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Generalistic Assessments of the Potential of Medical Drones in Urban Environment

Based on Microscopic Travel Time Comparison with Ground-Based Services

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Abstract. At the current development stage, the lower airspace above urban areas is only used to a very limited extent. Recent developments in the drone industry are making this area more accessible. The leading use case for drone applications is currently seen in the medical sector. Individual evidence shows that the use of drones to transport medical personnel for first medical response brings significant improvements in terms of cost and response time. Advantages in urban applications are seen as promising by some research projects, but this is not scientifically proven yet. This study deals with the simulation of transportation times of medical proposals by ambulance and drone in the metropolitan region of Stavanger and the comparison of transport times. The proposed methodology develops transferable results from concrete use-cases. By using a drone 80% of the expected operations can benefit from a reduction in transport time of up to 10 minutes with a variation of +/- 4 minutes through adjusted flight speeds due to weather conditions and variations in ambulance travel times due to different traffic volumes. The data set cleaned for the local special cases shows potential for a reduction of up to 20 minutes for the remaining operations, while the extracted individual cases even showing improvements of up to 60 minutes.

Keywords: VEMS-Drone, Medical eVTOL, Road-Network Simulation

1. Introduction

In the medical sector, timely transportation of goods and passengers plays a critical role, particularly in emergency situations where response time can significantly impact patient outcomes[1], [2]. Ambulance personnel rushing to incident locations and the transport of medical cargo, like transplant organs, rely heavily on efficient transportation systems. Currently, most medical transports are conducted using ground vehicles, which are constrained by various limitations such as traffic congestion [3], challenging geographic terrains like mountains or islands [4], [5], and personnel shortages [6]. These limitations often hinder the timely arrival of medical personnel or supplies to the required destinations.

Recent advancements in the field of electric aviation, particularly the development of drones for cargo and passenger transport, offer a promising alternative that can potentially address above-mentioned challenges. Companies in several countries (e.g., Everdrone in Sweden [7], and Zipline in Rwanda [8]) have already successfully implemented drone-based deliveries of medical goods, demonstrating the general feasibility and potential of air-based transportation in the medical sector. Other R&D projects, being funded by the European Commission (e.g., Flying Forward, Auroura, Amu-LED, AiRMOUR) or by the industry [10],[20] are actively investigating the future of drone-based medical delivery of goods and passengers. This work was created during the authors' collaboration in the AiRMOUR project with the support of other project partners. The study benefits through collaboration with the city of Stavanger and Ehang Scandinavia, with knowledge of the local rescue system, the drone Ehang 216 used in this study and support through data exchange. The local rescue system faces challenges due to the city's location on a peninsula and the connection to several islands via often just one main road. An increase in transport efficiency using drones seems obvious. However, the extent to which advantages can be found in urban areas and whether these can be found in other cities is less clear and requires closer examination.

Air rescue is currently not a new invention but is currently mostly carried out using helicopters. To understand the advantages of electric Vertical Take-Off and Landing aircrafts (eVTOLs) and thus the relevance of the project objective for real use cases, specifications are shown in Table 1 and discussed below. The D-Value indicates the smallest enclosing circle that encloses the aircraft from the top view. The eVTOL used in the study, the Ehang 216, has a significantly smaller D-value compared to the helicopters listed, which means that comparatively smaller landing sites can be flown to, according to [9]. This would encourage use in urban areas. Due to their similarity, drones and helicopters can be mainly compared by their max. flight speed and range. Table 1 shows specifications in relation to the data sheets of six eVTOLs currently under development or certification compared to the most common Airbus Helicopters used in helicopter emergency medical services (HEMS). While operational ranges for drones range from 30 to 175 km, currently deployed helicopters have ranges over 500 km. If the cruise speed is considered, some hybrid systems can keep up with helicopters. However, multicopters considered in the study have significantly lower speeds of 80 km/h and have hardly any capacity for patient transportation. Respectively, this would make them more likely to be used as a supplement to the ground-based emergency medical service (EMS) in Rendezvous-System in situations a helicopter is normally not used due to high operational costs, limitations through landing capabilities or other reasons. This approach is also assessed in [10] as early deployment.

