

Letter

Short-Range Transportation Using Unmanned Aerial Vehicles (UAVs) during Disasters in Japan

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Abstract: Larger types of small unmanned aerial vehicles (UAVs) are beginning to be used in the United States and Europe for commercial transportation. Additionally, some blood product transport systems have been commercialized in Rwanda and other countries and used in pandemic operations for the coronavirus disease 2019 (COVID-19) in infected areas. Conversely, implementing goods transportation for commercial purposes in Japan has been difficult, especially in urban areas, due to national legislation. This study examined UAV-assisted transportation in Japan, a natural disaster hotspot, with a focus on the potential uses of UAVs in situations where traffic blockages make ground transportation impossible. UAVs were used to transport 17 kg of medical supplies belonging to a disaster medical assistance team (DMAT), along with 100 emergency meals. We also transported insulin under controlled-temperature conditions, as well as many other emergency supplies. Using UAVs to transport emergency supplies could be an effective approach when dealing with disasters. This paper summarizes the effectiveness of this approach for medical care and disaster response activities. We present a method for using drones to bridge the gap between medical and firefighting personnel, such as DMAT personnel, who are engaged in life-saving activities at the time of a disaster, and those who are unable to transport necessary goods by land using terrestrial vehicles due to traffic interruptions.

Keywords: unmanned aerial vehicles (UAV); drone; automatic external defibrillator (AED); disaster medical assistance team (DMAT); transport; M1000; disaster

1. Introduction

Unmanned aerial vehicles (UAVs), or so-called “drones for civilian use”, have been widely used for purposes such as aerial photography [1], information collection during emergencies [2], and goods transportation [3]. Today, larger types of small UAVs are on the verge of becoming commercial mediums for goods transportation in Europe and the United States. However, urban implementation of

this approach is difficult in Japan because of legislation that aims to reduce falling risks, i.e., the danger of a UAV falling, which can result in damage to public facilities and injuries to people along the UAV's transport route.

Furthermore, the history of UAV-assisted transportation for medical supplies has progressively included the transportation of blood specimens [4,5], vaccines [6], and blood transfusions [7]. The United Nations Children's Fund (UNICEF) used UAVs to transport blood samples for human immunodeficiency virus (HIV) testing in Malawi [8]. During the coronavirus disease 2019 (COVID-19) pandemic, a market research organization named Research and Markets presented five benefits of UAVs regarding their functions related to health security, virus detection, spraying of disinfectants, food transportation, crowd management, and specimen transportation [9].

Before the pandemic, a UAV carrying blood specimens crashed into Lake Zurich [10]; fortunately, this incident did not result in a spread of infection. During peacetime, UAV flight paths that pass over people on the ground are not permitted to transport specimens such as sputum from patients suspected of being infected with tuberculosis or COVID-19 and are not permitted to transport blood samples containing infectious pathogens. It has been reported that the quality of blood transported by fixed-wing UAVs in Rwanda and other countries may not match the quality of a normal blood transfusion product [11]; furthermore, the feasibility of transporting blood transfusion products using multicopters in Japan was also reported [12].

The medical use of UAVs, as represented by the transportation of blood transfusion products, is essentially a countermeasure to traffic blockage. It is important to ensure the safety of UAV flights and the quality of transported medicines and medical materials; optimal transportation environments, including temperature control for goods and other conditions, should be maintained. During the COVID-19 epidemic in Italy, it was reported that UAV use for transportation of personal protective equipment (PPE) and automatic external defibrillators (AEDs) contributed to risk reduction [13]. Generally, it is important to note that traffic can be disrupted by incidents such as a fallen bridge and can also be disrupted by the artificial blockades that arise during an infectious disease outbreak.

Some studies have mentioned the use of UAVs for managing and monitoring disaster areas [14]. Furthermore, research has been conducted on UAV flight paths for efficient surveillance and other activities [15]. In contrast, this study focuses on the transportation of medical equipment and food, which are directly related to everyday life.

