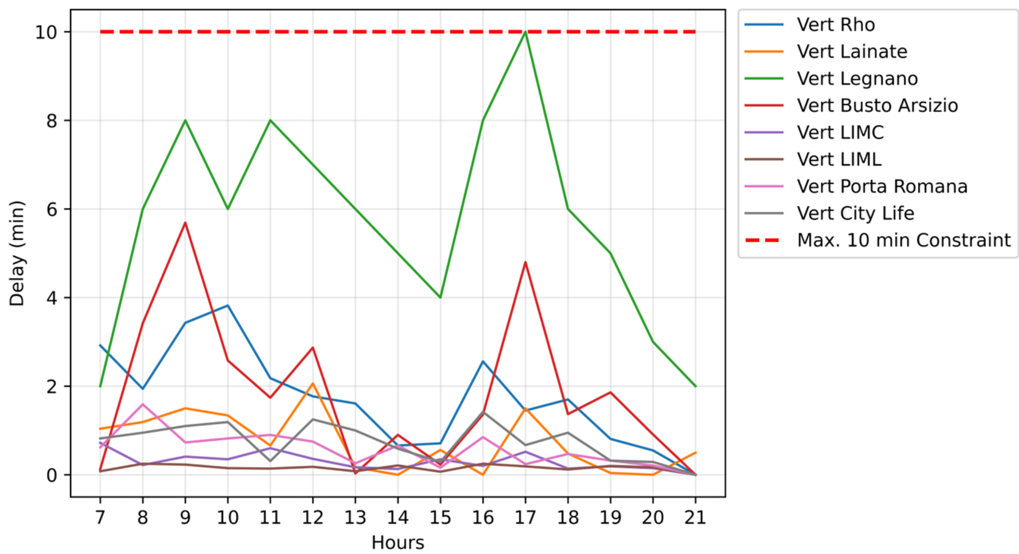

Figure 11. Configuration 2: average delay per aircraft.

The delay distribution is consistent with the traffic volume in the given time slots; in fact, the greatest delays are in the first time slot of 07:00–13:00 and at 17:00. Finally, the last analysis compares the trend of passengers of the two airports with the trends of arrivals and departures of the two airport vertiports. Specifically, each trend has been normalized to its daily average value to allow the correct overlap. Figures 12 and 13 show the total number of movements of the two vertiports and the total number of passengers at Malpensa and Linate airports, respectively. The simulated traffic at Malpensa is totally by the chosen distribution and compliant with the passengers' distribution. The lower consistency between simulated and actual passengers in the Linate case study is due to the distribution of departure traffic derived from the distribution of Malpensa, given the uneven trend of passengers at Linate during the day.