Table 1. *Parameter from the data sheets of the manufacturer and for E216 recommended by Ehang Scandinavia*

eVTOL	cruise-speed in km/h	operational range in km	max. payload in kg	D-value in m
Volocity [11]	(110 max.)	35	200	11.3
Ehang 216	80 (130 max)	30	220	5.61
Lilium Jet (2P) [12]	(250 max.)	175		
Archer Aviation Midnight [13, 14]	240	80	450	
CityAirbus NextGen [15]	120	80		
HEMS Helicopter [16]				
Airbus H125 (most cost competitive)	252	630	973	12.94
Airbus H135 (common in HEMS)	252	633	1 418	12.26
Airbus H145 (high performance)	241	650	1 905	13.54
Airbus H225 (search and rescue, coast)	263	840	5 401	19.50

The effectiveness of air transport in comparison to ground transport depends on several factors, including the type of road (highway, small road, etc.), the road circuit factor (road-distance divided by air-distance), traffic delays faced by ground vehicles, drone velocity, flight routes, and take-off and landing durations. For time-critical medical flight missions, it can be assumed that the drone can choose the fastest possible (linear) path to the scene.

Many studies show the advantages of drone applications in the medical supply of goods [17], [18], [19]. Despite the potential benefits, there is a scarcity of literature on the actual response time gains of drone-based transportation of medical staff for primary care. For example, a Google Scholar search for english and reviewed papers with the search term "VEMS medical drone", where VEMS describes an eVTOL employed in EMS, yielded no results. Further search queries returned non-matching results, often in the context of medical goods transportation by drone. The authors are only aware of the two studies by the University Medical Center Groningen and ADAC Air Rescue [10], [20]. This scarcity can be attributed to the industry's relative immaturity [21, p. 8] and the lack of publicly available georeferenced Emergency Medical Services (EMS) data. Furthermore, the existing literature does not address the question of the extent to which the integration of drones into rescue services has any transportation time advantages in urban areas. The authors therefore pose the following research questions:

- How can advantages in the transportation time of medical personnel using drones in emergency medical services be explored at a high level of geospatial detail?
- What methods can be employed to identify local irregularities?
- Where do local deviations appear and what could be the reason for the deviation?

The work explores the extent to which eVTOL deployments can complement the ground-based EMS service. Examples with clear benefits are quantified as well as relevance of the deployment in urban areas with dense road networks is put to the test. For this purpose, analysis methods are developed to evaluate the usefulness based on time advantages. Parameters of the drones have been adjusted to the Ehang 216 drone, as there was contact with the subsidiary Ehang Scandinavia during the analyses.

2. Methodology

The methodology is divided into four subsections. First, the structure of the traffic simulation describes how the SUMO model was built from a functional point of view. The second part deals with how the model was calibrated and shows the validation of the results. The third subsection deals with the procedure for determining the flight time of the drone. The last part describes how the results are combined and how the results are processed further.

2.1 Structure of the traffic simulation

The area around Stavanger shows common urban and suburban infrastructure in the city centre, west as well as south of the city, rural areas in the south-east as well as complex road routes to the northern islands as well as to the eastern mainland. Some islands are not connected to the road network. Due to the diversity of the road system, the area around Stavanger was chosen for a more detailed analysis.

The norwegian database provides statistical data on their EMS operations. Through cooperation with local authorities, detailed information on response times and distances is also available. Underlying real data of EMS operations in the wider area around Stavanger do not contain location information. To establish a local reference to EMS data, a microscopic traffic simulation was created. The SUMO software [22] was used for this purpose.

For the road Simulation, the network was obtained via OpenStreetMap, checked for open nodes and disconnected road segments, and manually matched and cleaned over satellite pictures.

Data from traffic counts were integrated into the model for the interaction of ambulances with general traffic. On average vehicles driven per day were imported from the geo-database of Norway [22]. The dataset contains 505 road segments and data of 2017. The LeuvenMap-Matching algorithm [24] was used to assign these count values to roads of the simulation.

Average traffic was adjusted by statistical distribution per time of day. The data available [25] were resampled in time steps of equal length and normalized with respect to the daily mean and plotted in Figure 1.

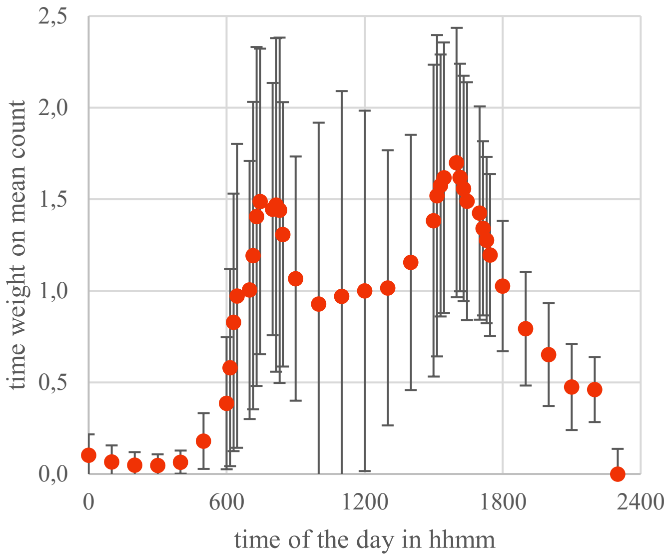

***Figure 1**. Average time deviation of the vehicle throughput from the average.*

Three traffic conditions were defined in the simulation. These are intended to describe the traffic at night, the average condition, and as well as extreme conditions. Extreme conditions are slightly above the mean maxima around 8 am and 4 pm due to the high variance in these areas. Derived from the distribution seen in Figure 1, the average traffic data of Stavanger is weighted with the following factors:

- night: 0.25
- normal: 1
- extrema: 2

Initially traffic with a total mass of about 3.000 vehicles for the normal condition is created randomly. With the counting data adjusted to the three traffic states, the previously generated random traffic is rerouted to meet the traffic volume at the counting points.

To be able to make meaningful statements, uniformly distributed operations are defined over the entire simulation area. In the norwegian projection of epsg:5105 a grid with point distances of 1 km is drawn over the whole simulation area. For each grid point, the next node point of the road network is searched by using the python library OSMNX [26]. In the Simulation a route from the hospital to each respective node is spawned with a delay of 30 seconds. The destinations are processed in random order, so that build-up effects due to nearby ambulances are reduced.

To be able to simulate the driving profile of ambulances, it must be ensured that they can realistically drive past traffic by forming emergency lanes. In the simulation with used the sub-lane model, other vehicles form emergency lanes, but the ambulance did not use them initially. This not only meant that the ambulances had no time advantage over normal road users, but also that the cars affected by this could only move to a limited extent in the simulation. Consequently, the parameter minGapLat, which sets the lateral safety distance for emergency lanes were changed among other parameters until the use of the rescue lane by ambulance was working on a functional level. MinGapLat was set from default 0.6 m to 0.05 m in the simulation described here. LatAlignment was set to left so that the ambulance is oriented in the left lane and has the shortest distance to the emergency lane, and the willingness to obstruct other drivers from the side was set to 100% with the parameter lcPushy. The ambulances are set without random variation of the driver profile parameters and are allowed to exceed speed targets up to 50%.

2.2 Calibration and validation of the simulated driving time

All vehicles are simulated with the EIDM car-following model, that was realistically calibrated in previous projects. [27]

The underlying real world EMS data [28] includes driving times of ambulances with patient transport. The data set was cleaned of HEMS flights and limited to category A urgency (life-threatening situation). Outliers were sorted out using logical exclusion criteria. Considering that trips at least include a small urban part, speed overshoots of 50% coincide with the distributions of mean travel times of the EMS logs of the three main speed groups: 30-50 km/h (city), 80 km/h (country) and 130 km/h (maximum speed ambulance). Mean speed of the simulation data of 72 km/h correlates with those of the EMS Logs with 71 km/h.

The road model is further validated over Google Maps travel time forecast by comparing 25 individual passenger car trips distributed over the entire area of the simulation, averaged over an entire week. The average time deviation is 2.2 +/- 4 minutes.

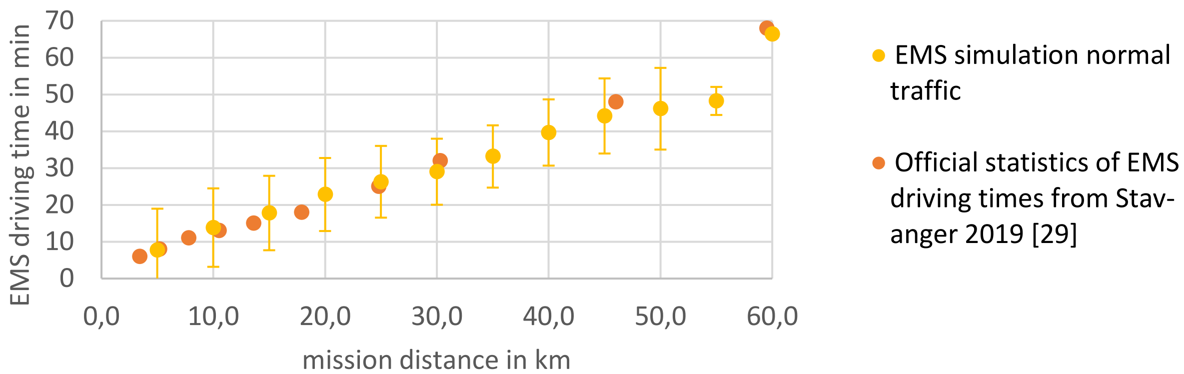

Figure 2. *Comparison of results of EMS drive time simulation real word datasets*

Figure 2 shows the comparison of the ratio of travel time to travel distance of the simulation with the official statistics from Stavanger 2019 [29]. This Datasets show a correlation with a R^2 of 0.9.