In 2017, Scott published a report on UAV-assisted transportation of drugs, automatic external defibrillators, blood samples, and vaccines. All of the transportation was carried out by Matternet, Zipline DHL Parcel, Flirtey, and Delft University, and the selected load weights were in the range of 2 to 4 kg [16].

We have long believed that using such lightweight transport vehicles for medical and disaster mitigation resources may prove ineffective during a real disaster. Out-of-sight flights are impractical if communication and safety cannot be ensured during a disaster. In contrast, UAVs with the same transport capacity as in this study could be used for medicine transport and disaster mitigation. Therefore, we set out to prove the results of the existing studies in a series of trials.

We transported more than 10 kg of cargo, which included disaster medical assistance team (DMAT) equipment, under visual flight conditions. Importantly, insulin and food shortages can be expected during a disaster. It is clear that solving this problem requires transportation methods that can respond to traffic disruptions. For this reason, we conducted a UAV transportation trial. We believe that the success of the trials could predict similar success in an actual disaster. Until now, no UAVs have been used as transport vehicles in natural disasters; therefore, this is a novel experiment. We hope that this study will increase the consideration of the use of drones for disaster medicine transportation and for the reduction of disaster damages in Japan.

2. Materials and Methods

2.1. UAV and Test Sites

We used a Japanese UAV, the M1000 (Mazex Co. Ltd., Osaka, Japan), which has a maximum take-off weight of 32 kg and a maximum speed of 58 km/h. UAV-assisted transportation experiments were conducted in Tomi (1060–1100 m above sea level) (Nagano Prefecture) and Fujisawa (35 m above sea level) (Kanagawa Prefecture) in Japan. Both are notably hilly regions. In Tomi, some land is too swampy and weedy to walk on; therefore, small hazards exist. We created restrictions on flights by situating routes across earthen obstacles and over streams.

2.2. Methods

The selected UAV (M1000) was used to conduct a goods transportation trial. The chosen CardioLife® automatic external defibrillator (AED) equipment (Nihon Kohden Corp., Tokyo, Japan) (weight: 3.7 kg; size: 44 × 26 × 10 cm) was transported using a rope suspension method under a pilot's manual supervision and control. The DMAT equipment rucksack (weight: 17 kg), foodstuffs (100 servings of alpha rice) (weight: 13.8 kg; size: 34 × 68 × 22 cm), and 60 hardtack meals (weight: 6.8 kg; size: 26 × 36 × 27 cm) were also transported using this method.

A simple blood glucose meter (Glutest-ai®, Sanwa Kagaku Kenkyusho Co., Ltd., Nagoya, Japan) and a drug-integrated insulin injector (Insulin glargine Kit “FFP” formulation® (Sanwa Kagaku Kenkyusho) were also transported. Next, a drug-integrated insulin injector in a simple refrigerator (Hexashi Portable Refrigerator®, Taihe Technology Ltd., Shenzhen, China) was transported at low controlled temperatures. Due to the light payload, these experiments involved automatic round-trip flights and automatic landing at the destination. Table 1 shows the schedule for the transport experiment, the location, and the transported goods.

Table 1. Flight schedule and study design.

Trial	Date	Place of Flight	Transported goods
1	29 June 2019	Tomi	Rucksack (DMAT Equipment)
2	6 July 2019	Tomi	Rucksack (DMAT Equipment)
3	26 July 2019	Fujisawa	Rucksack (DMAT Equipment)
4	26 July 2019	Fujisawa	Rucksack (DMAT Equipment)
5	22 September 2019	Fujisawa	Self-injection set. (insulin+glucometer)
6	5 October 2019	Fujisawa	Insulin in the refrigerator
7	20 October 2019	Tomi	Insulin in the refrigerator
8	28 December 2019	Tomi	Hardtack (disaster relief food)
9	1 January 2020	Tomi	Pregelatinized rice (disaster relief food)
10	15 February 2020	Tomi	Hardtack (disaster relief food)
11, 12	4 April 2020	Tomi	Automatic external defibrillator (AED)

Abbreviations: Tomi: Nishiiri-ku, Tomi City, Nagano, Japan; Fujisawa: Endo, Fujisawa City, Kanagawa, Japan; DMAT: Disaster Medical Assistance Team.

