

A Cost-Infrastructure Assessment of UAV-Based Automated External Defibrillator Transport in an Urban Polish Context*

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Abstract

Previous studies on UAV-based delivery of automated external defibrillators have mainly examined the potential reduction of AED arrival times in sudden cardiac arrest. This paper adopts a preliminary planning perspective by examining the basic costs and organisational resources that would need to be considered before such a concept could be tested in a Polish city. Using Kraków as an illustrative reference case, the study develops an ex ante cost-infrastructure estimate of UAV-based AED transport based on selected technical, staffing and regulatory assumptions. The analysis considers a two-UAV pilot scenario and a wider urban scaling scenario to indicate the order of magnitude of resources associated with different levels of system development. The results show that personnel costs and the need to maintain continuous operational readiness dominate the estimated cost structure. The study therefore provides a baseline planning estimate that may support further discussion on pilot testing, without treating the proposed scenarios as a ready implementation model. From a management perspective, the study highlights the need to treat UAV-based AED transport not only as a technological concept, but also as a resource-planning and cost-structuring problem before pilot implementation.

Keywords: AED transport; drone delivery; medical logistics; resource planning

Introduction

Ensuring timely access to medical care in emergencies such as sudden cardiac arrest (SCA) is a critical challenge for urban emergency systems (Shah et al., 2024). In this context, rapid access to life-saving intervention becomes particularly important. SCA is an abrupt loss of all cardiac activity caused by an irregular heart rhythm, resulting in respiratory arrest and loss of consciousness in the affected person (Mayo Clinic Staff, 2024). In 2018, emergency medical service (EMS) teams in Poland reported initiating cardiopulmonary resuscitation (CPR) in 26,873 patients. The survival rate from the onset of SCA until hospital admission or the initiation of transport by the air ambulance service was 36.3% (Nadolny et al., 2020). The average survival rate until hospital discharge between 2010 and 2019 was only 9.9% (Yan et al., 2020). The shorter the time from cardiac arrest to critical intervention, the higher the survival rate (Larsen et al., 1993). If defibrillation occurs within the first 4 minutes of cardiac arrest, the patient's chances of survival can reach up to 50% (Weisfeldt and Becker, 2003). Therefore, efforts should be made to minimise the time between SCA occurrence and access to an automated external defibrillator (AED).

Reducing transport times may be supported, among other methods, through the use of unmanned aerial vehicles (UAVs), understood as aircraft operated or intended to be operated without a pilot on board, either remotely piloted or autonomous (Commission Delegated Regulation (EU) 2019/945, 2019). Over the past years, UAVs have been applied in a wide range of operational contexts, including crisis management and search and rescue missions (Yaacoub et al., 2020). In healthcare, UAVs are increasingly being considered as tools supporting EMS,

for example by transporting vital supplies such as defibrillators and basic life support equipment (Shah et al., 2024).

Against this background, the use of UAVs for transporting automated external defibrillators should not be viewed exclusively as a technological innovation, but also as an organisational and infrastructural challenge. A preliminary assessment of such a concept therefore requires not only consideration of technical parameters, but also an evaluation of organisational, infrastructural, regulatory and cost-related implementation conditions. Such an assessment can serve as an initial step before more detailed operational analysis, pilot testing or decisions on broader implementation.

This study develops and applies a preliminary ex ante cost-infrastructure assessment of UAV-based AED transport using Kraków as an illustrative urban reference case. The aim is to identify the baseline costs, infrastructure requirements, staffing needs and selected regulatory conditions that should be considered before the concept can be moved from a technological idea towards operational testing or possible broader implementation.

Literature Review

Unmanned Aerial Vehicles in Medical and Emergency Applications

UAVs have increasingly been discussed and applied in situations where human health and life are at risk. Their ability to cover distance rapidly and reduce dependence on ground transport routes makes them potentially useful for locating patients, supporting search-and-rescue operations, assisting early triage and assessing the need for specialist support (Sanz-Martos et al., 2022). In prehospital emergency medicine, proposed and emerging applications include the transport of medicines, blood and medical equipment, as well as aerial observation and communication support at the incident site (Surman and Lockey, 2024). In medical logistics, UAVs have also been considered for last-mile delivery, particularly where ground transport is constrained by terrain, distance or limited infrastructure. However, these applications remain limited by payload capacity and by the need for appropriately qualified operators (Sharma and Sharma, 2024). UAVs have also been tested for short-term transport of biological materials, including blood samples for basic laboratory testing, with studies examining the conditions required to maintain sample integrity during transport (Amukele et al., 2015; Zailani et al., 2022). During the COVID-19 pandemic, UAVs were used in Ghana to transport samples from individuals suspected of infection. In that setting, transport time was reduced by an average of 67%, and in some cases by up to 86% (Sylverken et al., 2022). These applications indicate that UAVs may support selected areas of emergency medicine, particularly where time-sensitive delivery or access to medical resources is required.

