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FEASIBILITY OF UNMANNED AERIAL VEHICLE INTEGRATION TO STRENGTHEN THAILAND'S HEALTHCARE LOGISTICS

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Abstract. *This paper explores the potential of using Unmanned Aerial Vehicles (UAVs) to transport diagnostic samples between primary care facilities in rural areas and laboratories. Patients residing in rural areas heavily rely on primary care facility and often struggle to access center hospital that limit their ability to obtain a good care. Utilizing UAVs for sample collection at primary care facilities could enhance patient accessibility where they can access timely health examinations. 192 primary care facilities in Chiang Rai Province, Thailand were utilized to evaluate the feasibility of UAV integration, considering geographical barriers, aviation regulations, and costs. The findings indicate that a mere 4% of the aggregate primary care facilities are amenable to 5 m wingspan vertical take-off/landing UAV service, when area availability, ground risk, altitude, and airspace restrictions were considered. The results suggest that while UAV operations generated a 34% reduction in transit time, and a 24% in travelled distance, the implementation of UAVs lead to an overall cost increase of 21%, when compared to traditional van-based. In addition, performing diagnostic sample collection at the potential primary care facilities could benefit the patients, where patients could save their time up to 2 hours for driving and 3 hours for waiting various process at center hospital.*
Keywords: Healthcare logistics, UAVs collection, Diagnostic sample collection

1. **Introduction.** Diagnostic sample collection (blood, urine, stools) is one of the most common and essential processes, particularly for outpatients during health examinations and consultations [1]. Diagnostic sample collection is typically scheduled in the morning, requiring outpatients to fast and travel to center hospitals (hospital with fully advanced laboratory) for the collection of diagnostic samples. Limiting diagnostic sample collection to center hospitals may hinder rural patients' access to high-quality care services, timely health examinations, and consultations. Unrestricted access to healthcare services is pivotal for maintaining good health; however, patients residing in rural areas encounter an array of obstacles that hinder this access [2]. In addition, the center hospitals are faced with congestion issues due to a high volume of outpatients. Consequently, this has resulted in prolonged waiting times for patients awaiting diagnostic sample collection, potentially compromising the service quality. Fu et al. mentioned that the quality of diagnostic sample collection service serves as a direct indicator of hospital management perspectives and the overall perception of the national healthcare system among the populace. The protracted duration necessary for diagnostic sample collection not only elicits discomfort

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and heightened anxiety among patients but also detrimentally affects the doctor-patient relationship and inefficiently utilizes the patients' time [3,4].

Nonetheless, diverse strategies and approaches aimed at effectively reducing waiting times for diagnostic sample collection and alleviating congestion within center hospital have been undertaken with varying results. Notably, one effective strategy involves the conduct of diagnostic sample collections at primary care facilities (districts health promote hospitals) then transporting diagnostic specimens to laboratories at center hospitals. This strategy holds the potential to minimize congestion at center hospitals and reduce patients' waiting times for diagnostic sample collection before their consultation or health examination with a doctor. In addition, performing diagnostic sample collection at primary care facilities could facilitate rural patients in accessing healthcare services, timely health examinations and consultations. However, the effectiveness of this approach is contingent upon the establishment of a robust transportation system capable of surmounting challenges associated with the transportation of diagnostic specimens. The government has expressed a need to address this, to create a more inclusive operating environment for patients residing in remote area, to ensure that their continued access to timely healthcare services. UAVs delivery services have the potential to enhance the transportation system by reducing transit times and also promoting environmental sustainability.

The exploration of viable application for UAVs delivery in healthcare logistics is witnessing a discernible upsurge [5-7], with many preliminary trials conducted within both developing and developed countries. The potential of UAVs to address the logistics challenges associated with transporting diagnostic specimens from remote areas to laboratories, especially in the realm of tuberculosis and malaria treatment within South Africa context, was first recognized in 2007 through experimental implementations of the e-Juba UAVs [8]. Subsequent to these initial endeavors, there has been a proliferation of commercial UAV operations, exemplified by Zipline, which has established an extensive network of UAVs for the distribution of vaccines, medical supplies, and blood products to an expansive network of over a thousand medical facilities throughout Kaduna, Nigeria [9], and nationwide service for blood distribution in Rwanda [10]. UAVs are currently experiencing a notable emergence within the domain of healthcare logistics operations in both developing and developed nations. In this regard, there is a burgeoning interest in Thailand concerning the potential advantages to be gained through the integration of UAVs, particularly (i) the enhancement of healthcare system and, (ii) the mitigation of operational and environmental costs.

This paper presented how utilizing UAVs for sample collection at primary care facilities could enhance patient accessibility where they can access to timely health examinations. It starts from identifying the potential primary care facilities that could be able to integrate a UAV for diagnostic sample collection, where the geographical, altitude operations, and aviation regulations were considered. Furthermore, by utilizing a comprehensive dataset comprising historical diagnostic samples collected from patients in the Northern region, Thailand, specifically from a center hospital with advanced laboratory, the research examines both the potential advantages and concurrent challenges associated with integrating UAVs into the healthcare system. The remainder of this paper is organized as follows. Section 2 provides literature and discusses the potential advantages associated with the integration of UAV transport, challenges and barriers within the region of Thailand, and related cost of operations. Section 3 presents several methods and tools including the data required, how it was gained and analyzed. Section 4 describes the findings and discusses the results got from a case study. Conclusions and research suggestions are discussed in the final section.