2.3 Calculation of the drone flight time

Drone missions were assumed to be linear, and dynamics were not considered. The calculation of the drone flight times t_{drone} is carried out considering the ascent speed v_{acc} of 3,5 m/s, descent speed v_{dec} of 3 m/s and a constant cruising speed v_c of $22,\overline{22}$ m/s (80 km/h),after consultation with Ehang. Since different speeds can be assumed for different drone models, as shown in Table 1, and these may vary even more for future models, a sensitivity analysis is carried out on the assumed vertical cruising speed. Variations are analyzed based on 1.5 times (120 km/h) and twice (260 km/h) the specified speed. We calculate the flight distance d_{lin} by solving the inverse geodesic problem with the python library geographiclib [30].

$$t_{drone} = \frac{h_t}{v_{acc}} + \frac{d_{lin}}{v_c + v_{air}} + \frac{h_t}{v_{dec}} \quad (1)$$

According to [9], realistic approach paths consist of a vertical and a subsequent diagonal section until the drone has reached its cruising altitude of >= 152 m (500 ft). Power reserves are maintained for the drone at the defined cruising speed. The horizontal cruising speed can therefore be maintained to a certain extent, even if the drone is also moving vertically. In [9], the gradient of the second segment is given as > 4.5 % and 12.5 % for an exemplary drone type. The gradient can also be represented by the ratio of vertical to horizontal speed. For the flight speeds used in the study, this results in a possible gradient of 13.5 % for the climb and 15.75 % for the approach. The available power reserves appear to be reasonable and only the vertical part of the approach and departure paths resolves in the travel time. Due to the flat topology of the study area, a simplified method was used by setting constant height differences $\boldsymbol{h_t}$ of the landing and take-off points to 100 m. In addition, the average wind speed over Stavanger of 20 km/h was used to define the most beneficial states for the drone (tailwind, $\boldsymbol{v_{air}}$= + 20 km/h) and the ambulances (headwind, $\boldsymbol{v_{air}}$= - 20 km/h). The energy consumption of drones can be regarded as constant at the same relative speed to the ambient air [31]. To keep the drone's energy -reserves, consumption and efficiency approximately constant and to be able to absorb gusts, $\boldsymbol{v_{air}}$ is added to the defined drone speed, to form the ground speed.

2.4 Transformation of the results

For analysis of best/worst case scenarios, the amplitude of the mean wind speed is added or subtracted to the cruising speed and compared with the matching traffic conditions. The amplitude of the wind speed is assumed to be 20 km/h and derives from mean values of the weather data during the winter months in the last five years [32]. The maximum flight range is adjusted via the integral of the air speed.

Time advantages are set in relation to the distance traveled, as well as the distance to the nearest major road. The extent to which these procedures are suitable for describing the representative behavior of the comparison between both systems is being investigated. Groups of similar behavior are clustered in this ratio to highlight local variations in response time.

For relative evaluations, the sample routes are adjusted to the EMS volume by weighting them with the population density, which is the main dependency on EMS deployment density [33].

3. Results

The local distribution of the time advantages in the tree conditions can be seen in Figure 3 to Figure 5. Considering the local distribution, there is already a noticeable time advantage in areas that are not located on the same headland. The Simulated missions in the southeast are no longer part of the Stavanger Hospital's usual area of operation. Due to the close proximity and the possibility of flying over the sea area, the use of the hospital's own drones can increase the catchment area. EMS log data from 2013 to 2022 around Stavanger also show, with a significant share of 20%, missions that indicate more than 60 km. Since the usual operational area is covered from north to south with about 60 km, it can be assumed that some operations are also carried out in the wider area. In these locations, the drone can significantly shorten the distance through linear flight paths and thus provide clear time advantages. The evaluation of the worst condition for the drone (see Figure 5) shows that the time advantage on the headland is partly close to zero. A clear advantage still emerges in areas that are difficult to access e.g., the northern islands or in the extended south-eastern analysis area as well as in some areas in the city center or away from the main traffic routes.