UAV-Based AED Transport

The delivery and use of an AED by bystanders can significantly increase the likelihood of patient survival (Weisfeldt et al., 2011). Despite programmes aimed at improving AED availability, many SCA events occur in locations where an AED may not be available or delivered quickly enough (Surman and Lockey, 2024). UAVs may help reduce this barrier by transporting AEDs directly to the incident location. Simulations conducted in Stockholm showed that UAVs carrying AEDs could reach the scene faster than ambulances in 32% of incidents in urban areas and in 93% of incidents in rural areas (Claesson et al., 2016). In Toronto, a simulation study showed that modelled UAV deployment reduced the 90th percentile AED arrival time by 6 minutes and 43 seconds in highly urbanised regions and by 10 minutes and 34 seconds in the most rural regions (Boutilier et al., 2017). Research conducted in northeastern Germany involved autonomous UAV flights, with operators taking control only during landing. All participants were able to retrieve the AED within seconds of touchdown (Baumgarten et al., 2022). While these studies indicate potential time savings and selected operational aspects of UAV-based AED delivery, further insight can be gained from analyses of real-world implementations under operational conditions.

Existing Implementations and Pilot Projects

In Gothenburg, an 11-month implementation used five DJI UAVs stationed at different locations on the outskirts of the city and covered a service area of 194.3 km². The results indicated that UAVs shortened AED response and delivery times in 67% of cases, with an average reduction of 3 minutes and 14 seconds. The annual operating cost of a single UAV was estimated at approximately USD 125,000, with the system covering around 30,000-40,000 residents. UAV-delivered defibrillators were used in two cases, one of which was reported as a life-saving intervention (Gent, 2023). A reported case from Trollhättan involved a UAV delivering a defibrillator to a 71-year-old man who suffered cardiac arrest while shovelling snow on December 9, 2021. The device arrived within three minutes (Lea, 2022). Research conducted in Ontario, Canada, simulated cardiac arrest in a rural area north of Toronto. The test began with a mock emergency call to 911 and the dispatch of an ambulance from the Peel

Regional Paramedic Services base in Brampton, while a UAV carrying an AED was launched from a nearby industrial park. In each test, the UAV arrived at the scene before the ambulance (Favaro et al., 2019). Although existing studies and pilot implementations indicate the operational potential of UAV-based AED transport, they focus mainly on response-time reduction, while cost structures, infrastructure requirements and organisational conditions remain less developed, particularly in the Polish urban context. This study addresses this gap by applying a preliminary assessment approach that combines selected technical assumptions with baseline cost, infrastructure and staffing considerations relevant to pre-implementation planning.

Materials and Methods

Study Area and Polish Emergency Response Context

Polish EMS operates under statutory response-time thresholds, which, for cities with more than 10,000 inhabitants, set the EMS arrival-time limit at 15 minutes and the median threshold at 8 minutes (Act of 8 September 2006 on State Emergency Medical Services, 2006). In 2023, the 8-minute threshold was exceeded in all voivodeships for cities in this category, in some cases reaching twice the statutory level (Statistics Poland, 2024). In 120 Polish cases where bystanders used an AED, the average time from SCA onset to AED use was 3 minutes and 22 seconds, compared with 11 minutes and 58 seconds from SCA onset to EMS arrival (Żuratyński, 2020). Tests conducted by Farada in cooperation with the Polish Air Navigation Services Agency (PANSa) involved the transport of medical packages between Warsaw and hospitals in Pułtusk, Sochaczew and Otwock. The reported average UAV delivery time was approximately half that of ground transport, indicating that UAVs may support selected medical transport tasks in Poland (Polish Air Navigation Services Agency, 2020). Kraków was selected as an illustrative urban reference case for the preliminary assessment of UAV-based AED transport. The city has a population of 809,200 and an area of 327 km² (Krakow City Office, n.d.; Statistics Poland, 2025). In 2019, the average EMS response time to SCA in Kraków was 7 minutes and 38 seconds. The city recorded 945 SCA cases that year, including 211 in public places (Municipality of Krakow, 2021). Kraków also had 67 publicly accessible AEDs, which provides an existing reference point but does not eliminate the need to consider complementary delivery options for time-sensitive incidents (Krakow.pl, 2025).