2. **Literature Review.** UAVs have demonstrated substantial advantages in terms of travel time when compared to conventional transportation mode – road transport via van-based transport, particularly in regions marked by inadequate road infrastructure and intricate topographical features. This disparity becomes especially pronounced in areas where road networks are suboptimal and geographical conditions pose challenges. Notably, the airspace over less developing countries often exhibits lower levels of congestion and encompasses expanses with lower population densities, where UAV operations present fewer safety concerns [11]. This distinctive attribute of the airspace has rendered these regions conducive to the experimentation and validation of UAV service.

UAVs operate in diverse configurations, spanning electric or fossil-powered fixed-wing, multi-copter, or hybrid of these arrangements. These configurations are catered to a broad spectrum of tasks encompassing the collection and transportation of cargo, facilitated through mechanisms such as cable systems, parachute deployment, or dedicated cargo compartments integrated within the main fuselage [12,13]. However, Boon et al. highlighted that fixed-wing platforms are generally more efficient for prolonged flight over extensive distance in comparison to multi-copter UAV [14], but necessitate the availability of runway for take-off and landing procedures. Thus, multi-copter UAVs are favored because of their intrinsic ability for vertical take-off and landing. From Ministry of Public Health (MPH) perspective and observations made at primary care sites, it becomes evident that UAV operations that do not necessitate runway infrastructure would be essential, particularly considering spatial constraints around primary care facilities. Therefore, a hybrid fixed-wing with Vertical Take-off and Landing (VTOL) UAVs could be potential because of their ability for flight over intensive distance and vertical take-off and landing.

UAV deployments within healthcare logistics have predominantly involved with the exigent transport of lightweight and low volume such as patient diagnostic (blood, urine, stools), medical supplies (pharmacy related products, chemotherapy), and blood unit for transfusion purposes [7]. In the context of Nigeria, over 150 flights per day were operated under Zipline's country-wide blood delivery service program across Rwanda [10]. The cornerstone of this undertaking lies in the utilization of fixed-wing UAVs, each processing the capacity to carry a payload of 1.75 kg and capable of covering distances of up to 120 km, maintaining a consistent velocity of 100 km/hr Beyond-Visual-Line-of-Sight (BVLOS) operations, between distribution center and crucial medical facilities, facilitated by parachute deployment [15]. The increasing need is largely due to topographical characteristics, compounded by the road conditions of the terrestrial transportation network, resulting in unpredictable and unreliable travel times via road transport. However, the cost effectiveness of UAV operation has not yet publicly demonstrated or explored, with the healthcare improvement undertaken in Ghana, an estimated average cost of approximately $17 per flight, where the cost is significantly expensive than conventional transportation modes [9]. In case of Thailand, Skysport Drone Services company together with MPH received clearance from Civil Aviation Authority of Thailand (CAAT) and the National Broadcasting and Telecommunications Commission (NBTC) for experimental BVLOS and has successfully demonstrated a medical drone delivery. Small fixed-wing UAV carried 3 kg payload of medical supplies, taking from Satun hospital to Puyu Health Center covered a distance of 12 km within 7 minutes (reduced transit time by 87% when compared to traditional transport by van) [16]. This initiative is currently in the development stage, with a particular focus on the UAV regulation especially BVLOS operation.

However, the integration of UAVs into the domain of healthcare logistics within certain developing countries such as Thailand, had encountered a degree of deceleration, primarily attributable to the stringent legislative frameworks governing airspace management, including altitude operations (UAV flight must not exceed 90 m or 295 ft above ground level). Specifically, restriction of Beyond-Visual-Line-of-Sight operations, necessitates explicit authorization from the Civil Aviation Authority of Thailand [17]. According to the guidelines set forth by Thailand's national aviation authority, CAAT, UAV operators are mandated to uphold a continuous Visual-Line-of-Sight (VLOS) connection during all flight operations.

The increasing interest pertains to the utilizing UAV for diagnostic sample transport, particularly focusing on the enhanced efficiency of conveying diagnostic samples between remote medical facilities and laboratories or center hospitals. Typically, diagnostic samples are methodically collected from patients within center hospital settings, with an estimated 80% of subsequent treatment plans predicated upon various forms of diagnostic analysis [18]. Once collected, samples must be stored carefully under controlled conditions, and their analysis should be conducted within a specified timeframe [19]. While UAVs have exhibited advantageous contributions to medical logistics endeavors within Africa and Europe, their deployment in Thailand has been limited to initial and temporary trials. Similarly, both public and private organizations, particularly logistics enterprises in certain developed countries have significantly reduced their efforts aimed at advancing UAV services. This trend underscores existing challenges that may hinder the broader commercial adoption of UAV services [20,21]. Several crucial challenges must be addressed before the widespread implementation of BVLOS UAV operations can be realized. These challenges encompass the following aspects: (i) establishment and execution of an effective air traffic control system to facilitate the coexistence of UAVs and manned aircraft within shared airspace, (ii) comprehension of the design implications for UAVs due to specific regulations governing the transportation of diverse medical products including those categorized as hazardous materials, (iii) determination of optimal routes for UAVs that mitigate both aerial and ground hazards while also preserving their operational range especially pertinent for UAVs powered by batteries, (iv) assurance to regulatory bodies responsible for medical product oversight that the stability and integrity of these products would not be compromised by factors like excessive vibration or temperature fluctuations during UAV transportation, and (v) development of robust contingency plans to navigate periods of unfavorable weather conditions that could hinder UAV flights [20].

