AI & SOCIETY
https://doi.org/10.1007/s00146-026-02903-3

OPEN FORUM

Unpacking the message: visual cues to reduce bystander uncertainty about delivery drones in public spaces

Shiva Nischal Lingam[1,2] · **Sebastiaan Martinus Petermeijer**[1] · **Mohammad Obaid**[3,4] · **Marieke Martens**[5,6]

Received: 7 August 2025 / Accepted: 28 January 2026

Abstract

As drones are deployed in public spaces for tasks such as package delivery, drones will encounter the public as bystanders passing by. The distinctive character of bystanders is that they are not the package recipients, so they lack prior information about the drone. Clear communication of drone intentions is essential to reduce uncertainty and improve public safety and trust. Limited research, however, has examined how a drone's communication strategies affect bystanders. This online questionnaire study investigated how a drone's visual cues affect bystanders' uncertainty about a drone's intentions. Participants ($N = 150$) viewed software simulated scenarios of drones delivering packages either by landing or by cable drop, each with or without visual interfaces (on-board lights, on-board display, or ground projection). Participants rated the scenarios for uncertainty, convincingness, predictability, understandability, and trust, and provided qualitative feedback through textual comments. Results illustrate that explicit communication improves bystanders' ability to predict drone actions and influence bystanders' intentions. While lights posed challenges with visual clarity, displays were effective for conveying drone movements, and projections were most preferred for indicating landing locations and safety zones. We recommend adapting interfaces, particularly ground projection, to provide instructions to bystanders on how to act (e.g., whether or not to cross) during drone operations. Our study contributes to the introduction of safe and trustworthy drones in public spaces.

Keywords Drones · Human–robot interaction · Uncertainty · Public · Delivery application · Human–machine interfaces

1 Introduction

Drones are increasingly being integrated into daily life, particularly in the context of package delivery (Dutta 2024). The advancements in Artificial Intelligence (AI) have enabled drones to navigate to drop-off locations, avoid obstacles, and deliver packages with minimal human intervention (Nunkoo et al. 2024). This emerging trend has prompted discussions surrounding the economic, environmental, and societal benefits of delivery drones, as well as their potential for large-scale global adoption (Zeng et al. 2020). Global research and industry experts suggest that delivery will emerge as one of the primary Human–Drone Interaction (HDI) applications in public spaces over the next decade (Lingam et al. 2025a), highlighting the growing significance in HDI (Herdel et al. 2022). As drones begin to operate in public spaces to deliver packages, they encounter public users who are novice in two primary roles: recipients, who have requested the package delivery, and bystanders, who are not customers but present in the vicinity (Lingam et al. 2025c). Bystanders are likely to experience confusion (Kramer et al. 2025) and uncertainty

✉ Shiva Nischal Lingam
Nischal.Lingam@nlr.nl

Sebastiaan Martinus Petermeijer
Bastiaan.Petermeijer@nlr.nl

Mohammad Obaid
mobaid@chalmers.se

Marieke Martens
m.h.martens@tue.nl

[1] Royal Netherlands Aerospace Center, Amsterdam, Netherlands

[2] Eindhoven University of Technology, Eindhoven, Netherlands

[3] Chalmers University of Technology, Gothenburg, Sweden

[4] University of Gothenburg, Gothenburg, Sweden

[5] Eindhoven University of Technology, Eindhoven, Netherlands

[6] TNO, Helmond, Netherlands

about the drone's intentions (Lingam et al. 2025c). Feelings of uncertainty (referred to as uncertainty henceforth) will arise from a lack of understanding of drone intentions, leading to interaction breakdowns, reduced trust and safety concerns (Lingam et al. 2025b, c).

A possible approach to reducing uncertainty in HDI is to clearly communicate the drone's intentions, which has potential to affect human behavior and improve trust, usability, and public acceptance (Fink et al. 2023; Lingam et al. 2025a, b, d; Obaid et al. 2015; Shapira and Cauchard 2022). Research in Human–Robot Interaction (HRI) has examined motion-based cues (Bevins and Duncan 2021), as well as visual interfaces including LEDs, displays, and projection technologies (Hetherington et al. 2021; Obaid et al. 2015; Szafir et al. 2015). Much of the prior work on visual interfaces has focused on communicating robot intentions at ground level or in lateral directions, with comparatively little attention to the context of delivery drones. When operating in public spaces, delivery drones need to move vertically, for example, when descending to drop-off a package. During the descent, delivery methods could affect uncertainty of the users. For example, Lingam et al. (2025b) found that a drone descending to the ground raised higher uncertainty than a drone hovering above eye level and lowering the package via a cable. During these delivery operations, it remains unclear how drones should communicate with bystanders to reduce uncertainty. Existing empirical studies on HDI involving delivery drones (Lingam et al. 2025b; Sanfridsson et al. 2019; Zègre-Hemsey et al. 2020) have primarily investigated the recipient's perspective, with limited consideration to the bystander's role. Bystanders, who potentially represent a majority of the public, are likely to encounter robots (e.g., drones) more often than recipients in public spaces (Rosenthal-von Der Pütten et al. 2020). In contrast to recipients, bystanders are likely to experience greater uncertainty about the delivery drone's intentions due to diverse factors (see Lingam et al. 2025c). This raises the need to develop cues to address uncertainty for the bystanders during the delivery drone operations.