Technical, Organisational and Cost Assumptions for the Preliminary Assessment

For the purpose of the preliminary assessment, an initial scenario with two UAVs was adopted. This scenario does not represent a validated deployment plan, but defines the technical, operational, staffing and regulatory assumptions required to estimate the main cost and infrastructure components of UAV-based AED transport. The purpose of this scenario is to establish a baseline set of requirements rather than to define an optimised deployment configuration. The adopted UAV assumptions and the corresponding parameters of the reference platform are presented in Table 1.

Table 1: Technical assumptions and DJI FlyCart 30 parameters used in the preliminary assessment

Parameter	Assessment rationale	Adopted assumption	DJI FlyCart 30 parameter
Payload capacity	AED and protective packaging transport	min. 5 kg	30 kg
Flight speed	Time-sensitive delivery	min. 70 km/h (19.4 m/s)	20 m/s
Flight range with payload	Round-trip operation	min. 15 km	16 km
Communication	Urban communication reliability	ISM radio + 4G/5G	OcuSync 3 + 4G
Winch	Delivery without landing	Installed or installable	Installed
Emergency parachute	Third-party risk mitigation	Installed or installable	Installed

Source: own elaboration based on DJI (n.d.).

Based on the assumptions and presented reference parameters, the DJI FlyCart 30 was selected as a reference UAV platform for the cost and infrastructure assessment, rather than as a final procurement recommendation. Its estimated purchase price was approximately PLN 90,000 (≈ EUR 21,140; exchange rate as of September 1, 2025: 1 EUR = 4.2574 PLN) (Flystore, n.d.; National Bank of Poland, 2025). The dedicated cargo box can accommodate an AED, supporting the use of this platform as a reference case in the preliminary assessment (DJI, n.d.).

The AED reference device was selected according to weight, portability and ease of use. Under the adopted UAV payload assumption of at least 5 kg, the reference AED should remain sufficiently lightweight to allow transport together with protective packaging and mounting elements. The ZOLL AED 3 was used as the reference device because it is portable, suitable for emergency use and remains within the adopted payload margin (ZOLL Medical Corporation, 2022). It is also available in an Aviation version intended for aviation-related use. For the cost assessment, the purchase price of one AED was estimated at approximately PLN 12,000 ($\approx$ EUR 2,820) (Defib Expert Ltd., n.d.).

In the assessment scenario, UAV dispatch is assumed to occur in parallel with EMS activation after an emergency call. The UAV would be remotely monitored by a certified operator, while AED delivery could be performed using a winch mechanism without landing at the incident site. Integration with existing EMS dispatch systems is treated as a conceptual assumption and was not empirically tested in this study.

For the initial two-UAV system, the staffing estimate assumes one continuous operator shift for the whole system rather than a separate 24/7 operator assigned to each UAV. This corresponds to approximately 672-744 duty hours per month. With a monthly full-time workload of 166 hours in 2025, maintaining such coverage would require approximately five full-time operators (PoradnikPrzedsiębiorcy.pl, 2025). The annual labour cost per operator was estimated at approximately PLN 113,900 ($\approx$ EUR 26,750) (Ministry of Finance of the Republic of Poland, 2024).

The assumed UAV operation would fall within the specific category, as it combines BVLOS flight with a reference platform whose maximum take-off mass exceeds 25 kg. Under the European regulatory framework, this does not preclude operation, but requires an appropriate authorisation pathway, such as individual approval by the National Aviation Authority or operation under a Light UAS Operator Certificate (LUC) with relevant privileges (European Union Aviation Safety Agency, n.d.). The adopted assumptions exclude overflying assemblies of people, transporting passengers and carrying dangerous goods. Therefore, they do not indicate the certified category (Guidelines No. 7 of the President of the Civil Aviation Authority of 9 June 2021, 2021; Civil Aviation Authority of Poland, 2025). Operator training was estimated at approximately PLN 3,000 ($\approx$ EUR 705) per person, based on BVLOS/STS-type training prices (NaviGate, n.d.).