Each of these elements introduces a measure of uncertainty when attempting to calculate the expenses tied to UAV operations within urban and rural settings. Efforts have been made to undertake such cost estimations specifically within the domain of retail UAV logistics. Jenkins et al. undertook an analysis focusing on the cost assessment of Business-to-Customer (B2C) parcel deliveries utilizing VTOL UAV for packages weighing less than 2.26 kg. The study derived cost insights from 25 distinct commercial UAV operations. It was revealed the battery expense for powering a UAV carrying a 2.26 kg, payload over 16 km amounted to \$100, with a battery life expectancy of 250 hours. The propulsion system encompassed motors priced at \$60 each, with a requirement of four for propelling a 4.5 kg UAV across a 10 km distance. The cost of rotors was determined to be \$1 each, accompanied by a marginal electricity cost of \$0.25 per flight. Regarding operational costs calculated on an hourly basis, the estimation amounted to \$0.94 per hour. This aggregate encompassed various components, including insurance (\$0.02/hr), pilot-in-command and control operators (\$0.02/hr), communication (\$0.02/hr), labor (\$0.02/hr), maintenance (\$0.40/hr for batteries, \$0.08/hr for motors, \$0.01/hr for rotors, \$0.03/hr for electrical aspects), battery replacement (\$0.24/hr), and airspace charges (\$0.10/hr). Jenkins et al. conducted a cost, assuming an individual UAV platform cost of \$2,000, and with each UAV capable of conducting a minimum of 50 flights per week, where the cost incurred per trip amounted to \$1.74. This contrasts with the \$2.5 cost typically associated with conventional last-mile delivery method employing van-based approaches [22].

Concerning airspace expenses, the exact financial implications of UAV operators accessing airspace remain uncertain. Additionally, the comprehensive management of this aspect on a substantial scale for commercial services presents a challenge. Nonetheless, Thailand's national aviation authority, CAAT, in conjunction with the NBTC, stipulates prerequisites for UAV operators, encompassing the registration process and adoption of specific equipment aligned with UAV operations. This equipment involves UAV tracking mechanisms, communication devices, and detect-avoid sensors, etc., all of which entail associated costs. For instance, the registration fee for UAVs weighing over 2 kg with the NBTC is 414 THB, and an additional 1,000 THB is applicable if the UAV is deployed for commercial purposes, and must secure permission from CAAT, with total cost at 1,414 THB ($45) [23].

This section constitutes the background to justify the importance, advantages and challenges of UAV integration, and its significant characteristics. The concept of incorporating UAVs into medical logistics has gained increasing prominence on a global scale, and shows its significant benefits, particularly how medical supplies and related products were moved between healthcare facilities and center hospital and/or laboratory. Literature showed the advantages of UAV implementation, how different types of UAV have been used in delivering and/or collecting medical supplies and non-medical supplies in different areas. However, only a limited number of these conduct in moving diagnostic sample collection between remote primary care facility and laboratory, as well as how it could facilitate rural patients in accessing healthcare services timely, particularly diagnostic sample collection without travelling to the center hospital with advanced laboratory. In this study, a set of authentic datasets has been used to examine both advantages and obstacles associated with the integration of UAVs into the diagnostic sample collection services that operate within the Northern region of Thailand.

3. **Methodology.** This section provides an overview of the methodology used, and the stages of data collection, and discusses the data analysis, how potential primary care facilities were identified, as well as the potential advantages and challenges associated with the UAVs integration. The investigation centered on the prevailing logistics activities linked to healthcare system in Thailand, with a specific focus on the collection of diagnostic samples from patients at primary care facilities. This study was conducted in collaboration with the Mae Fah Luang University Medical Center Hospital (MFUMCH), situated within the city of Chiang Rai, Northern region of Thailand.

The study was separated into two phases, where the first phase is to identify the potential primary care facilities that are suitable for UAV operations, while the second phase is to examine both advantages and obstacles associated with the integration of UAV into diagnostic sample collection services that could potentially enhance patient accessibility.

In the first phase, the government sources of secondary data and publicly available data pertaining to the site locations, altitudes, geographical barriers, airspace control areas and aviation regulations were subjected to analysis in order to identity the potential primary care facility suitable for UAV operations. The data gathered from 192 primary care facilities located in the Northern region, Thailand were used for mapping the primary care facility locations. However, to accurately represent its locations, "Google Earth 3D", GIS application software was used to identify the primary care facilities and center hospital with advanced laboratory, associated site locations and routes, as well as the environmental around its facilities, allowing the travelling distance, driving times, geographical barriers, and suitable site locations to be quantified.