The UAV-assisted transportation was carried out 12 times. All of the goods except insulin were transported under visual flight conditions across straight-line distances of 30 to 100 m. The flight times included detours to avoid obstacles, ascending or descending from lowlands to plateaus, and detours along the flight route under the pilot's supervision until the goods were held static above the ground and carefully unloaded at the destination. The UAV was landed at the take-off point or indicated location. The auxiliary unit also performed visual UAV surveillance during the UAV flight, assisting the pilot with the positioning of the UAV during the UAV flight, loading and unloading, and landing at the final destination (Table 2).

Table 2. Characteristics of unmanned aerial vehicle (UAV) flight trials (conditions and flight information).

Trial	Outdoor Conditions				Flight Information				
	Elevation (m)	Weather	Temperature (°C)	Time (m-s)	Transport Goods	Loading Weight (kg)	Set up the Transport Goods	Control Method	Auxiliary Instruction at Goods Grounding
1	1110	Cloudy	24.6	2.21	DMAT Rucksack	17	Hung	Manual	Auxiliary Support
2	1060	Cloudy	24.1	Not recorded	DMAT Rucksack	17	Hung	Manual	Auxiliary Support
3	35	Sunny	32.0	Not recorded	DMAT Rucksack	17	Hung	Manual	Auxiliary Support
4	35	Sunny	32.0	Not recorded	DMAT Rucksack	17	Hung	Manual	Auxiliary Support
5	35	Sunny	27.1	1.40	Insulin plus glucometer	<1	Attached	Manual	No support
6	35	Sunny	36.2	11.7	Insulin in a refrigerator	<1	Attached	Automatic	No support
7	1060	Sunny	17.4	2.22	Insulin in a refrigerator	<1	Attached	Automatic	No support
8	1060	Sunny	-2.3	3.30	Hardtack	6.8	Hung	Manual	Auxiliary Support
9	1060	Sunny	-4.2	2.28	Pregelatinized rice	13.8	Hung	Manual	Auxiliary Support
10	1060	Sunny	12.3	3.35	Hardtack	6.8	Hung	Manual	Auxiliary Support
11	1060	Sunny	18.4	1.43	AED	3.7	Hung	Manual	Auxiliary Support
12	1060	Sunny	18.4	1.22	AED	3.7	Hung	Manual	Auxiliary Support

Abbreviations: m, minutes; s, seconds; AED, automatic external defibrillator; DMAT, Disaster Medical Assistance Team.

3. Results

The wind speed was below 7 m/s all day and there was no rainfall. All flights were stable with no unusual vibrations. No resonance or other abnormal vibrations occurred between the cargo and the aircraft due to the length of the hanging loops. The UAV hovered while positioning the transporter goods at the narrow destination point, without any impact, before landing safely at the endpoint.

The trials are summarized in Table 3, showing successful transport of DMAT equipment, AED transport, insulin transport, and emergency food transport.

Table 3. Short-range transportation of unmanned aerial vehicles.

Transported Good	Trial No.	Result	Comment
DMAT equipment	1, 2, 3, 4	Proven	No problem.
Insulin	5, 6, 7	Proven	Not able to control the temperature perfectly; however, this was not a problem for use.
Foodstuffs	8, 9, 10	Proven	Three types of emergency foods typical in Japan.
AED	11, 12	Proven	It swayed in the wind to an extent that was not a problem.

Abbreviations: AED, automatic external defibrillator; DMAT, Disaster Medical Assistance Team.