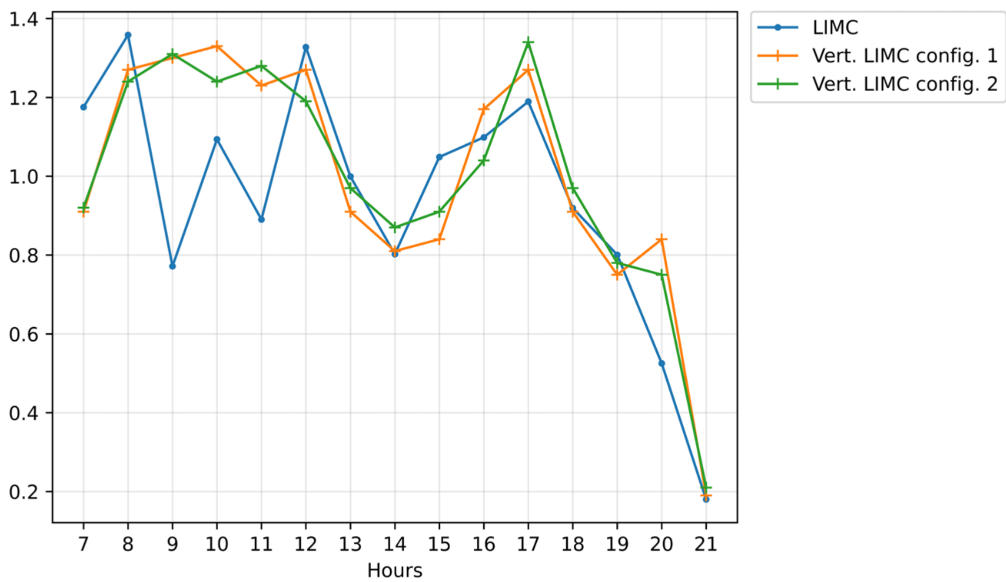

Figure 12. Normalized movements and passengers at Malpensa vertiport and airport.

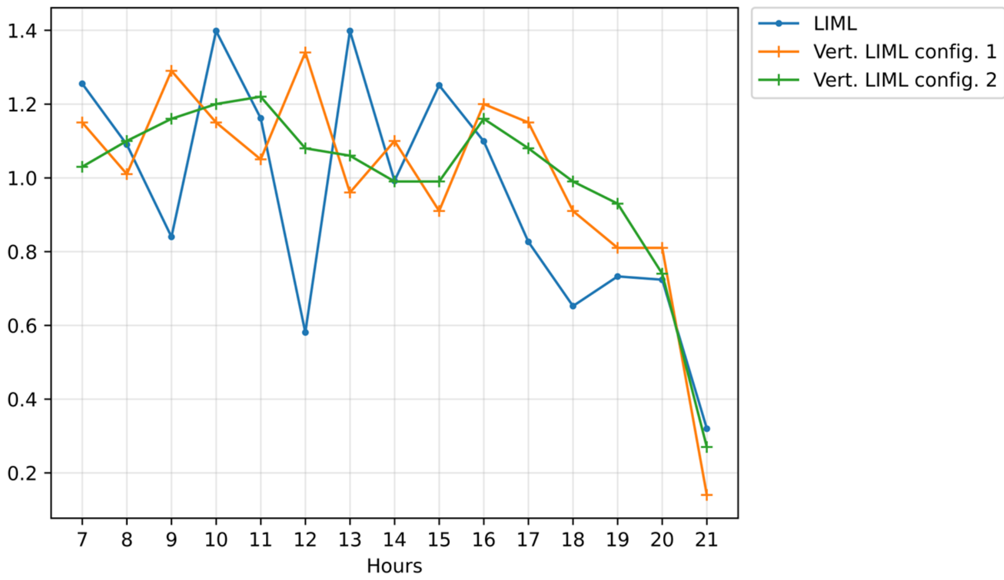

Figure 13. Normalized movements and passengers at Linate vertiport and airport.

Unpacking the total trends in arrivals and departures of vertiports and therefore passengers departing and arriving at the two airports, the following analyses are possible:

- Departures from the vertiport and arrivals at Malpensa airport: In Figure 14, passengers arriving at Malpensa can be served by drones departing from the vertiport. This confirms the correctness of the choice of drone distribution and the absence of departure blocks to maintain separations.

