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Behavioral Effects of a Delivery Drone on Feelings of Uncertainty: A Virtual Reality Experiment

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The use of drones is expected to increase for delivering groceries or medical equipment to individuals. Understanding how people perceive drone behavior, specifically in terms of approach trajectories and delivery methods, and identifying factors that induce feelings of uncertainty is crucial for perceived safety and trust. This virtual reality experiment investigated the impact of drone approach trajectories and delivery methods on feelings of uncertainty. Forty-five participants observed a drone approaching in an orthogonal or a curved path and either, delivering packages by landing or using a cable while hovering above eye level. We found that participants felt uncertain and unsafe, especially when looking up at drones approaching with orthogonal paths. Curved paths led to lower feelings of uncertainty, with comments such as being more natural, trustful, and safe. Feelings of uncertainty arose while landing on the ground due to altitude changes and potential collision concerns. Using a cable instead of actually landing for delivery reduced feelings of uncertainty and increased trust. The study recommends drones avoid hovering near humans, especially after landing. Furthermore, the study suggests exploring design solutions, including design aesthetics and human–machine interfaces, that clearly convey drone intentions to help reduce feelings of uncertainty.

CCS Concepts: • **Human-centered computing → Human computer interaction (HCI)**; **Empirical studies in HCI**;

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1 Introduction

We are currently experiencing a period characterized by pervasive computing, where robots, including drones, are becoming increasingly integrated into our daily routines [58]. Amongst others, drones are being used to monitor ground surfaces, inspect tall buildings, and transport packages. Using drones for delivery, such as groceries, vaccines, and medical equipment [24, 28, 56], directly to individuals is expected to grow in the next decades. Herdel et al. [22] reviewed 217 **Human–Drone Interaction (HDI)** studies across 33 applications, such as photography and rescue response, identifying delivery as the most common and socially significant use case. Some advantages of drone delivery include accessibility to remote areas, shorter delivery times, and lower CO_2 emissions compared to conventional road transport [41]. An expert interview study on HDI highlighted delivery as a crucial application in public spaces for the coming decade [34]. These observations indicate that drone delivery is likely to become a major application in public spaces, resulting in frequent interactions with the general public user in the form of recipients (i.e., humans who receive the package on the ground).

With the expected increase of drone entering public spaces, there is a concern that the recipients interacting with a drone, will feel uncertain, not knowing what to expect [34]. Lack of knowledge, experience, and/or information cause humans to feel uncertain when interacting with a robot, such as a drone [35]. Based on the expert responses [34], we define feelings of uncertainty, also referred to as psychological uncertainty, in HDI as "a state of doubt experienced by humans when drone interactions deviate from expectations, leading to a loss of understanding of the drone's intentions or next actions." Feelings of uncertainty in the interaction might reduce user trust [25, 31], which can have a negative impact on the effectiveness of automated systems, such as drones [29]. User's feelings of uncertainty need to be addressed to facilitate natural interactions between humans and robots (e.g., drones) [14, 39]. Despite the need to address felt uncertainty, literature on methods for investigating and mitigating uncertainty in HDI and its sister domain, **Human–Robot Interaction (HRI)**, remains scarce.

Among other factors, insufficient awareness of a drone's intentions may contribute to uncertainty during interactions, which in turn leads to a higher perceived risk associated with drones [34]. A potential solution for managing feelings of uncertainty is to convey drone intentions through HDI cues, which help recipients predict the drone's actions and determine their best course of action. Literature indicates that individuals can infer a drone's intentions based on its flight behavior (e.g., [4, 48]). A few possible forms of flight behavior to communicate intentions include approach trajectories, which signal approach behavior, and delivery methods, which indicate package delivery. These cues highlight the potential for drones to communicate intentions through flight behavior. However, the effects of these behaviors on recipient uncertainty remain largely unexplored in empirical studies.

Our study attempts to address this gap by investigating recipient's feelings of uncertainty related to delivery drone behavior, focusing on approach trajectories and delivery methods, in a public space. In this study, the approach trajectories mean the drone's aerial approach behavior when flying towards a recipient. The delivery method reflects the techniques through which a drone delivers a package near a recipient.

Specifically, our research aims to answer the following questions:

(1) How does the approach trajectory of the delivery drone affect the recipient's feeling of uncertainty?
(2) How does the delivery method of the drone affect the recipient's feeling of uncertainty?

To answer these questions, we conducted a **Virtual Reality (VR)** experiment. The created VR environment is made as an urban open space, where there is no dedicated infrastructure for drones. The scenario involved a drone delivering a medical package containing an **Automated External Defibrillator (AED)** to a recipient in a public park, inspired by expert reflections on the potential use cases in public spaces [34]. The study employed a mixed-method analysis, incorporating continuous measures from a physical slider, questionnaires, sketches, and interviews to gain comprehensive insights into feelings of uncertainty, focusing primarily on the flying behavior of delivery drones. This study will potentially contribute to the development of natural and safe interactions between recipients and drones in public spaces, particularly for delivery purposes.

Key contributions of this study include:

(1) Insights for drone operators and for automated drone developers on how drone trajectories and delivery methods affect user perception and feelings of uncertainty.
(2) Recommendations for explicit communication of drone intentions to reduce perceived uncertainty.
(3) Use of mixed methods to measure perceived uncertainty in HDI and HRI.

2 Background

Before presenting our study, we will first outline the related work on delivery drones and the recipient's role within HDI. Next, we will explore the topic of feelings of uncertainty, specifically within the context of HRI and HDI. Finally, we will examine potential directions for reducing feelings of uncertainty, especially by communicating through robot intentions.

2.1 Delivery Drones and Recipient's Role in HDI

A delivery drone may interact with recipients, such as when providing an external defibrillator to individuals performing **Cardiopulmonary Resuscitation (CPR)** during a medical emergency [44, 61]. Previous experimental studies have focused on delivering defibrillators to recipients in simulated cardiac arrest scenarios in public spaces [44, 61]. Sanfridsson et al. [44] investigated recipient experiences when retrieving an AED from a drone and performing CPR either independently or with assistance from another person. Zègre-Hemsey et al. [61] compared how recipients experience drone-delivered AEDs with that of manually locating a public AED. The findings indicate that recipients largely reported positive experiences with the drone technology used for delivering AEDs. While both studies [44, 61] highlight the importance of user drone experience particularly in emergency situations, they fall short in addressing how to improve recipient experience and manage uncertainties during drone interactions.

2.2 Feelings of Uncertainty

Feelings of uncertainty "is assumed to be an important mediator in situations with unknown outcomes" [55, p. 343]. It has been linked to negative emotions [37] and is commonly used as a measure of anxiety in humans [17, 18]. We discuss related work on understanding and measuring felt uncertainty within the scope of HRI and HDI below.

2.2.1 Understanding Feelings of Uncertainty in HRI and HDI. During the HRI, feelings of uncertainty often affect decision-making of the user [33], contributes to their perceived risk about the robot [34], and defines boundaries of their trust in automation [31]. Addressing these feelings is essential for improving natural interactions in HRI [39].

Factors influencing feelings of uncertainty in HRI include robot design, communication cues [16], type of robot, and the type of information needed by the user [20]. Franssen et al. [16] found that certain design elements of **Automated Vehicles (AVs)**, such as the absence of a steering wheel or the use of purple and red LEDs, heightened feelings of uncertainty. Hedayati et al. [20] observed in an online study that both for drones and for ground robots, users valued safety and navigation information. However, user information needs differed between drones and ground robots; for instance, privacy was identified as a priority for drones but not for ground robots.

In HDI, experts have identified feelings of uncertainty as a key human factors challenge in public spaces, raising awareness on drone intentions among the public, and linking it to other constructs such as perceived risk, trust, and public acceptance [34]. A lack of awareness or knowledge about drone technology and interaction protocols may contribute to feelings of uncertainty. According to a U.S. drone statistics report [32], only 15% of U.S. residents have experience flying a drone. Given the novelty of drone delivery technology, public exposure is expected to be even more limited. Recipients unfamiliar with drones and their intentions may feel uncertain or uncomfortable when approached by a delivery drone. An exploratory study [14], conducted with a DJI drone, stressed that recipients need clarity to reduce feelings of uncertainty in HDI. Despite the need, there is a gap in the literature regarding potential solutions to reduce the feelings of uncertainty of the recipient during interactions with delivery drones.

2.2.2 Measuring Feelings of Uncertainty in HRI and HDI. Limited research exists on methods to measure feelings of uncertainty in HRI and HDI. Traditionally, uncertainty has been assessed in psychology using Likert-scale questions regarding event probabilities, as demonstrated by [55], who asked participants to rate their uncertainty about hypothetical outcomes. However, this outcome-focused approach may overlook uncertainty linked to specific robot features (e.g., behavior, design), especially when the robot's goal, such as delivering a package at a specific location, remains constant. Franssen et al. [16] quantified uncertainty related to AV interior design using Likert-scale statements and static images in an online study. While this approach captures some uncertainty, it lacks qualitative depth to explain user experiences and why certain features heighten perceived uncertainty. Moreover, static images fail to capture how feelings of uncertainty evolve during interaction, limiting insights into how robot behavior affects uncertainty over time.