Primary care facilities were considered suitable if the following criteria (i) appropriate landing area in close proximity, defined as an open space of approximately 100 m^2, either located on-site or on public land immediately adjoining the facility, (ii) UAV flightpath characterized by minimal ground risk between the designated landing site and the laboratory, ensuring a risk of third-party fatality on the ground due to a UAV crashing, and (iii) not situated within flightpaths of airport or airspace control areas. To ensure a lowest risk of their-party fatality on the ground, Oakey et al. used a UAV flightpath at a rate of 1×10^{-7} fatalities/flight-hour or lower than 100 fatalities per billion flight-hour [24]. However, in this study, "DJI GS Pro" flight planning software was used to identify a UAV flightpath, flying times and distances to be quantified, as well as assigning the suitable flightpath between primary care facilities and laboratory.

In the second phase, the objective was to examine both advantages and obstacles associated with the integration of UAV into diagnostic sample collection services that could potentially enhance patient accessibility, where they can perform diagnostic sample collection at primary care facility just next to their home without travelling over long distance to the center hospital. To gather pertinent insights, a historical dataset was acquired, encompassing movements originating from the potential primary care facilities that were identified in the first phase. The implications for UAV operations necessitate careful consideration of essential specifications related to range, weight, and the quantity of diagnostic samples requiring transportation.

Additionally, a series of informal discussions were conducted with healthcare logistics professionals and UAV operators responsible for overseeing the operational aspects of patient diagnostic services for a thorough understanding of current operational procedures and possible opportunities for enhancement. The data acquired under standard operational conditions were then utilized in a computational analysis aimed at quantifying the anticipated frequency, transit times, and financial outlay of flight necessary to facilitate UAV-based transportation of diagnostic samples from primary care facilities (identified as suitable for UAV service integration). Moreover, this analysis sought to assess the potential advantages, particularly in improved service efficiency when compared to traditional transport, reduced travel distances for transportation, and decreased CO_2 emissions, and potential cost savings.

4. **Results and Discussion.** In this section, a case study was used to (i) identify the potential primary care facilities that could be able to integrate a UAV collection, and (ii) quantify the potential advantages and challenges associated with the integration of UAV for collecting diagnostic samples between primary care facilities and laboratory.

4.1. **Business-as-usual diagnostic collection service.** A case study of Chiang Rai Province shows that 69% ($n = 896{,}748$) of people reside in rural areas and found a difficult to connect to the center hospitals, where the primary care facility has been used for only minor injury. However, when they require more extensive medical evaluations, check-ups, follow-up care plans and/or treatment of severe injuries necessitating diagnostic tests, then they must travel to the center hospitals with advanced laboratory, which is mostly located in downtown. According to the literature, Guy and Thomas mentioned that 80% of subsequent treatment plans predicated upon various forms of diagnostic analysis [18].

In the BAU, diagnostic sample collection typically performed early in the morning, compelling outpatients to travel over long distances from their homes to reach the center hospitals. The data collected demonstrates that outpatients living in rural areas spend their time driving ranging from 1 to 2.5 hours to receive medical service at center hospitals. Although Chiang Rai Province is equipped with seventeen hospitals distributed across various locations to cater to its residents, patients are faced challenges related to overcrowding and relative scarcity of healthcare professional and medical resources. There were only three center hospitals identified as possessing fully-equipped laboratories, each with a bed capacity exceeding 300 beds. Consequently, patients experience prolonged wait times for diagnostic sample collection before undergoing health examinations and consultations. Based on the observations, outpatients are obliged to dedicate a minimum of 1.5 to 2 hours to complete various processes, including patient screening, pre-examination, and the collection of diagnostic samples (blood, urine, or stools). Subsequently, they spend an additional 1 to 2 hours, depending on the list of tests required, waiting for laboratory test results before meeting with their physician. [3,4] highlighted that extended waiting times not only lead to patient discomfort and anxiety but also adversely affect the doctor and patient relationship and waste the patient's time.

However, the empirical findings indicate that only two out of the three center hospitals are now expanding their medical services to primary care under their shoulder. Aimed at mitigating issues associated with patient congestion and improving patient access to healthcare services, where patient's diagnostic tests can be promptly conducted at primary care facilities before being transported to the laboratory for analysis, in this process, diagnostic samples taken at primary care are placed in specimen containers and transported at ambient temperatures using traditional van-based delivery. However, moving diagnostic samples between primary care and laboratory has proven to be inefficient, resulting in increased operational costs and restrictions on the frequency of services offered (twice a month).

Therefore, the implementation of an efficient transportation system for diagnostic sample collection at primary cares holds the potential to significantly enhance patient satisfaction, improve hospital performance, and strengthen national's healthcare system. The incorporation UAVs for transportation offer the possibility for outpatients to conveniently conduct diagnostic sample collections at primary care facilities located in close proximity. Then the diagnostic samples are flying from primary care facilities directly to laboratories, which results in a marked reduction in outpatient waiting times for essential processes such as screening, pre-examination, diagnostic sample collection at center hospital, prior to their consultation with medical professionals.