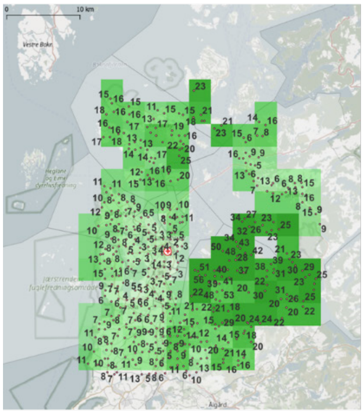

Figure 3. *Ambulance simulation at mean traffic vs. drone travel time calculation at zero wind (average)*

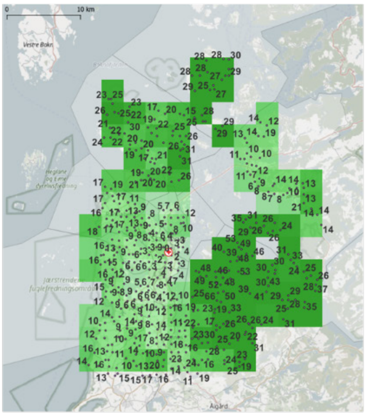

Figure 4. *Most beneficial conditions for drone (tailwind + rush hour/extreme traffic*

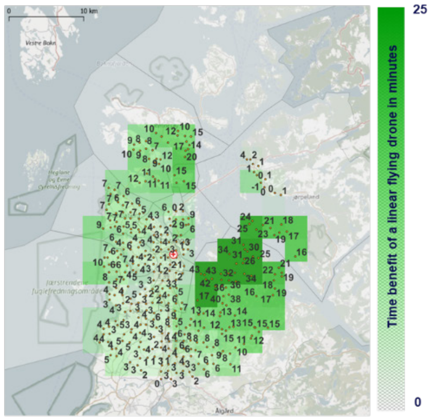

Figure 5. *Most beneficial conditions for ambulance car (headwind + nighttime traffic)*

The data from the simulation framework show, that despite the complex interplay of road network density, speed limits and traffic volume, there is a roughly linear relationship between the distance traveled on ground and the time advantage of the linear flying drone seen in Figure 6. Based on this, it is defined that missions which match linearity well, reflect the common travel behavior in the test area. Special cases that can be clearly identified, such as detours through complex road layouts, are to be taken as exceptions and increasingly deviate from linearity. The missions are clustered in the upper, lower, and outer envelope ranges of +/- 10 min around the common behavior shown in Figure 6. The local distribution of the four clusters is shown in Figure 8 and their local conditions are discussed later. Trips of the average traffic condition, which lie between the upper and lower envelope, form the "average generalistic behavior" data set used in the final results (see Figure 10). This removes obvious advantages and obvious bias arising from the selection of the Stavanger study area. The gradient of the travel time advantages is always directly dependent on the defined flight speed. The advantage of evaluating the average linear behavior as a function of the distance traveled by land seems to be a good indicator to show the benefits in a generalistic way regardless of the defined flight speed of the drone.

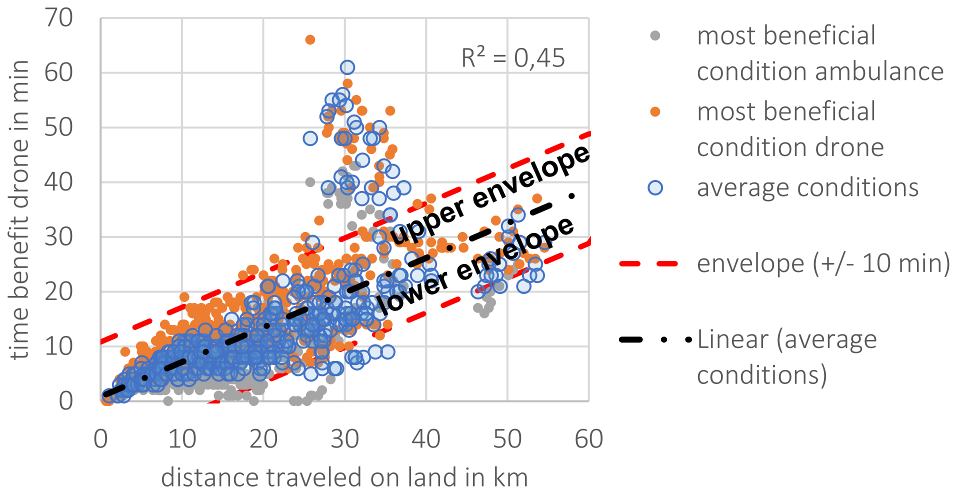

Figure 6. *Connection of the time advantages when using drones in the EMS sector to the distance to be driven on the ground.*

Figure 7 shows a slight correlation to the linear distance to the nearest major road (Open Steet Map type primary or higher). With an R² that is about half smaller than that of the previous method, this approach hardly shows any correlation. Clustered points located +/- outside a 10-

minute envelope are discussed below with regard to the local correlation but are not included in the final result. The local distribution of classified missions shown in Figure 8 point out, that exceedances of bout linearization methods are located on the neighboring spit of land, which is near the hospital but lead to long paths on the ground. This cluster mechanism is considered useful due to the obvious advantages of the drone. Disproportionate time advantages in relation to the distance to the nearest main road occur near the hospital, which is built close to the highway. This cluster mechanism is also considered useful because the drone has a large proportion of climbing and descending flights in the total flight time. The transport efficiency hereby decreases. Other undershoots are seen in peripheral areas of the simulation where proximity to a major road is present, but it is only reached via smaller roads with the integrated traffic network in the lower right corner of the simulation area. These results are difficult to interpret and do not appear to be relevant to the research question.