Although quantitative measures provide clear insights into patterns and trends, they often lack the depth needed to explain why certain interactions evoke uncertainty. Qualitative insights help bridge this gap by uncovering underlying factors and contextual nuances. A mixed-method approach captures both the quantitative and qualitative dimensions of uncertainty [10]. With this approach, researchers can comprehensively understand how and why uncertainty arises, which is crucial for developing design strategies that improves safe and trustworthy HDI.

Limited research explores the implications of feelings of uncertainty on human perception, such as understanding and predictability, which are central to our definition of uncertainty, as well as on human factors such as trust. Körber [30] questionnaire could provide quantitative insights on the understandability and predictability of robot behavior. Additionally, sketching robot trajectories, based on [13], offers a qualitative and visual interpretation of robot behavior. Measuring trust could deepen our understanding of how perceived uncertainty influences trustworthiness in interactions, given that trust is essential for managing uncertain situations [31].

2.3 Communication of Robot Intentions

A potential approach to managing uncertainties in HRI is through the communication of robot intentions, such as those of drones, to users. This helps users better understand and predict the robot's actions, enabling users to make informed decisions. Human factors research on AVs, a related field to HRI, has explored various cues to communicate vehicle intent to pedestrians, including vehicle behavior (implicit cues) and external displays (explicit cues) [9–11].

Robots can use interfaces to explicitly communicate their intentions. For instance, [7] and [52] investigated user experience towards augmented solutions, including augmented reality headsets and ground projections, as methods to convey robot intentions. Brock et al. [7] concluded that ground projections offer potential for direct interaction, such as navigating maps, and [52] found that showing future navigation points of a drone improved clarity of intentions and task efficiency compared to baseline with no visualization and only flying behavior. However, the drawback of such interfaces is the need for additional hardware, which limits their legibility and range [4]. Implicit cues, such as robot behavior, provide a natural form of communication. In HRI, for instance, [13] investigated how humans predict robot intentions, particularly when holding or moving objects, based on robot trajectories. The authors found that robots following curved paths were more legible than those with straight approaches, allowing users to better predict robot intentions. In order to make the link between drones and its intentions, potentially reducing feelings of uncertainty, drones can implicitly communicate through flying behavior. Elements of flying behavior for delivery drones include approach trajectories, delivery methods, and flying altitudes.

2.3.1 Communication through Approach Trajectories. Studies have shown that a drone can use approach trajectories to communicate its intention with recipients (e.g., [4, 48]). Bevins and Duncan [4] conducted a video-based study to test 20 different aerial forms (e.g., hover, U-shape, descend) and categorized the trajectories based on how participants perceived the drone's intentions. A straight descent was interpreted as a landing, while a U-shape was interpreted as a signal to not approach and to avoid following the drone. In a video-based study by [48], participants evaluated drone behaviors characterized by curved trajectories, anticipatory actions, and varying speed profiles in a horizontal plane. The results indicated that participants perceived the curved trajectories as more natural and reported feeling safer to interact with the drone compared to straight-line trajectories. The drones in the above studies fly at speeds less than 1 m/s, in contrast to delivery drones flying at greater than 10 m/s [45]. Faster flight speeds could affect how recipients perceive drone intentions and interact with them [8], making it necessary to empirically validated the findings in the context of delivery drones.

2.3.2 Communication through Delivery Methods and Flying Altitudes. Another form of flying behavior for delivery drones involves the delivery methods used to drop packages from varying heights. The delivery drones use different methods to deliver supplies [45]. For instance, drone companies such as Zipline and Wing employed drones to use parachutes [28] and cable rope [46, 56] to deliver packages on the ground while hovering. An ambulance drone prototype, developed by Momon [1], delivers an AED by landing on the ground. These methods may influence the recipient's sense of safety and predictability, which was rarely explored and reported in the literature. For instance, the parachute method presents challenges due to wind conditions, making it difficult to anticipate the precise delivery location on the ground [26]. Additionally, recipients may feel discomfort and unsafe when the drone descends [6], such as during landing process. Given the novelty of these delivery methods, recipients may find it difficult to predict the drone's intentions, which could increase feelings of uncertainty during interactions. There is a research need to investigate the effects of delivery methods on feelings of uncertainty and to propose strategies for reducing it. Positive perceptions can improve social acceptance of delivery drones [27].

In the context of social drones, some HDI studies have explored how flying altitudes influence human comfort in terms of proximity to the drone, particularly in indoor settings. Yeh et al. [60] found that participants kept a larger lateral distance from a drone with a social shape and face flying at an altitude of 1.8 m, indicating discomfort, compared to when the drone flew at 1.2 m. In contrast, [6] conducted a VR experiment where participants maintained a closer distance to a drone flying at an altitude above their eye level (1.95 m), suggesting comfort, compared to when the drone flew below eye level (1 m). These contrasting results highlight the need to examine how flying altitudes effect human comfort beyond the context of social drones, particularly for delivery purposes. Social drones are specifically designed for close human interactions, often serving as personal companions or assistants [3]. In contrast, delivery drones are built for outdoor environments, operating at significantly higher altitudes (>40 m) [56] and greater speeds (>10 m/s) [45] to deliver packages safely. Such variations in drone purposes (e.g., social vs. delivery) can significantly influence human expectations and attitudes towards the drone in the interaction [23].

3 Method

VR has emerged as a valuable tool extensively utilized in investigating user experiences in HRI scenarios, including interactions with AVs, drones, and social robots [6, 42, 43, 54]. VR experiments offer both internal and external validity, making them a reliable choice for studying HRIs [54]. VR serves as a method to address challenges related to safety and ethical regulations that currently limit interactions between public and delivery drones in proximity, especially in the Netherlands. Through the use of VR, we replicated drone movements utilizing proportional–integral–derivative controllers while maintaining safety and experimental control.

Participants were recruited for a VR experiment with a head-mounted display (i.e., Meta Quest 2; see Figure 1). Recruitment advertisements were shared on social media, student groups, and employee groups at the Royal Netherlands Aerospace Center and Eindhoven University of Technology. The recruitment criteria were age over 18 years and not being prone to motion sickness and VR sickness. The study design was reviewed and approved by the ethical committee of the Eindhoven University of Technology.

3.1 Independent Variables

This 2×2 within-participant study design comprised two independent variables:

(1) The approach trajectory consists of two levels: *Orthogonal* and *Curve*. *Orthogonal* approach involves an approach with two straight lines intersecting at 90° angle. *Curve* approach is symmetric and exists as a spherical chord between two points rather than as a straight line [48]. Specifically, the *Curve* approach is a quarter circle arc with a radius of 38 m, centered 45 m laterally away and 7 m vertically from the participant. The two approaches are shown in Figure 2. The drone flew at a height of 45 m [56], before lowering its height.
(2) Delivery method, with two levels: drone landing (*Land*) and cable drop (*Cable*). *Land* method involves a drone that descends to the ground from a height of 7 m and drops the package. *Cable* drop includes a drone that suspends a cable rope to drop the package on the ground when hovering at 7 m height. These delivery methods are adopted by drone companies as mentioned in [45] and are shown in Figure 3. The parachute method was not studied due to challenges with simulating realistic wind effects.

To manage the repeatability of the interaction, a filler scenario was added to the study design.

Fig. 1. A participant wearing a head-mounted display in the VR experiment assesses feelings of uncertainty as a drone approaches to deliver a package. In her hands, the participant holds a physical slider to express her feelings of uncertainty on a scale between 0 (absolutely certain) and 100 (absolutely uncertain).

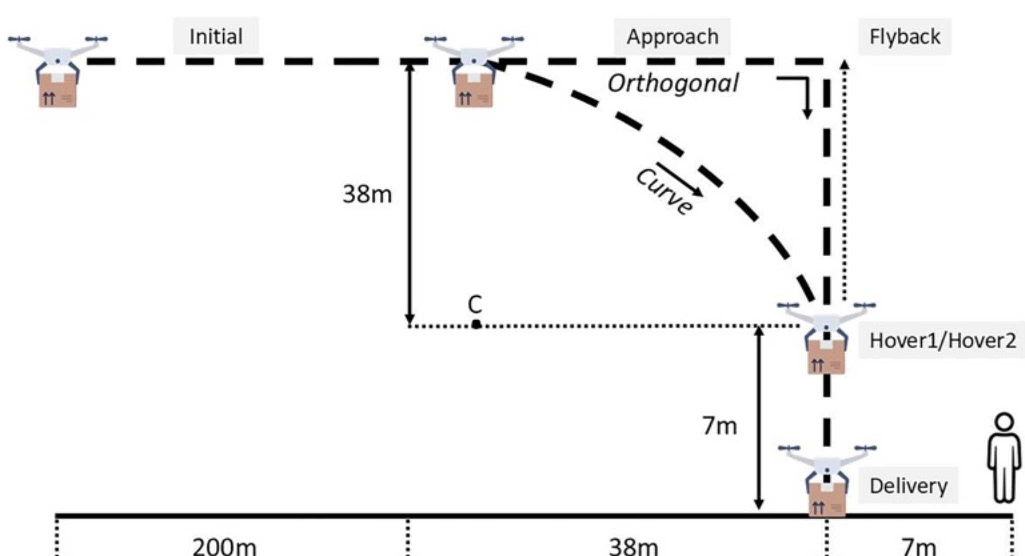

Fig. 2. Experimental layout showing the two approach trajectories, namely *Orthogonal* and *Curve*, and the six phases of flying behavior, occurring sequentially: Initial, Approach, Hover1, Delivery, Hover2, and Flyback. "C" represents the center of the *Curve* approach. Figure not to scale.