4.2. **Units of carriage (specimen container).** The analysis indicated that patient diagnostic samples are ordinarily collected at center hospitals and transported at ambient temperature within designated specimen containers (Figure 1), encased within a two-layer packaging adhering to the prescribed packing instructions stipulated by Thailand's Healthcare Accreditation Institute (HA), a standard practice commonly used within the hospital [25]. In this paper, the specimen container in Figure 1 routinely used by center hospital was taken as the unit of carriage, this container accommodates a maximum load

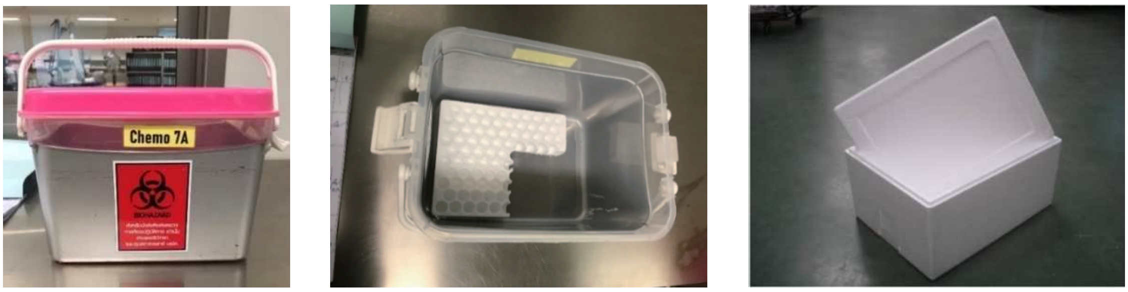

FIGURE 1. Specimen containers (Left and middle-samples are commonly used when transported diagnostic samples within the hospital; whilst right outer packaging used when moving samples outside the hospital.)

of approximately 50 samples. Left and middle-sample (specimen container) in Figure 1 is most commonly used for transported diagnostic between specimen collection unit and laboratory within hospital. The right-sample is outer packaging as the unit of carriage when diagnostic samples were moved outside the hospital (between primary care and laboratory) to protect diagnostic samples.

Within the framework of dangerous goods classification, Grote et al. underscored those biological materials classified as low-risk infections substances within hazard class 6 [27], which can be exempted from being classified as hazardous goods for air transport, contingent upon their packaging alignment with established standard packaging guidelines [28]. Consequently, these materials can be handled in a manner analogous to their transportation via ground transportation modes, in accordance with the directives outlined in the Good Storage and Distribution Practice [29]. International Air Transport Association (IATA) has emphasized that when transporting hazardous materials such as diagnostic specimens, the packaging used must possess high quality and strong enough during transport. The recommended packaging comprises a three-layer system according to the packing instruction 650 under the UN 337 (Biological Substance Category B – diagnostic specimen) [30]. However, aviation regulators including the Civil Aviation Authority of Thailand (CAAT) are currently in the process of formulating regulations within this domain [17]. The pertinent research endeavors have underscored the necessity for medical logistics operators to establish convincingly that the employment of UAVs for transportation purposes would not detrimentally impact the quality and stability of medical consignments due to the prevailing in-flight conditions encountered during transit [24,25]. The present comprehension of diagnostic materials transported via UAVs indicates that no significant damage is caused [31]; however, it is important to acknowledge that this outcome could differ upon the specific transportation platform, packaging, and the nature of the product being transported. The data suggested that when employing UAVs for the transportation of diagnostic samples, it is imperative to utilize packaging that possesses sufficient strength to endure the transportation process. Therefore, the outer packaging currently used in the operational contexts (Figure 1, right-sample) appears not to be consistent with packaging instruction 650 under the UN 337 guidelines, which pertain to the movement of diagnostic samples. Based on the literature review, the insulating outer packaging (Figure 2) would be a suitable choice for the safe carriage and protection of diagnostic samples during UAV collection services. The insulating outer packaging or "versapak insulate outer packaging" in Figure 2 has been consistently utilized by GP surgeries across Southampton, UK, for transporting diagnostic samples to laboratories both van-based and UAV delivery approaches [24]. This insulating outer packaging is available in three distinct sizes, chosen according to the transportation modes, where the medium and small sizes are commonly used for UAV transport.

FIGURE 2. Versapak insulate outer packaging used for UAV delivery in Solen region, UK [24]

4.3. **Possible UAVs used for moving diagnostic samples.** In the context of patient diagnostic samples logistics, it becomes apparent that although the individual diagnostic samples exhibit compact and lightweight characteristics, making them amenable to transportation via UAVs, they are consolidated into batches, allowing primary care facilities to dispatch numerous diagnostic samples on a daily basis. Each batch comprises approximately 50 individual samples for a round-trip journey according to specimen containers capacity.

In this scenario, it is imperative for UAVs to demonstrate the capacity to transport a payload encompassing a minimum of one specimen container (Figure 1) along with the insulating outer packaging (Figure 2), which has an approximately 50 samples and an empty weight of approximately 2.4 kg. In addition, observations conducted at primary care sites revealed spatial constraints, concerning the limited runway infrastructure in proximity to these primary care facilities. As a result, VTOL fixed-wing UAV with 5 m wingspan has been considered to facilitate the transportation of specimen containers between primary care facilities and laboratories. The payload capacity and their maximum flight duration hold implications for both the strategic planning and operational aspects, in line with aviation regulations, encompassing factors such as the number of flights and the chosen flight routes.