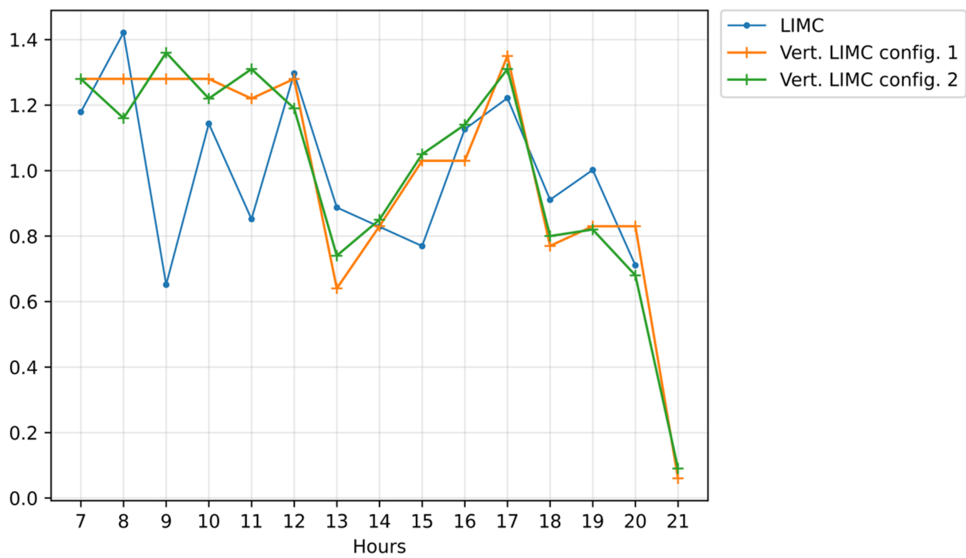

Figure 14. Normalized departing and arriving passengers at Malpensa vertiport and airport.

- Departures from the vertiport and arrivals at Linate airport: In Figure 15, the distribution of drone traffic can guarantee the service to passengers arriving at the airport. However, the minor overlap of trends lies in the generated base traffic.

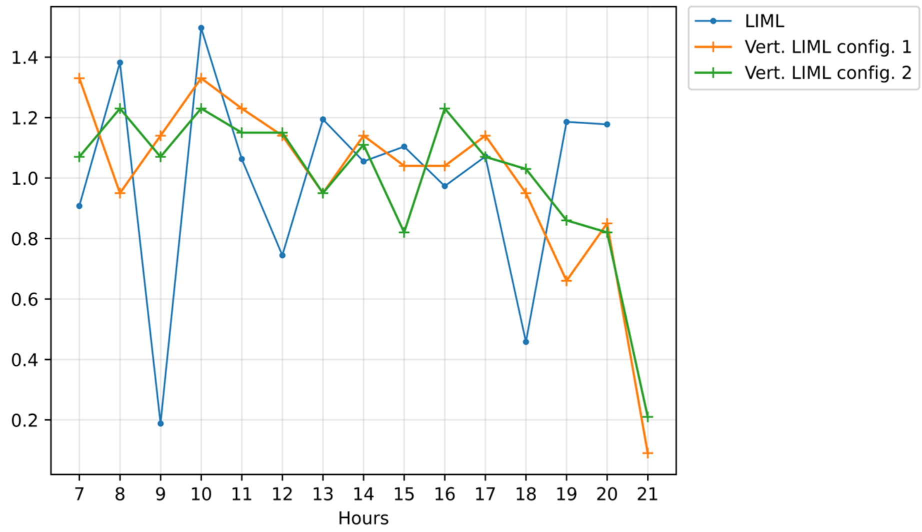

Figure 15. Normalized arriving passengers at Linate vertiport and airport.

- Arrivals at the vertiport and departures from Malpensa airport: In Figure 16, arrivals at the vertiport are consistent with passengers departing from the airport during the first two time slots. However, the sudden increase in demand during the third time slot implies that the peak of arrivals that should occur at 15:00 is shifted by one and two hours forward for the first and second configurations, respectively. This condition is due to a slow response of the system to the increase in traffic.