Fig. 3. The two delivery methods, namely *Land* (left) and *Cable* (right).

3.2 Experimental Design

The drone, in our study, is considered autonomous and has a hybrid vertical take-off and landing design, combining the advantages of multirotor and fixed-wing design. The dimensions (1.3 m × 1.0 m × 0.4 m; see Figure 4) of the drone model were inspired by the real drone model of Wing Corporation [56]. The drone model was designed with a sulfur yellow exterior (RAL 1016) to symbolize its medical delivery purpose, aligning with the color used for ambulances in the Europe [47].

The experiment was devised in Unity 3D (version 2022.3.5f1), employing a non-populated urban setting resembling a public park to have as few distractors and visual clutter in the scenarios (see Figure 5). A delivery drone approaches the recipient based on predetermined routes and over six different phases of flying behavior, namely Initial, Approach, Hover1, Delivery, Hover2, and Flyback (see Figure 6). The drone flew at a maximum speed of 11.11 m/s,[1] from a virtual lateral distance of 245 m, and it maintained a height of 45 m from the participant (referred to as Initial). Following the approach trajectory (see Figure 2; referred to as Approach), the drone hovered (referred to as Hover1) at a height of 7 m [56] and positioned 7 m laterally—which is considered within the realm of public space for human–human interaction as per [19]—for 5 s. The drone delivered the package using the designated delivery method within 6 s and retracted to its initial position (referred to as Delivery). After the package delivery, the drone hovered for 5 s (referred to as Hover2) before ascending to a height of 45 m (referred to as Flyback). Each trial took 59 s for the drone to complete six different phases. Figure 6 shows the speed of the drone in the four scenarios. The drone speeds were adjusted for the four scenarios so that the phases consisted of similar duration in all four scenarios.

In the filler scenario, the drone flew at a speed of 11.1 m/s and 45 m altitude over the public space. The drone started from a lateral distance of 245 m and flew 45 m past the participant. The drone had no intent to deliver the package to the recipient and thus, flew over. The filler scenario took 26.1 s to complete and was omitted from the data analysis as the drone did not deliver the package and the interaction time was not comparable. The videos of the scenarios can be accessed through supplementary material.

[1] Within the speed range of 11.1 m/s to 25 m/s, as observed in healthcare drone models by [45], the lower speed threshold was selected to ensure participants had sufficient time to interpret the approach method and respond.

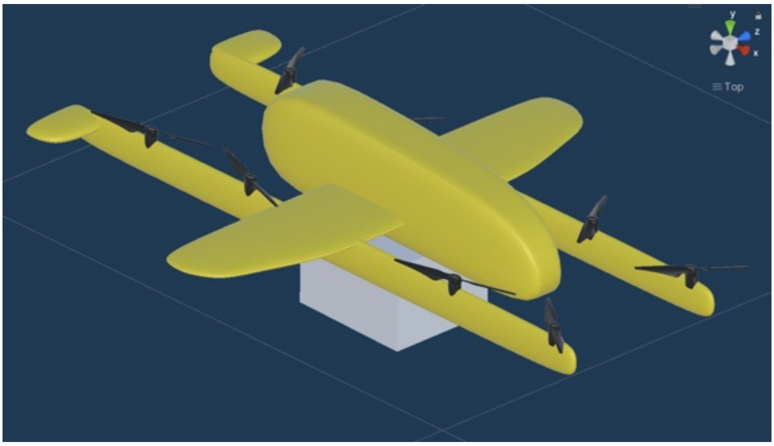

Fig. 4. 3D model of a drone in Unity 3D, featuring a package attached at the bottom.

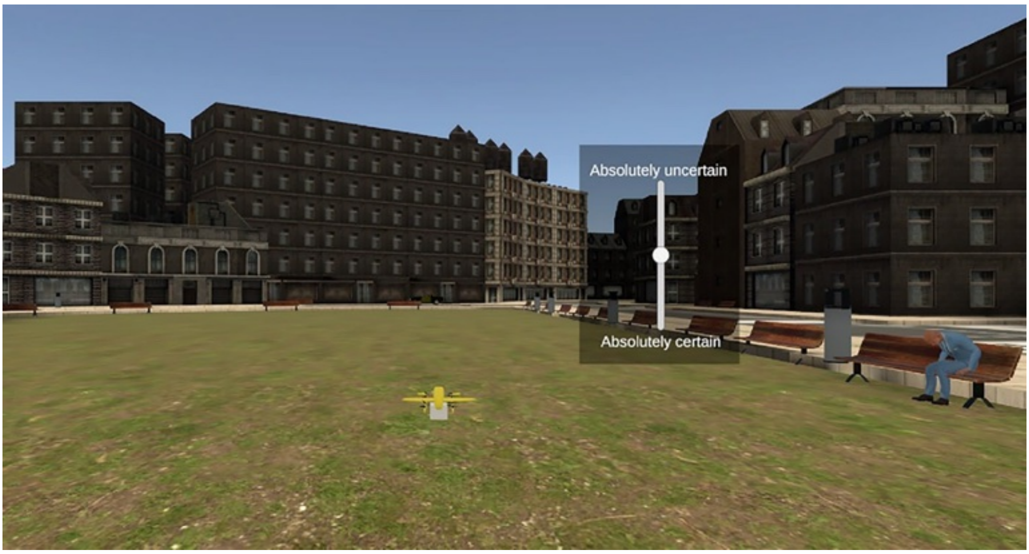

Fig. 5. Participant view of a scenario illustrating an environment where a drone descends to drop a package on the ground. The scene includes a slider scale and a patient needing medical assistance seated on a bench.

3.3 Dependent Variables

The dependent variables consisted of subjective responses from slider measures, questionnaires, interviews, and sketches (see below). While the slider measures, questionnaires, and sketches focus on feelings of uncertainty related to the drone's flying behavior, such as approach trajectories and delivery methods, the interview questions extend beyond flying behavior to explore additional factors contributing to uncertainty. Likert-scale questions on feelings of uncertainty, used for the physical slider and questionnaire, were adapted from [16].

3.3.1 Slider Measures. A physical slider, adapted from [51] and integrated with Unity 3D using Arduino,[2] was used as a continuous measure for the participant's level of felt uncertainty throughout

[2]Access the Arduino code here: https://github.com/bazilinskyy/crossbox.

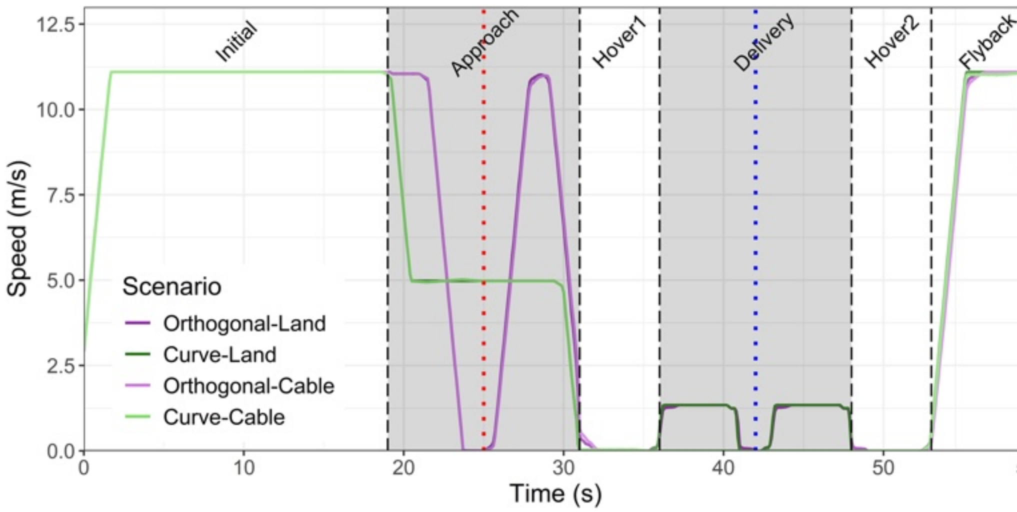

Fig. 6. Speed (i.e., the magnitude of velocity combining lateral and longitudinal components) profile of drone in different phases of flying behavior for the four scenarios. The approach and delivery methods are varied in the Approach and Delivery phases, respectively. A vertically red dotted line at 25 s and a vertically blue dotted line at 42 s represent the moment when the drone starts to descend from a height of 45 m towards the ground in the *Orthogonal* approach and when the package is delivered on the ground, respectively. The shaded gray areas indicate the phases of flight behavior where the manipulations were performed in the four scenarios.

the interaction with the drone. Participants were asked to indicate their perceived uncertainty level using the slider, assessed on a continuous scale ranging from 0 (absolutely certain) to 100 (absolutely uncertain), in the VR environment. The data were recorded at 10 Hz.

Mean uncertainty and phase range were calculated from the slider measure data for each participant, scenario, and phase. Mean uncertainty was computed as the arithmetic mean of slider values within each phase, while phase range was calculated as the difference between the maximum and minimum slider values recorded in each phase. Mean and phase range aim to provide insights into the central tendency and variability of the continuous slider data, respectively.