Annual servicing and maintenance costs were estimated at 5-10% of the UAV purchase value, while insurance was estimated at 2-4% annually (Business Plan Kit, 2025). A 4×4 m concrete-slab landing pad was assumed for each UAV station, with a unit cost of approximately PLN 4,300 ($\approx$ EUR 1,010) (Produktybetonowe.pl, n.d.). One battery charging station per UAV was assumed, with a unit cost of PLN 4,800 ($\approx$ EUR 1,130) (Dji-tpi, n.d.). The annual information campaign was estimated at PLN 10,000 ($\approx$ EUR 2,350), based on Kraków's public access defibrillator programme (Municipality of Krakow, 2021).

Based on these assumptions, the model estimates the baseline cost, staffing and infrastructure requirements of the reference scenario. Consistent with its pre-implementation scope, it excludes IT integration, emergency dispatch software, long-term infrastructure depreciation, potential regulatory compliance audits and LUC-related organisational costs.

Results

Two-UAV Pilot Scenario

The two-year pilot scenario includes one-time investment costs and recurring operating costs, as summarised in Table 2. On this basis, total scenario costs were calculated by multiplying the assumed quantities by unit costs and, where applicable, by the number of years covered by each scenario.

Table 2: Cost estimate for the two-year pilot scenario.

Cost	Quantity	Unit cost	Cost type	Total cost
UAV purchase	2	90,000 PLN 21,140 EUR	One-time	180,000 PLN 42,280 EUR
AED purchase	2	12,000 PLN 2,820 EUR	One-time	24,000 PLN 5,640 EUR
Operator training	5	3,000 PLN 705 EUR	One-time	15,000 PLN 3,525 EUR

UAV service and maintenance (10%)	2	9,000 PLN 2,114 EUR	Annual (calculated for 2 years)	36,000 PLN 8,456 EUR
Insurance (4%)	2	3,600 PLN 846 EUR	Annual (calculated for 2 years)	14,400 PLN 3,384 EUR
Operator employment	5	113,900 PLN 26,750 EUR	Annual (calculated for 2 years)	1,139,000 PLN 267,500 EUR
Landing pad preparation	2	4,300 PLN 1,010 EUR	One-time	8,600 PLN 2,020 EUR
UAV charging stations	2	4,800 PLN 1,130 EUR	One-time	9,600 PLN 2,260 EUR
Information campaign	1	10,000 PLN 2,350 EUR	Annual (calculated for 2 years)	20,000 PLN 4,700 EUR
Total two-year pilot scenario cost:				1,446,600 PLN 339,765 EUR

Source: own elaboration.

Personnel expenses are the dominant cost component in the pilot scenario, reflecting the labour-intensive nature of continuous UAV operation. A larger-scale scenario was then estimated to illustrate the cost implications of fleet expansion.

Twenty-Two-UAV Scaling Scenario

The scaled scenario assumes a total fleet of 22 UAVs, based on the reported coverage of approximately 30,000-40,000 residents per UAV in existing implementations and used here only as a heuristic planning assumption (Gent, 2023). The value of 22 UAVs represents an approximate planning value within this range rather than an optimised fleet size. For this fleet size, the model assumes two continuous operator shifts, corresponding to 10 full-time operators. Equipment, infrastructure, maintenance, insurance and staffing costs were scaled according to fleet size, while the annual information campaign remained unchanged. One-time purchase costs include only the additional units required after the pilot scenario, whereas recurring costs are estimated for the entire scaled fleet. Table 3 summarises the three-year cost estimate for the scaled scenario and the estimated annual operating cost thereafter.

Table 3: Cost estimate for the three-year scaled scenario.

Cost	Quantity	Unit cost	Cost type	Total cost
UAV purchase	20	90,000 PLN 21,140 EUR	One-time	1,800,000 PLN 422,800 EUR
AED purchase	20	12,000 PLN 2,820 EUR	One-time	240,000 PLN 56,400 EUR
Operator training	5	3,000 PLN 705 EUR	One-time	15,000 PLN 3,525 EUR
UAV service and maintenance (10%)	22	9,000 PLN 2,114 EUR	Annual (calculated for 3 years)	594,000 PLN 139,524 EUR
Insurance (4%)	22	3,600 PLN 846 EUR	Annual (calculated for 3 years)	237,600 PLN 55,836 EUR
Operator employment	10	113,900 PLN 26,750 EUR	Annual (calculated for 3 years)	3,417,000 PLN 802,500 EUR
Landing pad preparation	20	4,300 PLN 1,010 EUR	One-time	86,000 PLN 20,200 EUR
UAV charging stations	20	4,800 PLN 1,130 EUR	One-time	96,000 PLN 22,600 EUR
Information campaign	1	10,000 PLN 2,350 EUR	Annual (calculated for 3 years)	30,000 PLN 7,050 EUR
Total three-year scaled scenario cost				6,515,600 PLN 1,530,435 EUR
Annual operating cost thereafter				1,426,200 PLN 334,970 EUR

Source: own elaboration.