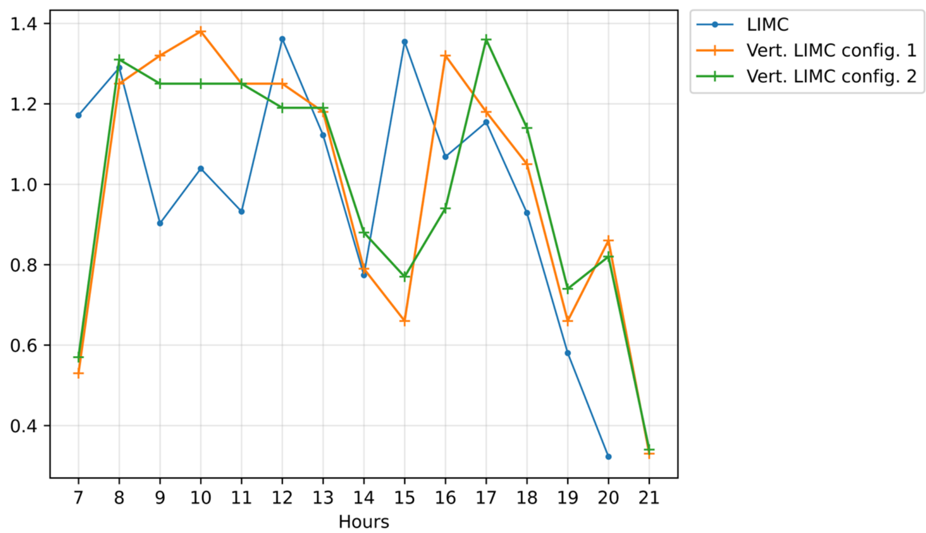

Figure 16. Normalized arriving and departing passengers of Malpensa vertiport and airport.

- Arrivals at the vertiport and departures from Linate airport: Beyond the overlapping of trends, in Figure 17, it is possible to observe two peculiarities. The first one concerns the amplitude of the oscillations of the first configuration being greater than the second one, and the second involves a blockage of departures from the provincial vertiports between 10:00 and 11:00. The beginning of heavy delays in the first time slot causes the blockage and leads to a one-hour shift forward in the peaks of vertiport arrivals between the two configurations. At 5:00 p.m., the system fully recovered from the delay of the first time slot, and the two trends resort back to overlapping.

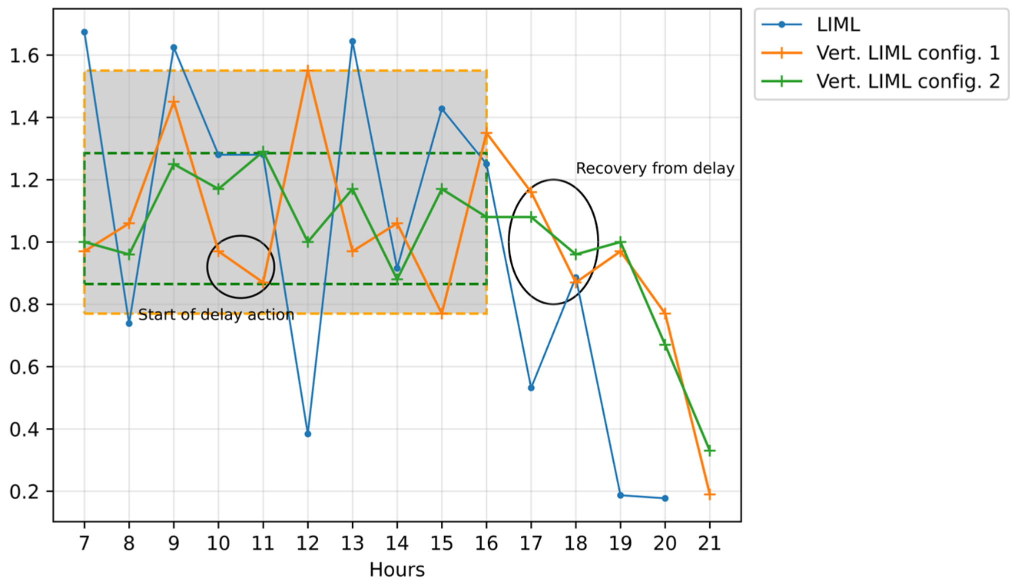

Figure 17. Normalized arriving and departing passengers of Linate vertiport and airport.

The final dataset allowed a capacity diagram for each vertiport (Figure 18). The point size corresponds to the number of arrival–departure pairs measured in the simulations. The data were filtered by omitting all those points for which the capacity was not balanced and were thus excluded. The Pareto frontier [50,51] in Figure 18 identifies the maximum capacity diagram of a given vertiport. In the figure each circle indicates a result of a simulation.