From the slider measure data in the Delivery phase, **"Time to Minimum Uncertainty" (TMU)** was determined as the duration from the start of the phase to the moment the slider value reached its minimum. TMU aims to offer insights into how quickly participants feel maximum certainty during the interaction with the two delivery methods.

3.3.2 Questionnaires. Questions (see Table 1) were asked in the VR environment after each trial on understandability/predictability, trust, uncertainty, and certainty towards the behavior of the drone using a five-point Likert scale (1: strongly disagree; 5: strongly agree). Questions on understandability/predictability and trust were based on [30].

After the experiment, participants were asked to express their preferred choices using an online questionnaire for both the approach trajectory and the delivery method.

3.3.3 Interviews and Sketches. Participants were asked to sketch the two approach trajectories they observed in VR using pen and paper on a templated A4 sheet (see Figure 7). The template ensured consistency and comparability across sketches, featuring a drone with a package, dotted trajectories representing the Initial (i.e., horizontal dotted line in Figure 7) and Delivery (i.e., vertical dotted line in Figure 7) phases, and a figure representing the participant. Participants were asked to connect the drone's positions in the Initial and Delivery phases to reflect their

Table 1. Questions on Uncertainty, Understandability/Predictability, Certainty, and Trust towards the Behavior of Drone

Measure	Question statement
Uncertainty	The behavior of the drone made me feel uncertain.
Understandability/ Predictability	The drone behavior was always clear to me.
	I was able to understand why things happened.
	The drone behaved unpredictably.[a]
	It's difficult to identify what the drone will do next.[a]
Certainty	I felt certain about the behavior of the drone.
Trust	I trust the drone.
	I can rely on the drone.

[a]Inverse statement.

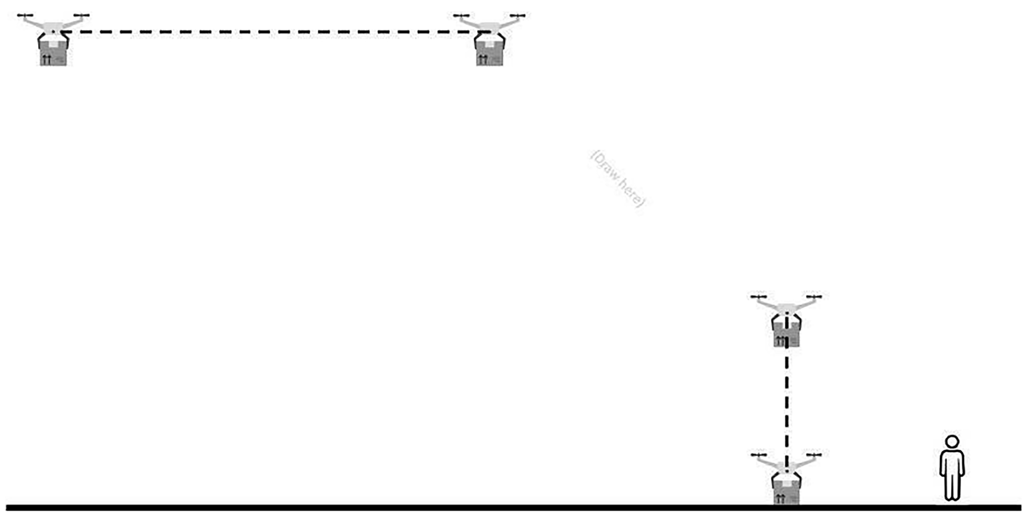

Fig. 7. Sketching template for the approach trajectories on an A4 sheet.

perceived trajectory. The sketches captured participants' perceptions of the trajectories, providing insights into how their understanding of the drone's approach trajectories aligned with or differed from the actual experimental paths [13]. The sketches also encouraged participants to reflect on their experience and deepen their understanding of the drone's movement. After completing the sketching task, semi-structured interviews were conducted to understand participant experience during the experimental study. Participants were asked to reflect on their expectations of flying behavior, their motivations behind their selected preferences, factors affecting their feelings of uncertainty (if any), any information that they would like to have gotten from or about the drone, and their overall experience with the experiment. The interview questions are provided in Table 2.

3.4 Procedure

Before the start of the experiment, participants were asked to fill in the demographics questionnaire and their affinity towards technology interaction [15]. Participants were then introduced to the VR setup, where a virtual drone approached their location in a public park to deliver an AED package intended for a patient seated visibly on a nearby bench. They were informed of the drone's arrival direction and its autonomous capability to perform the delivery task. After filling out the consent

Table 2. Interview Questions

No.	Questions
1	Would you like to interact with the shown delivery drone in reality? Why? Why not?
2	What do you expect from the flying behavior of delivery drones in future?
3	Which approach trajectory do you prefer and why? Would you prefer other approach trajectories that we did not show? If so, what? Why?
4	Which delivery method do you prefer and why? Would you prefer other delivery methods that we did not show? If so, what? Why?
5	Did something about the drone and/or scenario make you feel uncertain during the trials? If so, what? Why?
6	Is there information you want to know about the drone? If so, what? Why?
7	How was your overall experience with the experiment? Are there any other things that you would like to mention?

form, participants experienced a test scenario to familiarize themselves with the environment and slider. The test scenario was one of the four scenarios. After familiarizing with a test scenario, participants experienced all the experimental scenarios, including the filler, and each scenario is repeated three times (i.e., (4 scenarios + 1 filler) × 3 runs = 15 trials, in total). The repetitions allowed for reliable measurements and helped account for variability in participant responses. While the experimental design and the environment remained identical across the trials, the selection of test scenario and the order of trials were randomized using the Latin square method to reduce learning effects.

During each trial, participants continuously rated their feelings of uncertainty with a slider measure, based on the question: "How much do you rate your feeling of uncertainty on a scale from 0 (absolutely certain) to 100 (absolutely uncertain) about the behavior of the drone? The higher you rate, the more uncertain you feel." While the physical slider itself was not visible due to the obstruction by the VR headset, participants could view their input on the headset display within the virtual environment (see Figure 5). Participants began each trial with the slider set to a neutral position (50), indicating neither certainty nor uncertainty. This starting position was not expected to affect their responses, as participants were informed that they could adjust the physical slider to reflect their level of uncertainty as soon as they received the slider and the trial commenced. The 19-second duration of the "Initial" phase was designed to be sufficiently long for participants to make these adjustments to the slider. Participants were instructed to focus only on the drone and its behavior and not on the use of AED to treat the patient. This emphasis was intended to ensure that the study captured feelings of uncertainty related specifically to the drone and its behavior, and not the uncertainties from other elements, such as the use of AED and patient health.

Participants were not allowed to perform any secondary tasks and were asked to quit the experiment if they felt unwell. At the end of each trial, the participants rated their subjective feelings on predictability, trust, uncertainty, and certainty using a joystick (i.e., Quest 2 controller) in the virtual environment. After every five trials, a short break was scheduled. After performing all 15 trials, participants completed an online questionnaire on their preferences for the approach and delivery methods, completed the Presence Questionnaire[3] [57], sketched the perceived approach trajectories, and then answered interview questions. Participants were asked during the breaks and at the end of the experiment about any simulator sickness symptoms (e.g., disorientation, eye-strain, headache, nausea). They were instructed to stop the experiment and inform the experimenter if they experienced any symptoms. The total experimental duration was approximately 70 minutes.

[3]Virtual presence was measured with the Presence Questionnaire on a scale of 1 (not compelling) to 7 (completely compelling).

Finally, participants were debriefed, thanked, and compensated for their time with a 15 Euro bol.com voucher.

3.5 Participants

A total of 45 individuals (24 females, 21 males[4]) with ages between 23 years and 59 years (*M* = 32.3; SD = 11.3) participated. Eighteen participants were Dutch, 9 Indian, 6 Chinese, and the remaining were from 12 other nationalities including America, Belgium, Canada, France, Germany, Italy, Japan, Portugal, Romania, Spain, Taiwan, and Turkey. With regards to the level of education, 4 participants completed doctoral education, 28 Master's or equivalent education, 10 Bachelor's or equivalent education, and 3 Secondary education. Thirty-nine participants were employed and the remaining six were students.

All the participants reported having seen a drone in media or reality and five said to own a drone. Forty participants had seen a drone from a distance or in close proximity, 14 had experience piloting a drone, and 5 had never seen a drone in reality. Overall, participants claimed to have a positive attitude towards technology interaction (*M* = 3.8; SD = 1.0). Participants reported a compelling sense of virtual presence (*M* = 5.6; SD = 0.69), with no reported symptoms of simulator sickness during the study.

3.6 Analyses

A total of 540 trials (45 participants × 4 scenarios × 3 repetitions) were available for the analysis of slider measures and subjective measures. The TMU measure was available for 469 out of 540 trials; in the remaining 81 trials, the participant did not express a lower uncertainty score with the slider compared to their response at the start of the delivery phase.

The slider measure and Likert scale data were averaged over three repetitions and analyzed using parametric tests to maintain statistical efficiency and result homogeneity. Past research suggests that data from a Likert scale with 5 points or more and with a larger participant sample size (>30) leads to negligible Type I and Type II errors [9, 12, 36, 38]. A two-way ANOVA with repeated measures (henceforth, referred to as ANOVA) was performed and *post-hoc* pairwise comparisons with Bonferroni correction (henceforth, referred to as *post-hoc* test) were followed for significant effects.