Across the two-year pilot scenario and the three-year scaled scenario, the combined five-year cost was estimated at PLN 7,962,200 ($\approx$ EUR 1,870,200). The annual operating cost thereafter was estimated at PLN 1,426,200 ($\approx$ EUR 334,970). These estimates indicate the order of magnitude of baseline financial and organisational resources required before further operational testing or implementation planning. The results should therefore be treated as a baseline cost-infrastructure estimate rather than a complete feasibility assessment.

Discussion

Pre-Implementation Implications

The findings should be interpreted in relation to the main purpose of the study, which was not to verify response-time reduction, but to identify the baseline resources and conditions required before UAV-based AED transport can be considered for further urban testing. Previous studies and pilot implementations have shown that UAVs may shorten AED delivery times in selected contexts (Claesson et al., 2016; Boutilier et al., 2017; Gent, 2023). However, translating this concept into an urban reference scenario requires more than selecting a UAV capable of carrying an AED. The results indicate that such a scenario also requires continuous operator staffing, basic ground infrastructure, operator training, an appropriate regulatory pathway and future integration with emergency dispatch procedures. In this respect, the main pre-implementation challenge identified by the model is not the initial purchase of UAVs and AEDs alone, but the organisational and financial capacity to maintain operational readiness over time. In this sense, the model serves as a baseline pre-implementation estimate for identifying what must be financed, organised and verified before pilot testing or implementation planning.

Limitations and Further Research

Several limitations should be considered when interpreting these estimates. The model was not validated through operational deployment and therefore does not assess real-world response times, flight reliability or AED handover procedures. No GIS-based analysis was performed to optimise UAV station locations, flight routes, coverage areas or accessibility to incident sites in Kraków. The detailed authorisation pathway for BVLOS operations involving a UAV with a maximum take-off mass exceeding 25 kg was not assessed. EMS dispatch integration, public acceptance, bystander behaviour and willingness to use a UAV-delivered AED were not examined empirically. The estimates also exclude several system-level costs, including IT integration, dispatch software, long-term depreciation and LUC-related organisational costs. Further research should combine GIS-based deployment modelling, pilot testing, regulatory pathway assessment, EMS dispatch integration studies and public acceptance research to determine whether the concept can be operationally and institutionally sustained in Polish urban conditions.

Conclusions

Previous research indicates that UAV-based AED delivery may reduce delivery times in selected settings. However, before this concept can be considered for responsible urban testing, its basic resource requirements must be made explicit. This study therefore complements the existing literature by identifying the baseline financial, infrastructural, staffing and regulatory conditions that should be considered before UAV-based AED transport is tested in Polish urban conditions.

Using Kraków as an illustrative reference case, the study estimated the order of magnitude of costs associated with a two-UAV pilot scenario and a scaled 22-UAV scenario. The results show that the main cost driver is not the initial purchase of UAVs and AEDs, but the continuous staffing required to maintain operational readiness. Consequently, preliminary planning should treat operator availability, shift organisation and the cost of continuous readiness as central assumptions rather than secondary operating details. The staged structure of the model should therefore be understood as a way of organising baseline cost estimates and comparing resource requirements at different scales, not as a confirmed implementation pathway.

Within the adopted scope, the estimate captures the direct cost components required to construct a baseline reference scenario, including the UAV and AED units, operator training and employment, basic landing and charging infrastructure, servicing, insurance and information activities. At the same time, the study shows that this baseline should not be treated as a complete implementation budget, since system-level elements such as IT integration, emergency dispatch software, long-term depreciation, regulatory compliance audits and LUC-related organisational costs were excluded and would require separate assessment.

The model may support local and regional authorities at the preliminary planning stage by indicating which cost

categories, infrastructure elements and organisational conditions require assessment before pilot testing. The main contribution of the study is to complement the existing discussion on UAV-based AED delivery by defining the baseline financial, infrastructural, staffing and organisational conditions that must be considered before responsible pilot testing in Polish cities.

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