As drones begin operating in public spaces and moving vertically during delivery operations, their intentions shift across interaction stages (Lingam et al. 2025c). A lack of clarity regarding drone intentions may increase bystanders' uncertainty and reduce trust in drones. A research gap remains on how to effectively represent the intentions of delivery drones and communicate transitions between operational stages to bystanders, in ways that reduce uncertainty and improve trust in drone technologies.

Motivated by the above gap, our study investigated the possibilities for reducing bystander uncertainty using different delivery methods and visual interfaces to communicate a drone's intentions. To assess bystanders' uncertainty in response to the visual cues, an online questionnaire incorporating video-based scenarios was conducted. This study contributes to the field of HDI and HRI by investigating how visually communicated drone intentions during delivery operations influence bystanders' uncertainty, trust, and behavioral intentions. In addition, the study identifies bystander needs and concerns that extend beyond intention communication and provides recommendations for future research on drone services in public environments.

2 Background

2.1 Delivery drones and human interactions

Drones will interact with humans, particularly during the final delivery stage, such as when descending in a public space to drop-off a package and then take-off (Lingam et al. 2025b, c). Previous experimental studies in HDI related to delivery drones have predominantly focused on recipient roles (Lingam et al. 2025b; Sanfridsson et al. 2019; Zègre-Hemsey et al. 2020). A virtual reality study (Lingam et al. 2025b) investigated how flying behavior affects recipient uncertainty. The authors found that recipients felt less uncertain with curved flight paths compared to straight flights. Field studies (Sanfridsson et al. 2019; Zègre-Hemsey et al. 2020) explored recipient experiences with delivery drones, noting the ease of interaction. However, the aforementioned studies offer limited empirical insights into the role of bystanders during delivery operations.

Previous HRI research has emphasized the importance of considering bystander perspectives in the design of interactions with robots, such as for delivery tasks, to ensure safety and improve public acceptance (Nielsen et al. 2023; Pelikan et al. 2024; Puig-Pey et al. 2023). Drone interactions with bystanders may take many forms. For example, bystanders could be neighbors of recipients (Duncan et al. 2018), individuals assisting a medical drone in locating the delivery address of the recipient (Krämer et al. 2025), people seeking assistance from a drone during emergencies such as flooding (Brock et al. 2018), or people in the vicinity of a fire incident (Khan and Neustaedter 2019).

During drone deliveries in public environments, both bystanders and recipients may share the same space, yet their roles remain distinct. While recipients interact by retrieving their package, bystanders might be unaware of the drone's presence and purpose (Krämer et al. 2025; Lingam et al. 2025a). The bystanders might lack familiarity and understanding of a drone's intentions (Duncan et al. 2018; Herdel et al. 2022). This can lead to confusion (Krämer et al. 2025), uncertainty about the drone's intentions (Lingam et al. 2025a), reduce trust, and potentially create feelings of unsafety when being in the drone's vicinity (Lingam et al. 2025b). Furthermore, interaction challenges and acceptance issues may arise (Herdel et al. 2022). Boll et al. (2019) suggested that drones should be designed with consideration for bystander perspectives and reduce uncertainty by designing drones to avoid surprise or anxiety-inducing behavior. There is a need for developing and evaluating strategies from the perspective of bystanders to reduce uncertainty.