The results for the transport trials are presented in detail in this section. When transporting DMAT rucksacks with a load of 17 kg to their destination, an assistant's guidance was utilized (Figure 1a,b). With regard to the transportation of foodstuffs, alpha rice and dried bread were safely transported with no impact. For the transportation of insulin injections, a simple blood glucose meter, drug-integrated insulin syringes, a set of needles, and disinfectant cotton were transported via stable flights. A cold storage flight carrying insulin in a simple refrigerator also took place without problems. However, the temperature in the refrigerator was 12 °C at the beginning of the experiment and 16 °C at the end of the experiment due to the intense heat in Japan. As a maximum outside temperature of 36 °C was measured immediately after the flight, this means that insulin was transported at a temperature 20 °C lower than the outside temperature.

The AED, which weighed 3.7 kg, could be transported using the suspension method (Figure 1c,d).



Figure 1. The UAV transports the DMAT rucksack and the AED. (a,b) The UAV transported the disaster medical assistance team (DMAT) rucksack on June 29, 2019 (M1000; Mazex Co. Ltd., Osaka, Japan) (maximum take-off weight: 32 kg; maximum speed: 58 km/h) and transported the rucksack containing DMAT equipment (load weight: 17 kg) by manual control under visual flight conditions with auxiliary support. (c,d) UAV-assisted transport of an automated external defibrillator (AED) on 4 April 2020 (M1000; Nihon Kohden Corp., Tokyo, Japan) (load weight: 3.7 kg; size: 44 × 26 × 10 cm) by manual control under visual flight conditions with auxiliary support.

4. Discussion

This series of transportation experiments showed that under the autonomous control of the pilot and the flight instructions of the assistant, UAVs were able to safely transport 17 kg of goods to the destination, including periods of visual observation and hovering.

For insulin transportation, maintaining a temperature of 2–8 °C is desirable. The simple portable refrigerator box was maintained at room temperature during summer. However, insulin can normally still be used within a few weeks as long as the storage temperature remains below 30 °C [17].

Japan ranks fourth among countries facing the greatest threat from natural disasters [18]. Thus, it is necessary to consider the transportation of medical supplies during emergency situations in a large-scale disaster. Snow damage is also considered a major natural disaster in Japan. Sudden and heavy snowfall can make it difficult for blood transfusion vehicles to proceed, thus making it difficult to transport blood across a distance in locations that can be observed with the naked eye [19]. UAVs can be particularly useful when low temperatures prevail outside; in addition, it is desirable to maintain a temperature range of 4–6 °C for blood transportation. We achieved a temperature of −8 °C for outside conditions and ensured that blood could still be transported in environments with lower temperatures. This finding also applies to the transportation of emergency relief supplies to ships that may find berthing difficult because of an infectious disease outbreak and in instances of bridge failures during a disaster, among others. We believe that the original UAVs can be used for transporting goods to areas less than one sight distance away.

Helicopter emergency medicine (HEM) vehicles, which are used for air medical treatment, are operated by air traffic control units. In contrast, UAVs are prohibited from flying in designated areas of the Ministry of Land, Infrastructure, Transport, and Tourism (e.g., airports), as well as in areas that are more than 150 m above land or a water surface. Furthermore, without a permit, UAVs cannot fly in densely populated areas in Japan [20].

UAVs and HEMs must usually operate in different flight zones; however, UAVs can be an interference while operating HEMs. In fact, there were reports of near misses involving UAVs and HEMs in 2016 [21,22].

We believe that in future HEM emergencies, goods transportation by UAV from a landing site could be a new key element in many emergency phases. At the 2019 symposium of the Japan Aeromedical Society, HEM and UAV collaborations were identified as desirable because information

collection by UAVs in the field could provide valuable information for HEM operations and flights. However, obtaining external information and collecting information from UAVs involves issues such as maintaining stable communication. Moreover, during a large-scale disaster, satellite communication is the only way of maintaining contact; however, even if one is able to use a satellite phone, a large earthquake could cause problems related to satellite phone congestion and data transmission speeds [23]. Given these issues, the use of UAVs under visual flight conditions may be the most promising first approach for UAV use in disasters (especially in large-scale natural disasters).