Each participant generated sketches for the two approach trajectories, yielding a total of 90 sketches. The sketches were subjected to a thematic analysis to identify patterns of similarities and differences in the sketched trajectories. The analysis produced categories based on participants' perceptions of (horizontal) distance from the drone and the forms of the two approach trajectories. Perceived distance was classified by visually comparing participants' sketches with the simulated VR distance of 7 m in horizontal plane between the participant and the drone attempting to deliver a package. Sketched trajectories were categorized as reflecting a distance of 7 m if any part of the trajectory (see blue lines labeled "a1" and "a2" in Figure 8) did not cross the reference line. Conversely, trajectories were classified as reflecting a distance of less than 7 m if any part of the trajectory (see blue line labeled "b" in Figure 8) crossed the reference. The first author categorized the sketches and analyzed the interviews.

The interviews were transcribed using automatic transcription software (Otter.ai), and the transcribed text was reviewed and corrected based on the recordings by the first author. A thematic analysis was conducted on the transcribed interview data, with themes and codes emerging from the data in accordance with [5]. The codes were developed to understand the reasoning behind participants' preferences for approach trajectories and delivery methods and to identify factors

[4]None of the participants expressed their gender as non-binary or "prefer not to say."

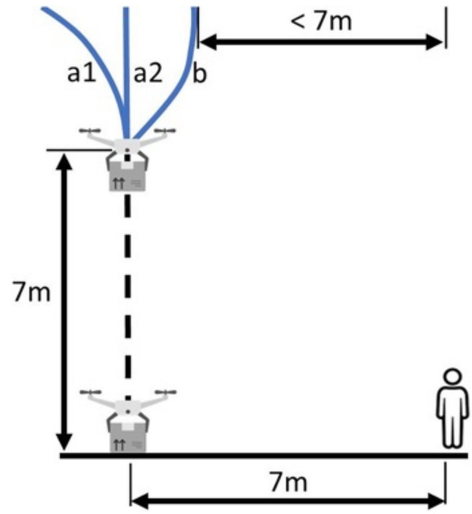

Fig. 8. An illustrative example analyzing sketches based on the perceived distance between the participant and the drone attempting to deliver a package. The vertical dotted line, representing the attempt to deliver the package, is the reference line. Blue trajectory segments represent parts of the sketched trajectories: "a1" and "a2" indicate drone trajectories perceived at a lateral distance of 7 m from the participant, while "b" represents a trajectory perceived to be closer than 7 m.

influencing feelings of uncertainty. Codes were then assigned to potential themes, based on similarities, differences, and repetitions. Additionally, sketches were used to support a few interview results, aiding in understanding participants' perceptions of the approach trajectories.

4 Results

4.1 Slider Measures

Figure 9 exhibits the mean uncertainty score for the four scenarios over the different phases of drone behavior for every 1 s interval.

An ANOVA was performed to evaluate the effects of approach and delivery methods on the mean uncertainty over the different phases. The ANOVA results showed significant main effects and larger effect sizes of the approach trajectory during the Approach ($F(1, 44) = 49.54$, $p < 0.001$, $\eta_p^2 = 0.53$), Hover1 ($F(1, 44) = 15.35$, $p < 0.001$, $\eta_p^2 = 0.26$), and Delivery phases ($F(1, 44) = 7.79$, $p = 0.008$, $\eta_p^2 = 0.15$); and significant main effects and larger effect sizes of the delivery method during the Delivery ($F(1, 44) = 20.42$, $p < 0.001$, $\eta_p^2 = 0.32$), Hover2 ($F(1, 44) = 16.7$, $p < 0.001$, $\eta_p^2 = 0.28$), and Flyback ($F(1, 44) = 7.7$, $p = 0.008$, $\eta_p^2 = 0.15$) phases.

In Figure 10 (top), mean uncertainty and error bars show variations across phases for the four scenarios. *Post-hoc* tests revealed significant differences in mean uncertainty between *Orthogonal* and *Curve* during Approach, Hover1, and Delivery phases. Notably, mean uncertainty was significantly higher for *Land* than *Cable* in Delivery, Hover2, and Flyback phases.

The ANOVA results for the phase range measure indicated significant main effects and medium effect sizes of the approach trajectory during the Approach ($F(1, 44) = 24.75$, $p < 0.001$, $\eta_p^2 = 0.16$), Hover1 ($F(1, 44) = 9.57$, $p = 0.002$, $\eta_p^2 = 0.07$), and Delivery ($F(1, 44) = 9.23$, $p = 0.003$, $\eta_p^2 = 0.07$) phases; and significant main effects and medium to large effect sizes of the delivery method during the Delivery ($F(1, 44) = 6.68$, $p = 0.011$, $\eta_p^2 = 0.05$), Hover2 ($F(1, 44) = 27.63$, $p < 0.001$, $\eta_p^2 = 0.17$), and Flyback ($F(1, 44) = 30.7$, $p < 0.001$, $\eta_p^2 = 0.19$) phases.

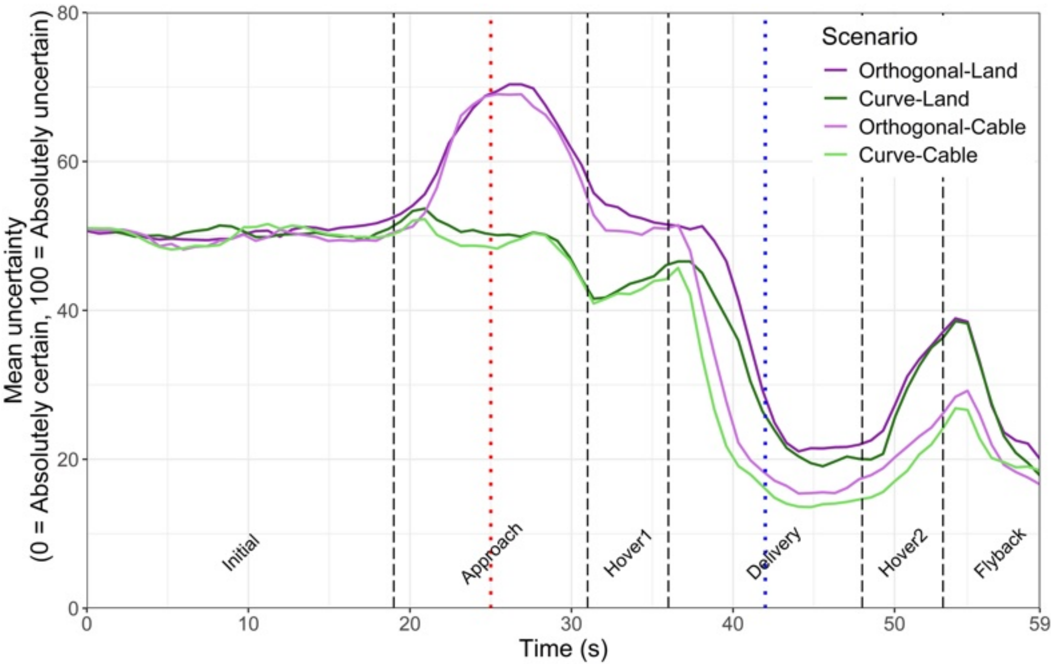

Fig. 9. Mean uncertainty score as expressed in the four scenarios over the five different phases of drone behavior. A vertically red dotted line at 25 s and a vertically blue dotted line at 42 s represent the moment when the drone is about to descend from a height of 45 m towards the ground in the *Orthogonal* approach (referred to as above-head) and when the package is delivered on the ground, respectively.

Phase range and error bars in Figure 10 (bottom) illustrate the mean and variations across phases for the four scenarios. *Post-hoc* tests revealed significant differences in phase range between *Orthogonal* and *Curve* during Approach, Hover1, and Delivery phases. Phase range was significantly higher for *Land* than *Cable* in Delivery, Hover2, and Flyback phases.

ANOVA was performed to evaluate the effects of approach and delivery methods on TMU. The results indicated a significant main effect and larger effect size for the delivery method ($F(1, 44) = 11.86$, $p < 0.001$, $\eta_p^2 = 0.22$). Minimum uncertainty was expressed earlier by participants in the *Orthogonal-Cable* ($M = 5.38$; SD = 2.94) and *Curve-Cable* ($M = 4.82$; SD = 2.78) compared to the *Orthogonal-Land* ($M = 6.25$; SD = 2.12) and *Curve-Land* ($M = 6.17$; SD = 3.05), respectively. The *post-hoc* test suggested that TMU was significantly lower for *Cable* than *Land* method.

4.2 Questionnaires

ANOVA was conducted to evaluate the effects of approach and delivery methods on the Likert scale measures, namely certainty, understandability/predictability, trust, and uncertainty evaluated after each scenario. The means and error bars for the four Likert scale measures are presented in Figure 11 below.