2.2 Feelings of uncertainty in HRI

Uncertainty can negatively impact decision-making (Lindley 2014) and shape trust in automated systems (Lee and See 2004). Managing uncertainty is considered a significant challenge when integrating drones into public spaces (Lingam et al. 2025a). Previous HDI research (Lingam et al. 2025b) described uncertainty in HDI as "a state of doubt experienced by humans when interactions with drones deviate from the expected, leading to a loss of understanding of the drone's intentions or its next actions." In an interview and focus group study (Lingam et al. 2025c), the results show that bystanders imagined to experience higher levels of uncertainty with delivery drones than recipients, making it crucial to address bystanders' uncertainty. Various factors influence uncertainty in HRI, including communication cues (Lingam et al. 2025c), the type of robot, and the information required by the user (Hedayati et al. 2021). Such uncertainties may give rise to safety concerns. For example, Lingam et al. (2025b) reported that participants felt unsafe, fearing a potential crash or a package dropping on them, when a drone descended into a public space and its intentions were not communicated clearly. Prior work (Lingam et al. 2025c) found that when bystanders are uncertain about a drone's intentions, safety concerns arise, with bystanders noting that uncertainty might lead them to interfere with the delivery process. This raises the need to address uncertainty. One possible approach is to design drones with clear communication mechanisms that convey the drone's intentions (Boll et al. 2019; Jane et al. 2017; Lingam et al. 2025a, b).

Uncertainty has previously been measured in HRI research using Likert-scale questionnaires (Franssen et al. 2024; Lingam et al. 2025b; Windschitl and Wells 1996). Although Likert-scale measures of uncertainty capture feelings of hesitation, examining related human factors, such as understandability, predictability, trust, and convincingness, provides deeper insight into how designing for reduced uncertainty influences bystander perception and intentions in HDI. Understandability and predictability are central to how uncertainty is defined in HDI (Lingam et al. 2025a) and reflect users' ability to interpret a robot's (e.g., drone's) actions and anticipate its next steps (Dragan et al. 2013). Higher levels of understandability and predictability are associated with lower levels of uncertainty. For example, Lingam et al. (2025b) found that recipients reported lower uncertainty for the cable-drop delivery method, which they rated as more understandable and predictable than a direct landing method. Trust is essential for understanding how individuals respond to situations marked by uncertainty (Lee and See 2004). Drone cues that reduce uncertainty levels are associated with higher trust levels (Lingam et al. 2025b). Convincingness (of cues) offers insights into human decision-making and actions during HRI (Herse et al. 2018). For instance, designing drone cues for reduced uncertainty may convince bystanders to feel certain in their intentions (e.g., crossing the drop-off spot). It is therefore reasonable to aim to design drone cues that reduce uncertainty, as such cues have the potential to improve the clarity and predictability of drone actions and enable bystanders to act with certainty and trust during HDI.

2.3 Need and cues to communicate drone's intentions

Users in a prior study (Lingam et al. 2025c) reported challenges in interpreting current delivery drone designs (e.g., Wing and Amazon) in public spaces and noted that these designs do not adequately communicate the drones' intentions. Prior research has highlighted the necessity of communicating the drone's intentions, such as directional cues, drone state, and landing location, to reduce uncertainty and improve trust (Lingam et al. 2025c) and user experience (Sanfridsson et al. 2019; Zègre-Hemsey et al. 2020). Various communication cues of a drone, including movement and Human–Machine Interfaces (referred to as 'interfaces'), were explored (Bevins and Duncan 2021; Lingam et al. 2025b; Obaid et al. 2015). For delivery drones, the delivery method acts as an implicit cue for drone intentions. A descending drone signals an imminent landing (Bevins and Duncan 2021), whereas hovering with a cable-suspended package suggests an aerial drop-off, as employed by delivery operators (Shankland 2023; Wing 2025). Delivery methods, such as ground landing versus aerial cable drop-off, can influence trust, perceived safety, and uncertainty (Lingam et al. 2025b). The interfaces are required to clarify the timing and location of package release (Lingam et al. 2025b).

Previous studies have investigated the use of visual and auditory interfaces to explicitly convey intent of drones (Bretin et al. 2025; Herdel et al. 2021, 2025; Obaid et al. 2015; Szafir et al. 2015; Yeh et al. 2017). Bretin et al. (2025), Herdel et al. (2021, 2025), and Yeh et al. (2017) investigated the use of on-board displays to convey emotions, to improve recipient engagement with drones and their acceptance. Furthermore, recipients have been shown to feel more comfortable and to approach more closely when a drone displays emotions, such as a smiling face (Bretin et al. 2025; Yeh et al. 2017), or when the drone signals inattentiveness by averting its 'eye' gaze (Bretin et al. 2025). Szafir et al. (2015) found that LEDs blinking in a manner similar to automobile turn indicators improved recipients' ability to anticipate a drone's directional changes (i.e., left or right). In an online study, Obaid et al. (2015) found that drones using projected light and audio cues prompted recipients to dispose of waste in public spaces. However, participants found the use of multiple colors ambiguous for conveying drone intentions. The aforementioned studies on drones primarily focused on ground-level or lateral communication with recipients.