Given the specific requirement in this case study, which necessitates the transportation of at least one specimen container from each primary care facility across varying distances, spanning from approximately 3 to over 40 km one-way, it became imperative to employ a robust platform capable of bearing substantial weight, with a minimum capacity of around 5 kg and flight times ($>$ 1 hour). Furthermore, in order to mitigate the infrastructure requirements for take-off and landing, the UAV must possess VTOL capabilities, which can be achieved through a fixed-wing hybrid platform or dedicated VTOL system. VTOL fixed-wing UAV with a wingspan of 5 m as illustrated in Figure 3, was recognized essential to facilitate the efficient transportation of such a payload across distances surpassing 40 km in variable wind conditions and diverse geographical terrains.

FIGURE 3. VTOL fixed-wing UAV (a 5 m wingspan) used for diagnostic samples delivery in Solen region, UK [24]

4.4. **Identifying an appropriate site for service via UAV.** As mentioned above, primary cares facilities were considered suitable if they met the following criteria: (i) appropriate landing area in close proximity, defined as an open space of approximately 100 m^2 as depicted in Figure 4, (ii) a UAV flightpath characterized by minimal ground risk between the designated landing site and the laboratory, and (iii) were not situated within flightpaths of airport or airspace control areas. [6] mentioned that the UAV landing process was not an easy task, where the impact of wind speed, horizontal dilution of precision, and environmental around landing area need to be considered. However, in this paper,

FIGURE 4. Example site for take-off and landing. Left-sample is take-off and landing site at center hospital, right-sample at primary care (approximately 100 m^2).

an open space of approximately 100 m^2 was the only factor that was used to identify a suitable site.

The finding suggested that, within the dataset encompassing 192 primary care facilities, a discernible proportion of approximately 19% of the sites exhibited the potential to theoretically accommodate the landing of a VTOL fixed-wing UAV possessing a wingspan of 5 m, capable of transporting a specimen container, as depicted in Figure 5. The assessment process involved a meticulous examination of each primary care facility, utilizing Google Earth 3D imagery, to identify and quantify suitable landing areas that would not significantly disrupt the facility's existing functions (the ability to continue using its parking areas). However, the results indicated that the number of primary care facilities suitable for landing increased to 47% when employing a smaller VTOL UAV with 2 m wingspan.

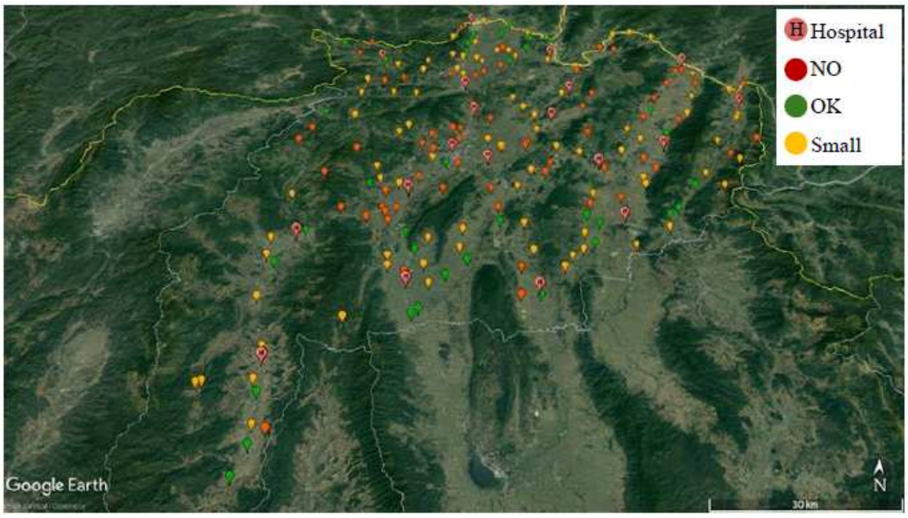

FIGURE 5. (color online) 192 primary care sites in Chiang Rai Province were categorized on their suitability for UAV landing. "OK" for sites deemed appropriate for a 5 m fixed-wingspan UAV to land with a reasonable safety buffer, "Small" for those suitable for a 2 m VTOL UAV, and "NO" for those unsuitable for a UAV of any size.

However, in compliance with the aviation regulations stipulated by CAAT, UAVs are mandated to uphold a minimum separation distance of 50 m from individuals and properties not under the direct operation's control. Additionally, these regulations dictate that UAVs should not exceed an altitude of 90 m (approximately 295 ft) and must maintain a distance of at least 9 km from airports [17]. However, it is noteworthy that reasonable exceptions can be negotiated, particularly in specific circumstances. While the literature underscores the benefits of airspace over rural areas, which generally experiences lower levels of congestion, however, altitude operation has emerged as a pivotal barrier due to specific geographical characteristics. The findings indicate that 14% of primary care facilities were deemed unsuitable for UAV flights due to altitudes surpassing 90 m high, and increased when airspace control zones were considered, particularly in bordering areas.