The results (see Table 3) for the four Likert scale measures indicated significant main effects and larger effect sizes of the approach and delivery methods. *Post-hoc* tests indicated that the certainty, understandability/predictability, and trust scores were significantly higher for *Curve* than for *Orthogonal* approach trajectories and were significantly higher for *Cable* than for *Land* delivery methods. *Post-hoc* tests showed that the uncertainty scores were significantly lower for *Curve* than

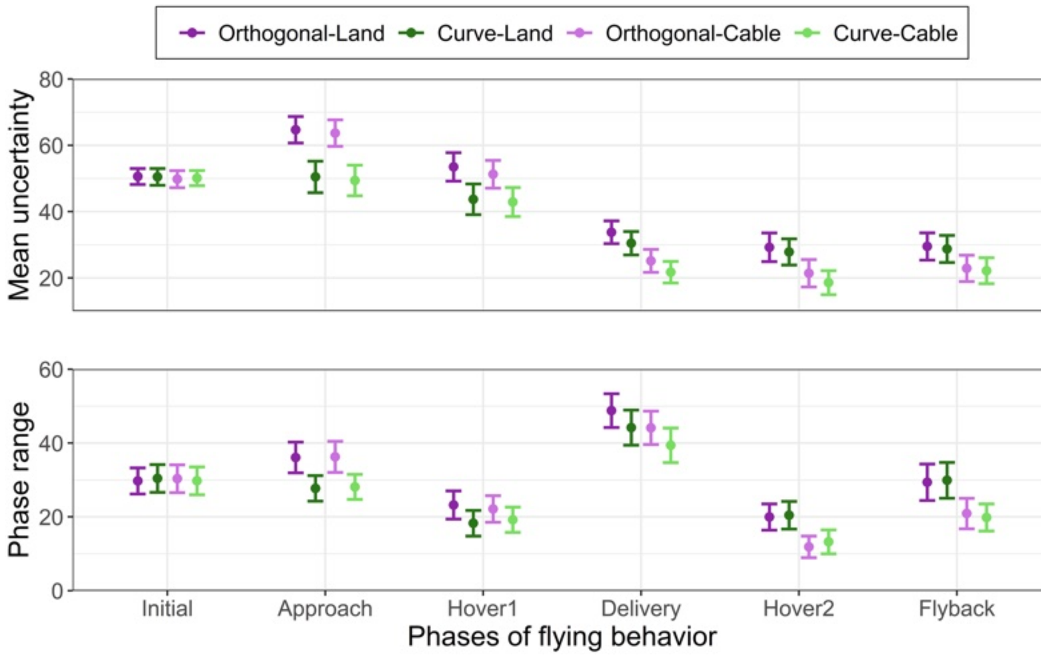

Fig. 10. Mean and error bars (CI ~ 95%) of the mean uncertainty (top) and phase range (bottom) for the four scenarios in six different phases of flying behavior.

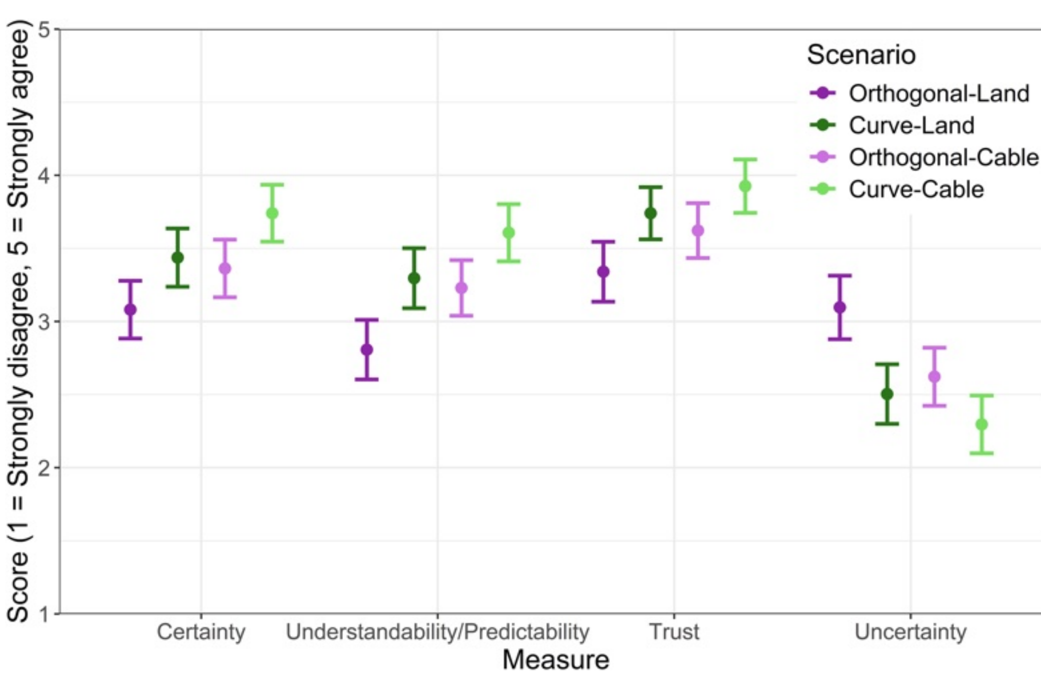

Fig. 11. Mean and error bars (CI ~ 95%) of the certainty, uncertainty, understandability/predictability, trust, and uncertainty measures for the four scenarios.

Table 3. ANOVA Results for the Four Likert Scale Measures, Namely Certainty, Understandability/Predictability, Trust, and Uncertainty

Measure	Effects	F(1, 44)	p	η_p^2
Certainty	Approach	18.53	$<0.001^{**}$	0.3
	Delivery	10.66	0.002^{*}	0.2
Understandability/ Predictability	Approach	23.87	$<0.001^{**}$	0.35
	Delivery	13.95	$<0.001^{**}$	0.24
Trust	Approach	26.07	$<0.001^{**}$	0.37
	Delivery	8.24	0.006^{*}	0.16
Uncertainty	Approach	19.93	$<0.001^{**}$	0.31
	Delivery	11.13	0.002^{*}	0.2

$^{**}p < 0.001$, $^{*}p < 0.01$.

for *Orthogonal* approach trajectories and were significantly lower for *Cable* than for *Land* delivery methods. With regards to the approach trajectory, post-experiment results indicated that 91.11% of participants preferred *Curve*, 8.89% preferred *Orthogonal*, and none selected "no preference." Regarding the delivery method, 55.56% of participants preferred *Cable*, 31.11% preferred *Land*, and 13.33% selected "no preference."

4.3 Sketches

Figures 12 and 13 illustrate the categories of sketches, with examples, as perceived by participants for the *Orthogonal* and *Curve* approach trajectories, respectively. The three categories of the *Orthogonal* approach comprise sketches where the drone was (i) perceived at a lateral distance of 7 m (N = 13), (ii) perceived at a lateral distance of less than 7 m (N = 30), and (iii) rationalized at a lateral distance of 7 m but felt to be less than 7 m (N = 2). Within category (ii), the drone was perceived to descend to the Hover1 position either (iia) without a vertical straight approach (N = 24) or (iib) with a vertical straight approach (N = 6). The two categories of the *Curve* approach include sketches where the drone was (i) perceived at a lateral distance of 7 m (N = 40) and (ii) perceived at a lateral distance of less than 7 m (N = 5).

4.4 Interviews

This section presents themes and quotes from the thematic analysis, accompanied by sketches, and organized by participant numbers in the order of their recruitment (1–45).

4.4.1 Reflections on the Curve and Orthogonal Approach Trajectories. Majority of the participants preferred the *Curve* approach and perceived it as natural, predictable, and safe.

> *"I prefer (the) arc path (Curve) because it's more natural (...) When you see the skydivers land or birds landing or when you throw a stone into the air, that's more like the parabolic flight and not straight ahead." (P11)*

> *"Arcs (Curve) are just visually easier to read." (P22)*

> *"I felt safer watching the drone descend (as a Curve) than the other, straight lines." (P39)*

A few participants explicitly noted that they observed the drone, following the *Curve* approach, within their line of vision (see Figure 13 (left)): *"I don't have to look far overhead" (P43).*

In the *Orthogonal* approach, when the drone was about to descend from a height of 45 m, most of the participants had to look up, perceiving the drone as above head (see Figure 12 (top-right)). The *Orthogonal* approach evoked feelings of uncertainty and unsafety.