2.4 Research gap and aim

As drones enter public spaces for deliveries and operate in vertical spaces, their intentions shift across interaction stages (Lingam et al. 2025c). For example, drones descend while dropping off a package and ascend to take-off. Bystanders in the vicinity of a delivery drone often have limited insight into the drone's dynamic intentions, goals, or purpose (Krämer et al. 2025; Lingam et al. 2025c), and may be unsure how to respond or behave around the drones (Krämer et al. 2025). This can generate uncertainty, not only in interpreting the drone's behavior, but also in feeling safe around the drone (Bhat and Zhao 2022), and in determining an appropriate response, particularly when needing to pass through the space directly beneath it. A possibility to address such an uncertainty is to use visual cues to communicate drone intentions with the bystanders. There is a lack of empirical research examining the effects of visual cues on bystanders' uncertainty about intentions of delivery drones operating in public spaces.

To address the above gap, our research aims to answer the question: *How do visual cues, in terms of delivery methods and visual interfaces, affect bystanders' uncertainty during drone delivery in public spaces?* We investigated two delivery methods: (1) a drone that lands to deliver the package, and (2) a drone that hovers above eye level and releases the package using a cable. The visual interfaces evaluated include: (a) a display mounted on the drone, (b) ambient lights attached to the drone, and (c) projection on the ground. Delivery methods and visual interfaces are selected based on the expert and user recommendations from prior studies (Lingam et al. 2025a, b, c). The study focuses on the drop-off and take-off stages of the delivery operation, each preceded by a preparatory stage to ensure stabilization and operational safety (Lingam et al. 2025b).

3 Methods

Participants took part in an online video study using a within-participant design, in which they viewed software generated videos of a specific scenario with a drone. To understand uncertainty, participants rated each video according to several criteria. The visual interfaces presented in the videos were adapted from a previous study on visual interfaces designed for delivery drones (Lingam et al. 2025d), as described below.

3.1 Visual interfaces for the online study

The current study adapted visual interface concepts from a previous design study (Lingam et al. 2025d). These concepts were developed by a professional designer based on input obtained from a series of focus groups with seven participants. They were asked to imagine a drone delivering a package in a park and to generate ideas for three types of interfaces (Display and Lights on the drone, and Projection on the ground) to communicate three delivery intentions: package drop-off, take-off, and preparation for drop-off or take-off. From the six resulting concepts, three were selected for this study—one from each interface category: Directional Display (hereafter Display), Indicator Lights (hereafter Lights), and Helipad Projection (hereafter Projection). These concepts were chosen to maintain diversity in interface types and to support intuitive interpretation based on familiar mental models, such as elevator displays, vehicle indicators, and helipads. The interface concepts are explained below.

1. Display: A front-facing display on the drone presented animated (up/down) arrows to indicate vertical movement, drawing inspiration from elevator indicators and prior studies on directional cues for robotic intent communication (Hetherington et al. 2021). The arrows animated in the direction of movement during the drop-off and take-off stages, and remained stationary during the preparation stage.
2. Lights: Two vertically aligned LED lights mounted on the drone's front conveyed the direction of the package movement during drop-off and take-off stages. The lower light blinked when the package was descending, the upper one blinked during ascent, and both blinked during the preparation stages. This cue design was inspired by the existing turn indicators on motor vehicles (Hetherington et al. 2021).
3. Projection: Inspired by helipad designs, this interface projected a visual landing marker on the ground. An "H" symbol (as used on the landing platforms of helicopters) indicated the drop-off zone, surrounded by a circular safety boundary with a fixed radius. The "H" blinked during the drop-off stage, while the circle flashed during take-off, indicating the drone's drop-off and take-off intentions, respectively. Both elements (i.e., "H" and circle) remained static during the preparation stage.
4. Baseline: A scenario without any visual interface was used to evaluate the effect of visual interface presence on participant perceptions.