UAVs can provide an optimal solution for critical air transport of medical supplies from points where HEM and DMAT vehicles have reached the vicinity of disaster areas. Thus, UAVs offer one of the best disaster medicine and disaster mitigation and intervention strategies at the present time.

After determining the acute phase of a disaster, which is the initial life-saving period, the primary issue becomes finding useful transportation methods to supply food and drugs to secure local healthcare services. For example, medicine transportation to temporary pharmacies in affected areas was disrupted during the Great East Japan Earthquake [24]. UAVs could also provide an important means of transporting drugs in such large earthquakes. In particular, if it is possible to use a mobile pharmacy to perform tests on transfusion and other products, it would be possible to use UAVs for the temporary but stable transport of blood for transfusion.

Considering the amount of time that has elapsed since a disaster has occurred and the response from the frontline base involving DMAT, HEM, mobile pharmacy, and other organizations in the disaster area, UAVs could transport emergency supplies for disaster medical care, including so-called DMAT equipment, emergency blood transfusions, and so on. After some time has passed, UAVs could transport food and other items, as well as non-emergency drugs and blood for planned transfusions (Figure 2). We believe that this process could build greater health security within a community.

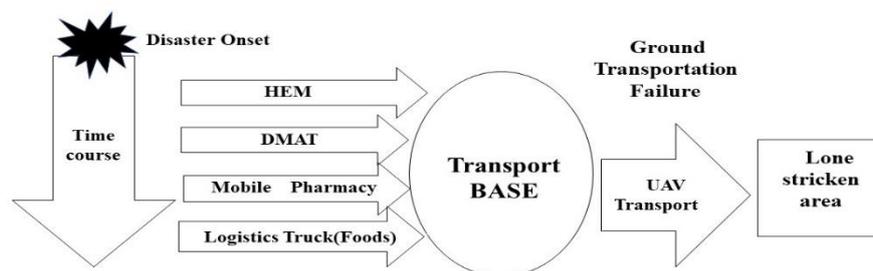


Figure 2. Model of UAV-assisted transport for a disaster.

Figure 2 is a conceptual diagram of the movement of goods to a transport base, which can vary in terms of the time taken based on distance from the disaster and whether HEMs, DMATs, mobile pharmacies, or logistics trucks are used. Then, UAVs can be used to circumvent short-distance traffic disruptions. UAVs are dispatched from the frontline base to the disaster area and first transport emergency disaster medical care supplies, so-called DMAT equipment, emergency blood transfusion products, and so on. Next, UAVs transport food, drugs, and other items.

5. Conclusions

This experiment suggests that UAVs can be used during disasters, especially when traffic is blocked (as mentioned above) in both urban and suburban areas, in affected areas where people's survival is threatened by medicine and medical supply shortages, and in areas where there is a need to secure food after the disaster. Automatic UAV flights that pilots are capable of visually monitoring are less susceptible to communication infrastructure issues. Although fully automated UAVs are effective during peacetime, their use is not completely feasible during disasters. Considering UAVs' practical uses, including transporting medical resources, food, and so on over short distances, the use of UAVs under visual observation may become an important response during emergency situations.

There are several limitations to this study. The biggest problem is that the trial was conducted in non-disaster conditions. While we do not wish for a disaster, we would like to demonstrate the effectiveness of transporting medical resources by UAVs by actually dispatching these in a disaster zone. Moreover, the trials were conducted under conditions of low winds and little or no rain. There is no legal limit to flying based on wind speed, but due to the capacity of the UAV aircraft, it was unable to fly at a wind speeds of 10 m/s or greater; therefore, the effectiveness of its use in actual disasters may be viewed somewhat negatively. Along these lines, this study did not clarify the weather conditions under which UAV transport is effective. Additionally, there are no other existing trials against which to compare our trial.

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