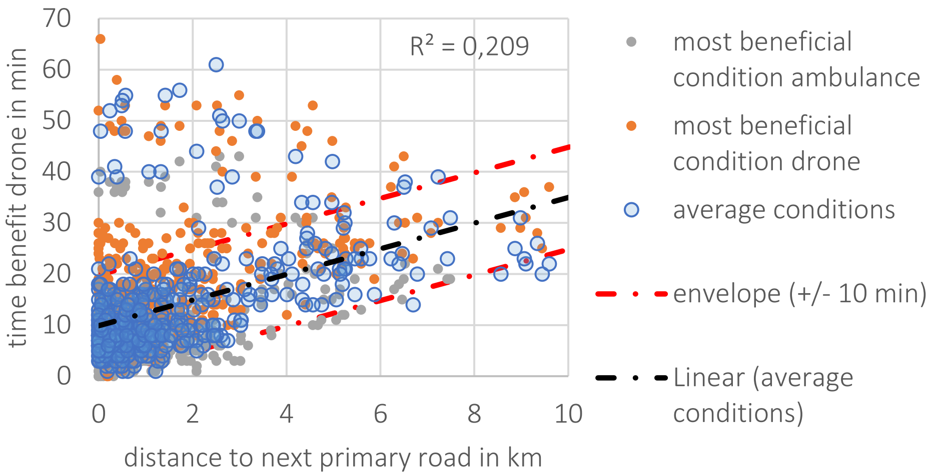

Figure 7. *Connection of the time advantages when using drones in the EMS sector to the proximity of the deployment site to the next street of the OSM street group primary road or higher.*

Up to 10 minutes above-average time advantages in relation to the driven distance of ground-based ambulances, are located primarily in densely populated areas. From this it can be deduced that use in inner-city areas can offer an above-average time advantage. The distribution in Figure 9 supports the statement that, relatively more improvements are evident in more densely populated areas.

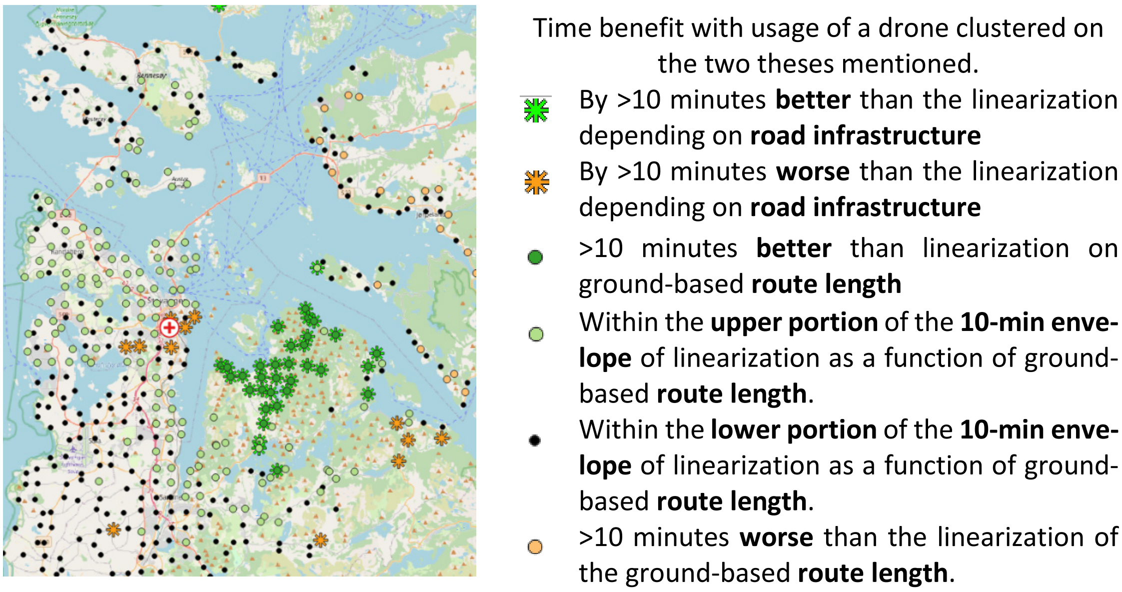

Figure 8. *Time benefit, clustered over on ground-based route length and infrastructure.*