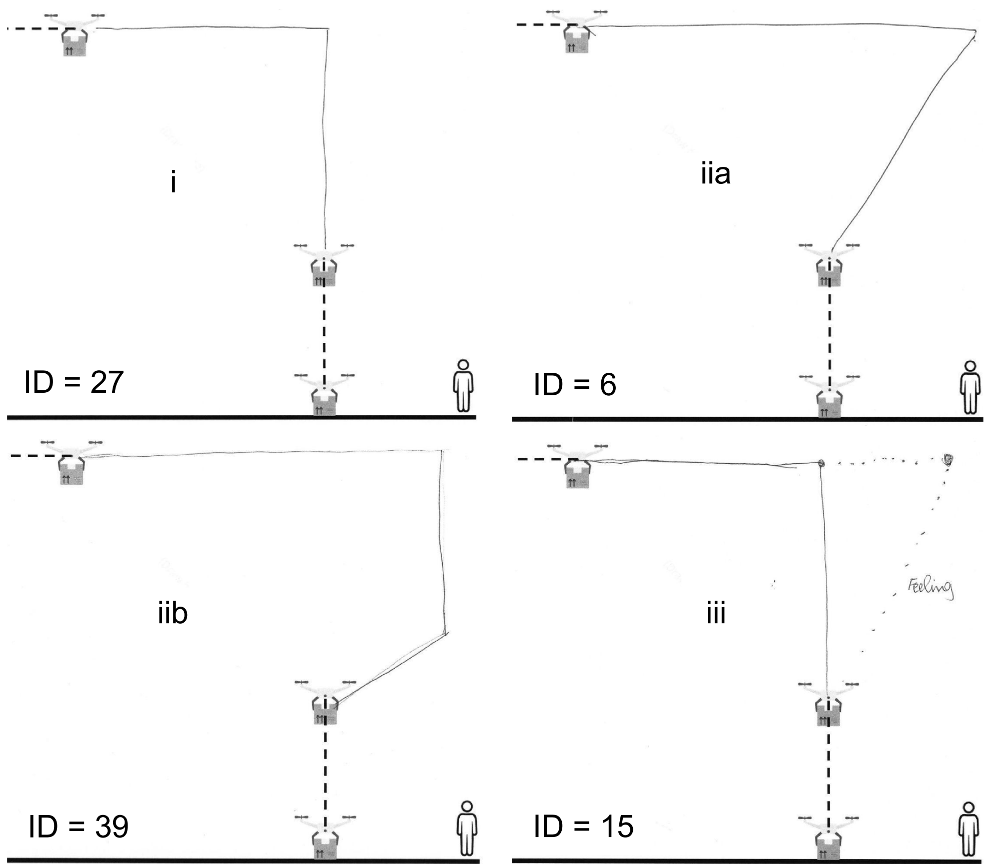

Fig. 12. Example sketches of the *Orthogonal* approach, as perceived, for the three categories with participant ID. See categories (i), (iia), (iib), and (iii) in the top-left, top-right, bottom-left, and bottom-right subfigures, respectively.

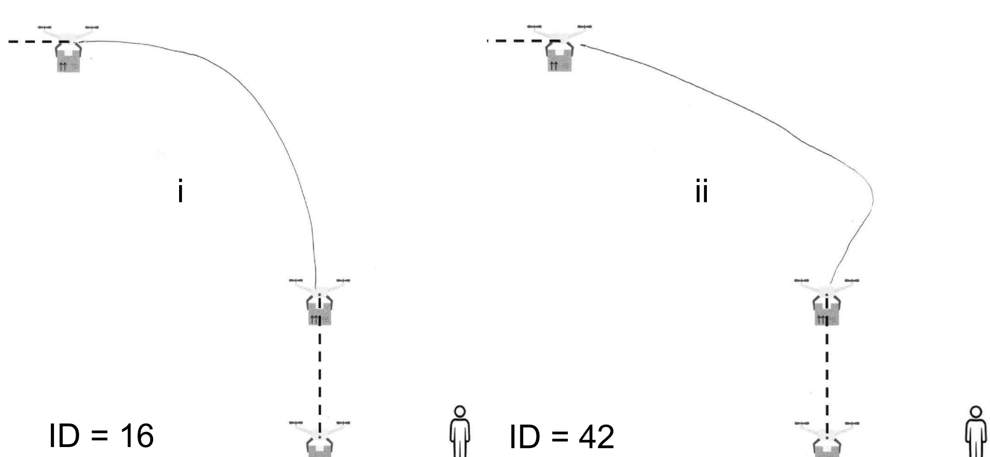

Fig. 13. Example sketches of the *Curve* approach, as perceived, for the two categories and with participant ID.

"When it was over my head, I was uncertain what exactly it's going to do?" (P1)

"The straight-line approach made me feel the drone is directly above my head and it felt a bit more threatening." (P38)

"What if the package drops on my face?" (P39)

4.4.2 Reflections on Hovering Behavior and Alternative Approach Trajectories. The hover phase made the majority feel curious and uncertain about the drone's intentions, especially after the Delivery phase.

"When it stays (hovers), I was like, okay, I'm not sure what you're gonna do. Are you gonna attack me?" (P7)

"Hovering made me feel uncertain because I knew that something would follow, but I didn't know what." (P17)

"Before delivery, stalling (hovering) was mostly fine. But after delivery, (with) stalling (hovering), I was like, what is it going to do? Is it going to do something that I'm not sort of used to seeing so far?" (P38)

Beyond the current approach trajectories, few participants suggested exploring other trajectories such as circular motion, spiral motion, or approaching from a different direction but within the participant's line of vision.

"I have been thinking that the approach could basically be from the side. So you start up, then you will fly straight, and then you move to the left or the right within my vision. (...) If you take it in a circular motion, you actually use multiple points (...) When I look at it, the drone, from my point of view, is in a circular motion, I do incorporate more of the surroundings into its motion, which makes me feel safer." (P12)

"The drone should identify the subject and then start spiraling around him for at least one turn and then smoothly descend." (P45)

4.4.3 Reflections on the Cable and Land Delivery Methods. Most of the participants generally preferred delivery through *Cable* as the drone maintained a safe distance and they felt certain and clear about the drone's intentions.

"It makes the intentions of the drone much clearer. You know, there's a package coming down." (P12)

"With the cable drop, I felt the most certain in the entire experiment." (P19)

"When it (drone) is far from the ground it feels safe, that it will not touch anyone." (P28)

During the Hover2 phase, some participants experienced less uncertainty with the *Cable* delivery, *"because the hovering part was a bit more clear" (P44)* and *"the hovering isn't that obvious (by itself)" (P18)*, than with the *Land* delivery, where it *"felt abrupt" (P44)* and induced uncertainty feeling about the landing intention: *"Then I was not sure, okay, is it (drone) coming down again? (...) it felt a bit tricky as to what it (drone) is doing" (P44).*

While some participants found the *Land* method familiar, others expressed uncertainty regarding the delivery intention and safety.

"(…) it felt more familiar when it (drone) came down to (the) ground by landing." (P3)

"While drones come down, they have rotor blades rotating, maybe someone like kids can try to touch the blades." (P19)

"It's unclear when it (drone) is going to drop the package and when it (drone) is going to stop and how long it (drone) is going to stop, so there was more uncertainty with drone landing." (P20)

4.4.4 Uncertainties and Safety Issues about an Alternative Delivery Method. A few participants acknowledged delivery through a parachute as an alternative method where a drone could maintain a safe distance. The method, however, was not preferred to the other methods due to practical wind challenges and was perceived as unsafe, and unpredictable.

"It's so unpredictable and so unnecessary (…) Also, you don't want something falling on your heads." (P14)

"With a parachute, the package may have a chance to get stuck on the trees, lamp posts or any other things." (P19)

"(…) in the Netherlands, with the wind, I'm not sure about that one (parachute method). I feel like I'd get hit in the face with a parcel." (P43)

4.4.5 Need for Explicit Information and Potential Solutions to Mitigate Feelings of Uncertainty. Beyond the approach trajectories, hovering behavior, and delivery methods, the lack of explicit information about the drone's intentions was identified as a factor contributing to their feelings of uncertainty. The majority of participants emphasized the importance of receiving clear and explicit information regarding the drone's purpose and delivery intentions.

"Why and what are you doing and what are you doing now?" (P4)

"It would have helped to have an expectation of where and when it is going to be landing or all of these details like what do the brakes (hovering) mean." (P5)

"If the package is being delivered near me, then I should know about it beforehand. (…) What is inside the package and who is sending it, the sender information and the purpose of the package." (P39)

The design of the drone's appearance and the **Human–Machine Interfaces (HMIs)**, such as lights and sound from the drone or text on mobile phones, were stated as potential solutions to communicate drone intentions and handle feelings of uncertainty.

"If you consider a medical drone, and if it would go with the medical noise and the medical lighting, that would be very appropriate, then you know what is going on and will happen." (P12)

"We receive an alert from the Netherlands government, first Monday of every month. Being able to receive an alert like that on your phone would help, if there is somebody that is having a panic attack close by. (…) If you can easily identify that the drone is from a hospital, like a specific brand, then I would be less scared of what it's doing." (P15)

"When the drone flies at a distance above you then it says 'start landing,' when it starts to land, and when it is finished then say 'task finished' and fly away. That is more clear to me, instead of the drone doing nothing but stays (hovers)." (P17)

"In case the drone is not dropping the package, there should be a red light and when it is going to come down then a green light to indicate that it is coming down. So it will give an idea of what it's going to do and it will help you to feel certain." (P19)

5 Discussion

This study aimed to understand how the behavior of a delivery drone, specifically in terms of approach and delivery methods, influenced the recipient's feelings of uncertainty. Forty-five participants took part in a VR experiment, observing the drone approach using both *Orthogonal* and *Curve* trajectories and delivering packages either by landing (*Land* method) or using a cable while hovering (*Cable* method). Their perceived uncertainty was assessed through a combination of slider measures, questionnaires, interviews, and sketches. Overall, the results from the mixed method analysis indicated that participants experienced a higher level and larger range of uncertainty and lower level of understandability, predictability, trust, certainty, and preference when the drone followed an *Orthogonal* approach compared to a *Curve* approach, and when the drone delivered the package using the *Land* method compared to the *Cable* method. When the participants reflected on their reactions, they mentioned a lack of clarity regarding purpose and intentions as additional factors contributing to their feelings of uncertainty, extending beyond the explored behavioral characteristics.