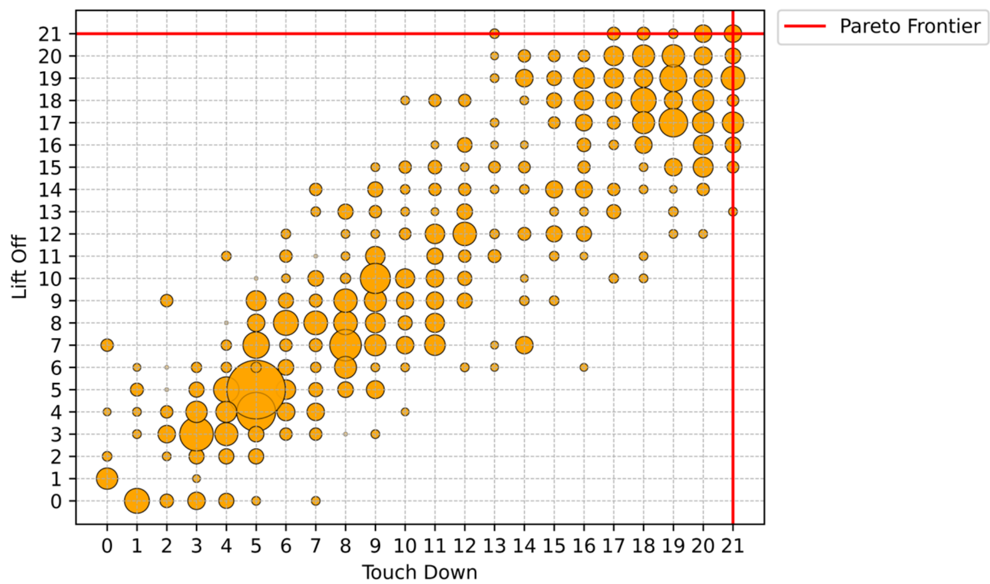

Figure 18. Pareto frontier for a vertiport.

Concerning traffic, the proposed system is sensitive to the distribution chosen at the outset of the basic traffic. The total network capacity occurs at a traffic equal to 120% and 300% of the base traffic for the first and second configurations, respectively. The results are given in Table 3.

Table 3. Capacity of each vertiport.

Vertiport	Vertiport Type	Capacity: Configuration 1 (Arrivals–Departures)	Capacity: Configuration 2 (Arrivals–Departures)
LIMC	Airport	42 (21-21)	90 (45-45)
LIML	Airport	28 (14-14)	60 (30-30)
Porta Romana	City center	20 (10-10)	42 (21-21)
City Life	City center	20 (10-10)	42 (21-21)
Rho	Provincial	8 (4-4)	18 (9-9)
Lainate	Provincial	8 (4-4)	18 (9-9)
Legnano	Provincial	8 (4-4)	18 (9-9)
Busto Arsizio	Provincial	8 (4-4)	18 (9-9)

4. Discussion

The traffic network analyzed in this study was designed with two distinct configurations of vertiport infrastructure. The first configuration featured vertiports equipped with a single FATO (Final Approach and Takeoff Area), while the second configuration incorporated a double FATO setup. This difference in vertiport design had a direct impact on the modeled take-off and landing procedures for drones, which were used to assess the overall network capacity. Concerning the first configuration, Legnano and Busto Arsizio are the first two vertiports to reach saturation. Iin contrast, in the second configuration, only Legnano vertiport is critical. The saturation traffic is about directly proportional to the number of FATOs, and the capacity of the vertiports has more than doubled from the first to the second configuration. A similar capacity is observed in provincial vertiports (i.e., Rho, Lainate, Legnano, and Busto Arsizio). Indeed, they have the same capacity as the two vertiports in the city center (i.e., Porta Romana and City Life). This depends on how basic traffic flights were initially distributed among all vertiports. Therefore, the sum of the capacities of all the provincial vertiports and the two vertiports in the city center is equal to the sum of the capacities of the two airport vertiports. Future research should explore ground infrastructure simulations that are informed by a more detailed analysis of the selected vertiport sites.