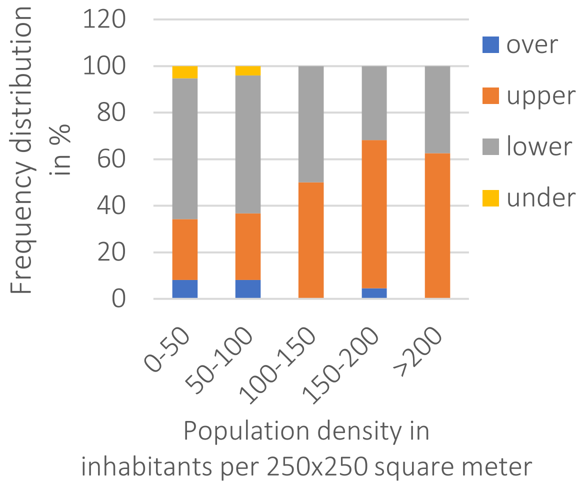

Figure 9. *Reference to the envelope of the ground-based driving distance combined by population density.*

Figure 10 shows the cumulative frequency when scaled the likelihood of the simulated EMS missions by population density [34]. To form the average generalist behavior only missions inner the envelope of the linearization between the route-length of the ground-based service and the time benefit is weighted by population density.

80 % of the weighted missions have time savings below 10 minutes at average, 6 minutes for the most beneficial scenario for ambulances and 14 minutes for drones. Except a few special cases expected for the generalistic behavior, the remaining time savings are in the range of up to 20 minutes. In the entire study area around Stavanger, about 5 % of missions show benefits between 20 and 60 minutes under average condition. For the most beneficial state for the drone the highest 5 % of time savings are in between 25 and 60 minutes and for the most beneficial state of the ambulances in between 10 and 40 minutes.

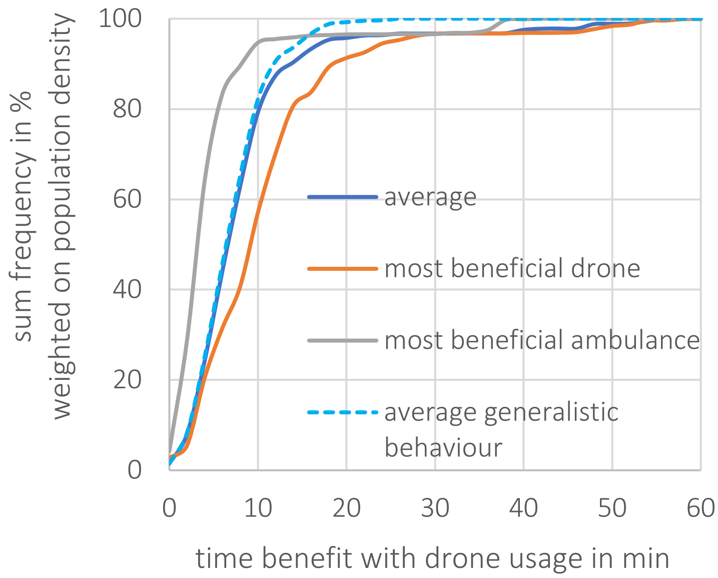

Figure 10. *Relation of temporal benefits with population density.*

The sensitivity analysis of the assumed cruising speeds shows a shift in the time advantages up to the 95th percentile in the sum frequency of the weighted EMS operation locations, as shown qualitatively in Figure 11. Table 2 shows quantitative statements on this topic. Here, the time advantages of different speeds were normalized compared to the original parameterization. When the speed is scaled by a factor of 1.5 and 2, a similar scaling of the time advantages up to the 80th percentile can be seen. The majority and above all lower time savings therefore mainly benefit from an increase in cruising speed. As the time savings increase, a reduced advantage of increasing the cruising speed can be observed.

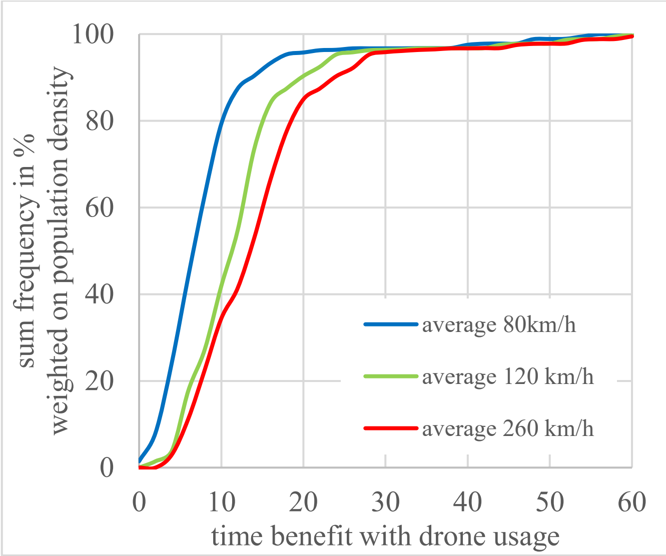

Figure 11. *Shift in occurrence of time savings with variation in drone vertical cruising speeds.*