In addition to identifying suitable landing locations, it is imperative to establish appropriate flight paths for UAV operations. The planning of flight paths requires meticulous consideration of diverse factors, encompassing airspace restrictions and the demarcation of airport control zones, to uphold the safety and security of fellow airspace stakeholders. In addition to the aforementioned considerations, flight path planning necessitates a careful assessment of ground risk overflights, particularly emphasizing the heightened risks associated with potential crash landings when traversing densely populated areas. Other factors include the presence of nature reserves and noise considerations.

To proficiently address these considerations, the utilization of planning tools and UAV Traffic Management (UTM) systems is essential. However, it is important to acknowledge that certain primary care facilities might locate in areas that cannot be accessed without violating existing regulations or bylaws. Consequently, the number of primary care facilities that can currently be served is likely to be more restricted. Therefore, based on the analysis of landing area availability, ground risk assessment, altitude operations, and airspace restrictions around Chiang Rai International Airport, the study finding suggests that a mere 4% of the aggregate primary care facilities are amenable to UAV service (Figure 6).

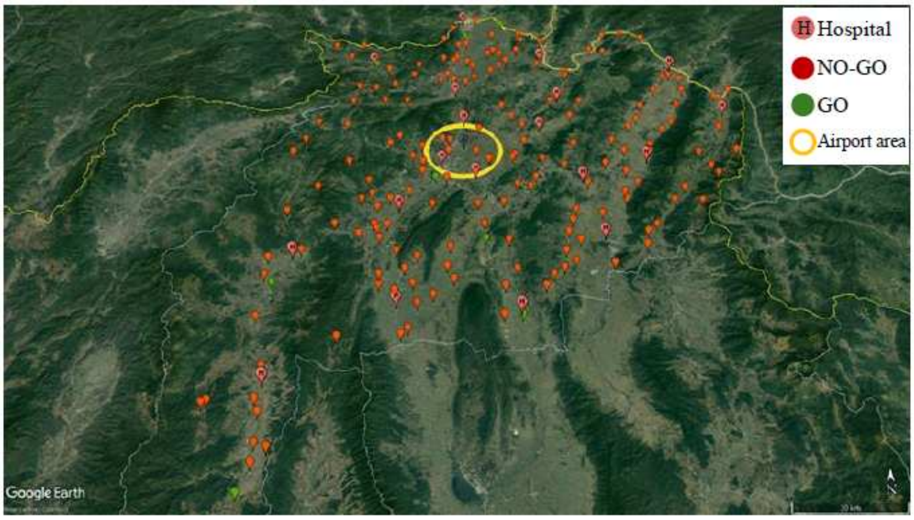

Figure 6. (color online) Primary care facilities have been categorized based on their suitability for UAV landings, based on ground risk, airspace restrictions, and altitude operations (GO = suitable, NO-GO = inappropriate).

The envisaged flight trajectories from center hospitals to these primary care facilities are depicted in Figure 7 (yellow lines indicate the UAV flight paths). These flight paths entail a shared trajectory over the urban area surrounding the center hospital before branching off in diverse directions to reach their respective destinations.

4.5. **Advantages and challenges for flying a UAV.** In this study, a comprehensive cost analysis was conducted to compare the economic implications of integrating UAV

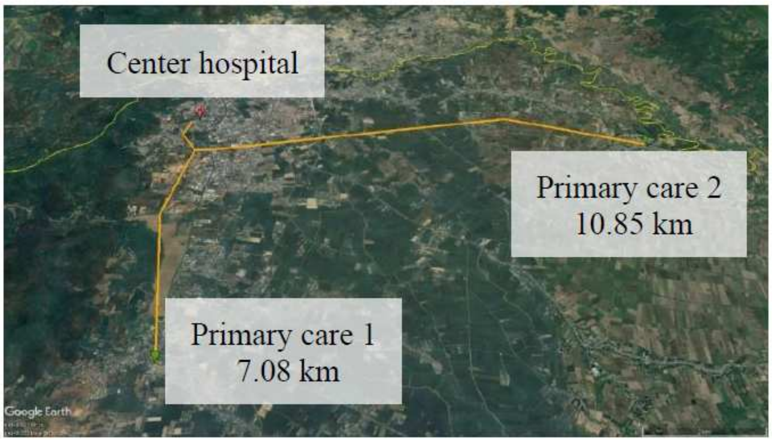

Figure 7. UAV flight paths between center hospital and primary care facilities

services with the conventional van-based specimen collection services. To estimate the costs associated with the UAV collection service, a combination of data was sourced from existing literature, informal discussions with UAV operators and commercially available resources, specifically from [32].

In this particular instance, the cost estimate applied for the UAV collection service amounted to 30 THB/km for the deployment of a 5 m fixed wingspan VTOL UAV. In addition, the analysis considered a CO_2 emission factor of 0.24 kg/km for UAV operations. Oakey et al. [24] highlighted the possibility of additional expenditures associated with activities like hazardous goods training and airspace management. For the case study, these aspects were not explicitly considered in calculations. Furthermore, it is essential to recognize that the cost may further increase when a third-party operator is engaged, necessitating the inclusion of their profit margin within the overarching cost assessments.