Finally, it is possible to estimate the share of passengers who could use the UAM service:

- Milan Linate: The maximum capacity is 28 movements in configuration 1 and 60 in configuration 2; consequently, the number of passengers is 56 and 120, respectively. Given that the maximum number of hourly passengers on the reference day is approximately 3000, the UAM service can cover, as a minimum, 1.8% and 4% of the total traffic for the two configurations, respectively;
- Milan Malpensa: The maximum capacity is 42 movements in configuration 1 and 90 in configuration 2; consequently, the number of passengers is 84 and 180, respectively. Given that the maximum number of hourly passengers on the reference day is approximately 8000, the UAM service could cover, at a minimum, 1% and 2.5% of the total traffic for the two configurations, respectively.

Therefore, considering the maximum number of passengers per hour at the two airports as approximately 11,000, the hourly capacity of the entire network is equal to the sum of the capacities of the two airport vertiports (i.e., 70 and 150 for the first and second configurations, respectively), and the whole network could handle, at a minimum, 1.26% and 2.72% of the total passengers for the two configurations, respectively. Concerning the total number of passengers on the reference day (i.e., approximately 113,000), the network at maximum capacity throughout the day can handle 1.72% (about 1950) and 3.7% (about 4200) of the total passengers.

5. Conclusions

This study evaluated the feasibility of implementing a U-Space within a city context, such as Milan, to connect two airports with the city center and the most populated provinces. This context, given the considerable number of vertiports, is a futuristic scenario implementable under some conditions: (1) the availability of all U-Space services will be available and 100% integrated with the current services for the management of unmanned traffic, (2) all the aspects related to the regulation of the ecosystem will be mature and available, and (3) the social acceptance will be reached and the actual usefulness of the UAM understood.

The simulation in the AirTOp environment can reproduce the behavior of highly complex dynamic systems, such as an airport and the ATS network. Unlike analytical models, in this case, the functioning of the system is not mathematically modeled; instead, the system is replicated by modeling each actor involved using specific tools. Therefore, the simulation model is a simplified and virtual replica of a real system, capable of reflecting a set of characteristics deemed relevant to the study's objectives. AirTOp provides theoretical output data, that is, a theoretical capacity, based exclusively on the input data entered. The reliability of the results therefore depends on the validity and representativeness of the operational reality of the input data. The extreme accuracy of a tool such as AirTOp allows the transfer of the methodology to any urban reality.

The traffic network designed and studied was proposed with two configurations of vertiport infrastructure. In particular, the first configuration featured vertiports equipped with a single FATO, while the second one featured a double FATO. This difference affected the drone take-off and landing procedures modeled to assess the network capacity. The other relevant factors were the applicable separations, the traffic distribution during the day, and above all the lack of an effective land-side infrastructure in terms of parking stands and special procedures applicable during the flight (i.e., vectoring, route changes, altitude, and waiting points, circuits, or hover points). Therefore, this study overlooked safety, security, obstacles, and spaces available to construct vertiports. All these factors could change the location of the vertiports, routes, procedures, and the final network capacity.

The key findings indicated that doubling the number of FATOs can effectively double the capacity of each vertiport and, by extension, the overall network capacity, allowing for a greater volume of flights and passengers. However, a dual FATO configuration also significantly increases associated costs. A larger area is required to accommodate additional parking stands, expanded passenger terminals, and enhanced facilities, all of which drive up construction, operational, and maintenance expenses. Moreover, traffic management becomes more complex, with implications for service providers that must be taken into account. Future work could explore simulations of ground infrastructure, incorporating a more detailed analysis of the selected vertiport sites, which might also necessitate revisions to air and ground procedures.

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