Table 2 also shows the parameters of the linearization, illustrated by Formula 2, via the variation of the cruising speed. When the airspeed is increased by 50 %, the time advantage over ground-based EMS increases by 1 min per 10 km. Furthermore, the additional time advantage increases by 4 min (120 km/h) or 5.2 min (260 km/h) via the offset of the parameter "a".

$$dt_{in\ min} = b * x_{in\ km} + a \tag{2}$$

Table 2*. Scaling of the time advantages in relation to the scaled travel speed, divided into frequencies of occurrence.*

	Scaling in relation to the configured drone.				**Parameters of the linear approximation (see formula 2)**	
	Percentile of occurrence around Stavanger				**Min. saved on average, additionally in every journey.**	**Min. saved / km driven**
Horizontal cruising speed variation factor	**50%**	**80%**	**90%**	**95%**	**a**	**b**
1 (80 km/h)	1.0	1.0	1.0	1.0	0.83	0.63
1.5 (120 km/h)	1.7	1.5	1.4	1.3	4	0.72
2 (260 km/h)	2.0	1.9	1.7	1.6	5.20	0.81

4. Summary & Discussion

In areas of good road infrastructure, a linear relationship could be established between the distance traveled and the benefit from using linear flying drones. Areas that are connected to the EMS station via complex roads show a clear deviation from the linear behavior and are therefore classified as local special conditions. In this work, the average generalistic behavior was formed by linearizing the time advantage over the ambulance driving distance and a time buffer was added around the linearisation.

The local use case shows that the time advantage shrinks in areas with good motorway connections. Very high time advantages show up in areas of low population density. Low population density is associated with low volume of EMS deployments, whereby main roads have an increased EMS volume. [29]. However, even small-time differences in the EMS area are significant. In some areas of the city center, there is an above-average potential for time improvement of about 10 minutes. Generally, it can be expected, that an eVTOL with design of a multicopter in most cases is at least as fast as a ground-based system in every traffic condition. 80% of EMS-missions could have time savings below 10 minutes at average. The remaining time saving for use cases that are considered to be generalistic and transferable to a typical (sub-)urban area is, with a few exceptions, in the region of up to 20 minutes. In the specific extended area of application around Stavanger, around 5 % of the average conditions offer higher benefits of up to 60 minutes. For every 50% increase in the drone's flight speed, the time advantage over ground-based EMS can be increased by about 1 minute per 10 km of ground-based driving distance.

It should be noted that the need of secondary transportation will cause delay due to distances between the next nearest landing point and the emergency side. eVTOLs of the current state of development have a limited ability to land on unpaved ground, which could result in additional transport routes. Implementation of a variety of well-placed vertiports can mitigate this weakness. Personal drones are still at an early stage of development. It can be assumed that their specifications are still improving, especially in terms of speed, range, and payload. While the methodology can continue to be applied to changing drone parameters, the easily interpretable results of the distribution of time benefits in amplitude will change. An in-depth landing site analysis is being considered for the following work and will reduce time advantages compared to the improvement potential discussed here.

A hybrid model (ground ambulances and complementary drones for the cases with the highest time savings) may be most useful for real-world cases and should be further developed by EMS stakeholders.

Data availability statement

The data that supports the findings of this study are available within the referenced sources. Detailed information on the input data used in this research can be found in the respective publications and repositories mentioned in the references.

Additionally, a supplementary dataset obtained from Stavanger Universitets Sykehus has been utilized for validation purposes. However, due to a data processing agreement with the institution, this specific dataset cannot be published directly as part of this study.

Author contributions

Felix Wachter: Conceptualization, Methodology, Software, Formal analysis, Validation, Writing - Original Draft **Jannik Krivohlavek:** Writing- Reviewing and Editing **Jonas Rossa:** Methodology, Software, Investigation **Andreas Rupp:** Supervision

Competing interests

The authors declare the following competing interests: This study was conducted within the AiRMOUR project, exploring a specific use case in depth. The City of Stavanger and EHANG Scandinavia AS were consortium members. The authors also declare that the study was not directly influenced by this collaboration. The collaboration primarily involved defining the use case and facilitating the exchange of data, parameter sets, and systematic knowledge.

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