The cost estimates utilized for the van-based collection method were obtained from the Department of Land Transport, Thailand. Specifically, the vehicle operating costs, amount to 18.98 THB/km for diesel van $\leq$ 3.5 tons gross weight [33]. These costs were determined by factoring in various elements including the average annual distance travelled, fuel expenses, tires, maintenance, and general overhead costs (salary, driver licenses, etc.). To ensure consistency in this analysis, a CO_2 emission factor of 0.72 kg/km was obtained from the same source, for a diesel vans with gross weight $\leq$ 3.5 tons.

In this comparative analysis, when examining the weekly collections for eight primary care facilities, a significant increase in operational costs becomes evident when comparing van-based and UAV collection services. Van-based collections incur an operational expense of 19,739.2 THB/week, while UAV collections amount to 23,861.4 THB/week. The findings in Table 1 suggested that the cost-effectiveness of UAV collection service is compromised in certain primary care facilities, because they have to perform multiple trips when compared to van-based collection, resulting in inefficient transportation cost. Importantly, improvements in transit times have been achieved across all primary care facilities served by UAVs. The durations for van-based collection varied from 5 to 116 minutes, yielding an average round-trip duration of 52 minutes. In contrast, UAV collection times exhibited a range of 4 to 90 minutes, with an average duration of 39 minutes. As a result, the implementation of UAV collection services holds the potential to notably decrease weekly transit times by 34% in comparison to the van-based alternative. This translates to a reduction from 37.4 hours for van-based to 22.7 hours for UAVs. In terms of environmental benefits, the results in Table 1 suggest that the utilization of UAVs for

Table 1. Summary of flight operations and costs analysis between van-based and UAV collection services within each primary care facilities (PC)

Scenarios	Statistic (per week)	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Van-based	Samples collection	245	164	231	176	340	160	299	226
	Van-based (rounds)	5	5	5	5	5	5	5	5
	Duration (h:m)	2.3	9.7	1.9	9.2	0.4	3.6	4.6	3.0
	Distance (km)	69	290	57	276	13	107	139	89
	CO_2 (kg)	49.7	208.8	41.0	198.7	9.4	77.0	100.1	64.1
	Cost (THB)	1,309.6	5,504.2	1,081.9	5,238.5	246.7	2,030.9	2,638.2	1,689.2
UAV	Flight	5	5	5	5	7	5	6	5
	Duration (h:m)	0.4	6.1	1.4	6.5	0.4	2.4	3.7	1.8
	Distance (km)	15.4	212.1	49.3	227.2	12.8	84.8	129.8	64.0
	CO_2 (kg)	3.7	50.9	11.8	54.5	3.1	20.4	31.1	15.4
	Cost (THB)	461.6	6,363.0	1,480.2	6,816.0	383.5	2,544.0	3,893.0	1,920.1

Note: PC = primary care facility was identified for UAV service

Table 2. Total costs, transit time, travelled distance, and CO_2 emission covered 8 primary cares

Scenario	No. of rounds	Cost (THB)	Duration (mins)	Distance (km)	CO_2 (kg)
Van-based	40	19,739.2	34.7	1,040.0	748.8
UAV integration	42	23,861.4	22.7	795.4	190.9
Reduction	+2 **+5%**	+4,122.2 **+21%**	11.9 **34%**	244.5 **24%**	557.9 **75%**

multiple trips across eight primary care facilities, in lieu of deploying van-based transportation, could lead to a substantial 75% reduction in CO_2 emission, amounting to 557.9 kg/week.

One benefit of employing a UAV collection service is the provision of more frequent and faster collections, leading to shorter transit times compared to traditional van-based collection services. Furthermore, the reduction in vehicle travelled distances in UAV operations can demonstrate additional advantages, particularly in terms of CO_2 emission and diminished costs associated with air pollution.

In addition, utilizing UAVs for sample collection at primary care facilities could enhance patient accessibility, where they can access timely health examinations. A case study shows that the potential eight primary care facilities located in four different districts in Chiang Rai Province could potentially increase patients' accessibility. This could benefit 73,616 local people or 30,732 households in those areas. As mentioned in the business-as-usual section, the patients could save their time up to 2 hours for driving to center hospital and waiting time for various process at center hospital up to 3 hours.

5. **Conclusion.** This paper presents the potential advantages, challenges and barriers associated with UAV integration. It provided promising results when UAV transport was implemented for diagnostic sample collection between primary care facilities and laboratory. A case study shows that 8 out of 192 primary care facilities potentially served by UAV service for diagnostic sample collection, where the patient can access to timely health examinations just next to their home area instead of travel over long distance to the center hospital with advanced laboratory. Not only operational and environmental

benefits gained from integrating UAV services. Introducing UAVs does offer other potential benefits such as faster diagnosis and subsequent patient treatment plan development due to travel times, as well as minimize the congestion of patients at center hospital. In addition, integrating UAV service could improve Thailand's healthcare system where the rural people who are disconnected with the center hospital could possibly access to health examinations and consultations.

The finding shows that there could be more primary care facilities able to be served by UAV transport if airspace restriction zone has been relieved. Furthermore, should regulatory modifications permit more load consolidation and allows Beyond-Visual-Line-of-Sight UAV operations, enabling UAV to extend their reach to a greater number of remote primary care facilities and capitalize on economies of scale through increased load capacity, significant benefits may accrue.

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