5.1 The Effect of Approach Trajectory

The mixed-method analysis showed that participants found it challenging to predict the *Orthogonal* approach and felt uncertain about it, especially when the drone was about to descend from a height of 45 m. Due to the tendency of humans to overestimate the approach angles of moving objects [53], such as drones, the drone's vertical viewing angle of 81.16° (i.e., $\text{Tan}^{-1}(7/45)$) is perceived directly above the head. This perception contributes to feelings of unsafety and uncertainty regarding the possibility of the package dropping on the head. As a recommendation, drone designers and pilots should consider flying drones at a lower vertical angle when approaching the recipient to instill a sense of certainty and safety. Further, we suggest that future research investigate the effects of an earlier descent time for the *Orthogonal* approach to reduce feelings of uncertainty and improve perceived safety.

In contrast to the *Orthogonal* approach, participants perceived the *Curve* approach of the drone to be within their line of vision and expressed that this was more readable. This could be explained by the drone's gradual descent in the *Curve* approach, which contrasts with the sharp descent in the *Orthogonal* approach, making the *Curve* approach more legible. On similar lines, [13] recommended the use of *Curve* trajectories in the horizontal plane for robots, as participants rated them higher in legibility compared to straight trajectories. Consequently, participants in our study rarely experienced uncertainty or unsafety towards the drone behavior for the *Curve* approach. The *Curve* approach was the preferred choice and was consistently described as natural, predictable, and trustworthy. This aligns with the findings of [48], where the *Curve* approach trajectory in a horizontal plane was perceived as natural, safe, and usable. Interestingly, our results contrast with those of [4], where participants viewed another form of the *Curve* approach (i.e., U-shape) as unapproachable and expressed to stay away from the drone. An explanation may be that participants in [4] study interpreted the drone's vertical departure at the end of the U-shaped trajectory as a signal to maintain distance. Future research should delve deeper into exploring human perceptions of various forms, including spiral and circular motion as suggested in our interview results, and parameters (e.g., speed, direction, altitude) of the *Curve* approach to identify the most natural and least uncertainty inducing approach trajectory.

5.2 The Effect of Delivery Method

Participants favored the *Cable* and *Land* methods over the parachute method, during the interviews, citing practical challenges related to weather that might impact their ability to interpret where the package would land on the ground and safety concerns. It took more time before participants felt certain during the *Land* method, and they reported lower levels of safety, certainty, and trust compared to the *Cable* method, where the drone's hovering at 7 m height and delivery via cable made them feel safe and certain about the drone's intentions. Despite the drone being located 7 m away from the participant in both delivery scenarios, the variation in altitude during the drone's descent to deliver the package increased feelings of uncertainty. Participants expressed difficulty in discerning the timing of the drone's actions with the *Land* method. They reported feeling unsafe, primarily due to concerns about potential collisions with humans (e.g., kids) on the ground. Our findings are in parallel with previous studies [4, 6], indicating that humans express discomfort and tend to move away from drones undergoing altitude changes or those positioned at an altitude lower than eye level (e.g., 1 m). To enhance the recipient experience during the interaction, the drone designers are recommended to prioritize the implementation of the cable for package delivery over the drone landing on the ground.

Hovering after the delivery made participants uncertain about the drones' intentions, particularly with the *Land* method. Participants perceived the maneuver as abrupt, leaving them uncertain if the drone intended to perform a follow-up task and sparking curiosity. In line with the findings of [4], participants interpreted hover as the need for visual attention. We suggest restricting the hovering time to minimize uncertainty felt by the recipients. If required for external factors (e.g., stabilizing the drone in strong winds), future research should investigate methods to clearly communicate the rationale for hovering.

5.3 Other Factors Affecting Feelings of Uncertainty

In interviews, participants highlighted the significance of clarity regarding the purpose and intentions of the drone as a means to reduce perceived uncertainty. This aligns with the notion that providing information diminishes surprise and improves the acceptance of drones, as discussed by [49]. Two methods were discussed for providing explicit information: appearance and HMIs. Designers are advised to explore the appearance of delivery drones, drawing inspiration from road vehicles such as using ambulance-inspired designs for medical deliveries and delivery truck aesthetics for grocery transport, to convey their purpose and reduce feelings of uncertainty. Participants recommended the use of HMIs to explicitly communicate delivery intentions. The suggested HMIs varied based on the type of information, ranging from lights and speakers on the drone for real-time delivery actions to textual alerts on mobile phones for drone's arrival, and user role expectations. In cases where it is difficult to execute an "ideal" approach trajectory, HMIs become increasingly vital to inform on the alternative approach trajectory and reduce ambiguity. Previous research on social drones has attempted to explore the use of HMIs like a display attached to the drone to communicate emotions [21], sound to navigate a visually challenged recipient [2], and these efforts were perceived to be beneficial. The intentions of social drones, such as emotional engagement, differ significantly from those of delivery drones, which prioritize quick package transport. Consequently, recipients' preferences for information seeking also differ. For example, none of the participants expressed interest in the emotional state of a drone. Instead, they sought information about the actions of the drone, consistent with the findings of the indoor study by [52]. Future research should carefully consider the differences in purpose, while building upon the existing knowledge on social drones, when investigating interfaces designed to communicate the intentions of delivery drones, aiming to reduce perceived uncertainty for recipients.

5.4 Implications for Practice and for Drones beyond the Delivery Purpose

Delivery companies can improve user trust in their drones by adopting a curved approach, using a cable for delivery, and avoiding post-delivery hovering. Unlike current models from delivery companies like Matternet, Wing, and Zipline, which have distinct designs and no HMIs on board, delivery drones should adopt a consistent aesthetic principle and incorporate HMIs to improve user interaction and certainty. In order to uphold their branding distinctiveness, delivery companies might consider designing package aesthetics to mirror their branding.

Further investigation is required to understand the relevance of our observations towards social drones flying close to humans. Our findings are in contrast with [60], where participants maintained a smaller lateral distance from a drone flying at a height of 1.2 m compared to 1.8 m from the ground and were comfortable allowing the drone within their personal space (less than 1.2 m lateral distance). The difference in use cases (social vs. delivery), and the associated expectations humans may have, could influence how humans perceive intentions and maintain a comfortable distance from the drone.

5.5 Considerations and Limitations

While participants found the VR experience and the virtual drone model compelling, the study had limitations in simulating public space dynamics, such as weather conditions, environmental noise, and the presence of other agents. Additionally, real-world factors like wind gusts from propellers and the risk of injury, which could increase user's perceived uncertainty, were not accounted for. These variables were controlled to minimize random events and ensure meaningful conclusions, but simulating such factors in VR remains challenging. This highlights the need for validation through field experiments. However, current regulations prohibit delivery drones (>500 g) from flying near humans, requiring a horizontal distance of at least 50 m from people [40]. If regulations change, future research should aim to validate these findings with real-world field experiments on approach trajectories and delivery methods.

Before the experiment, participants received detailed briefings on their roles and the drone's purpose, which helped alleviate potential ambiguity and feelings of uncertainty. However, in real-world scenarios, uninformed users may be at risk due to their unfamiliarity with safety protocols. These individuals may also need to transition between different roles [3, 50] and manage associated expectations. For instance, a pedestrian may need to understand safety protocols and their role when transitioning from a bystander to a recipient while receiving a medical package and assisting a victim. A lack of clarity on roles and safety protocols could result in feelings of uncertainty. Hence, future research should focus on exploring effective methods to clearly and unambiguously communicate safety protocols and user role expectations, thereby minimizing feelings of uncertainty.

Our study examined the effect of two types of approach trajectories and delivery methods, taking into account sample size and statistical power. Bevins and Duncan [4] investigated 20 trajectories for social drones using free-response and forced-choice testing with participants, expanding the exploration of flying behavior to enhance further understanding of social drone design and evaluation. Similarly, future research should explore various approach trajectories and delivery methods for delivery drones through free-response, sketching, and interview methods, followed by testing with larger sample sizes.

Participants were instructed that the drone approaches from the front in all scenarios, aligning with preferences noted in [59]. It is crucial to recognize that drones might approach from various directions, posing a challenge in their identification within an urban environment. Wojciechowska et al. [59] observed discomfort and anxiety among participants when drones approached from the rear, possibly linked to perceived uncertainty [18]. Future research should delve into HMIs for effectively communicating directional information to recipients.

In this study, one-to-one interactions were tested between the drone and the participants. In a busy urban environment, where multiple individuals may be present, visual or auditory distractions from other elements in the environment can lead to other types of uncertainties regarding interaction protocols. Future research should delve deeper into the impact of approach trajectories and delivery methods in scenarios involving multiple individuals, additional distractors, and congested environments.

6 Conclusion

The current VR study investigated how the aerial paths and delivery methods of a delivery drone affect the uncertainty felt by recipients on the ground. Addressing this is vital for establishing a safe and natural HDI, expediting the introduction of delivery drones in public spaces, and potentially saving human lives. The study revealed that recipients perceived curved paths as natural, safe, certain, trustful, and predictable, contrasting with feelings of uncertainty and unsafety when observing orthogonal paths that required them to look up during the descent. In contrast to attempting landing delivery, hovering above eye-level (i.e., 7 m above ground) and utilizing a cable for delivery reduced feelings of uncertainty and instilled feelings of safety and trust. It is advisable to approach recipients with a curved path and employ a cable for delivery to mitigate perceived uncertainty and promote feelings of safety and trust. Drones should avoid hovering near humans, especially after attempting a landing delivery, to prevent ambiguity regarding drone intentions. Additionally, clear and explicit communication of drone intentions was found to reduce feelings of uncertainty in the interaction. Therefore, future research is recommended to explore design aesthetics and HMIs for communicating drone intentions.

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