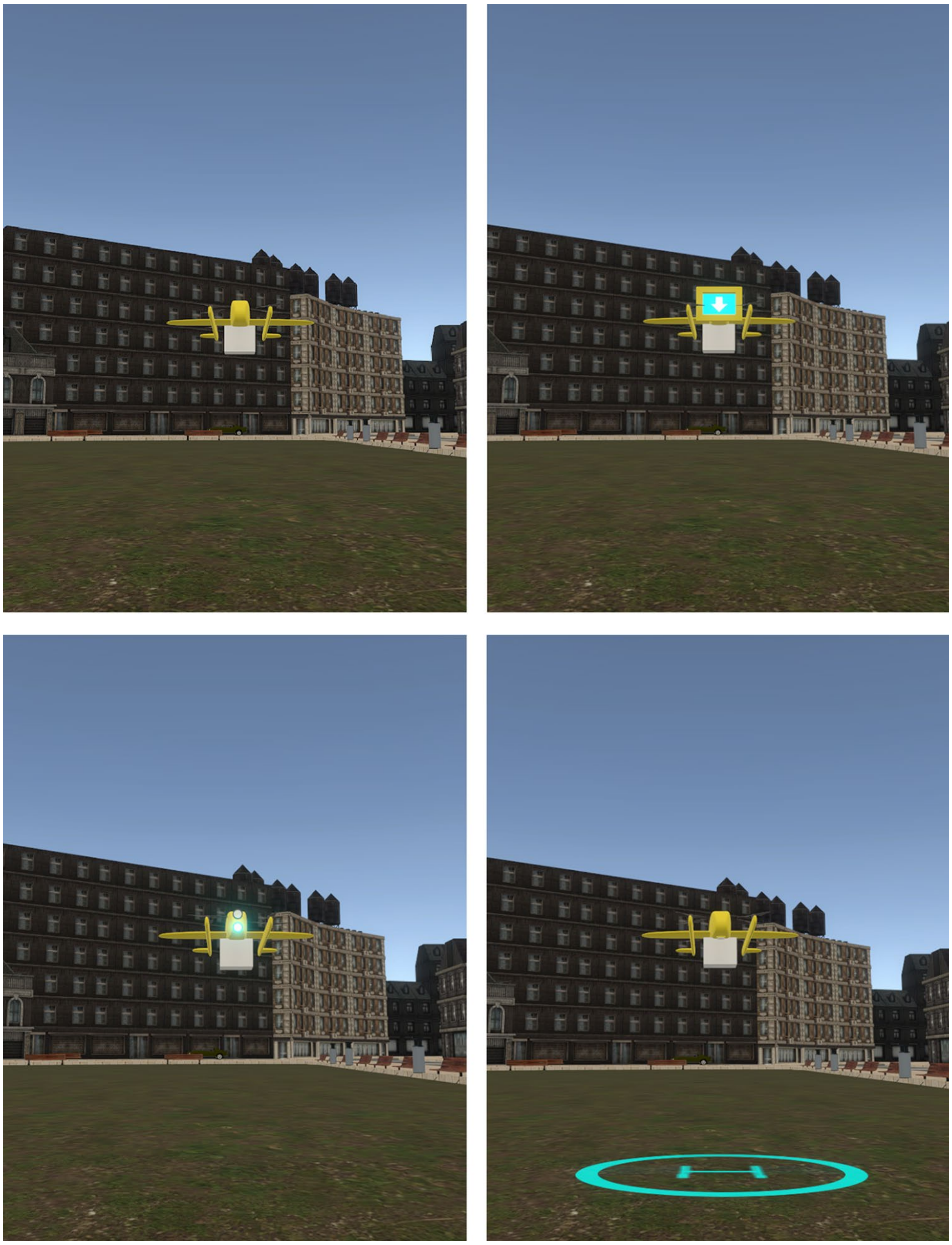

Fig. 1 Illustration of 4 interface conditions, namely Baseline (top-left), Display (top-right), Lights (bottom-left), and Projection (bottom-right) when the drone is landing on the ground to drop-off the package

Figures 1 and 2 illustrate the four interface concepts for a drone landing on the ground and for a drone hovering and lowering the package via a cable, respectively.

3.2 Online questionnaire study

The online questionnaire was administered in English using Qualtrics (https://www.qualtrics.com/). The following sections detail part of the video stimuli, measures used in the questionnaire, procedures, participant characteristics, and data analysis methods.

3.2.1 Video stimuli and environment

A total of 8 videos were developed to illustrate a drone carrying out delivery tasks within a simulated public park setting. The propeller noise was synchronized with the drone movements to achieve realistic replication. The virtual environment and drone model (dimensions: 1.3 m × 1.0 m × 0.4 m) were adapted from prior VR research on HDI with delivery drones in a public park (Lingam et al. 2025b).

The study employed two independent variables: interface, with four conditions (Baseline, Display, Lights, and Projection), and delivery method, featuring two modes (Cable and Land). In each scenario, the drone began by descending to

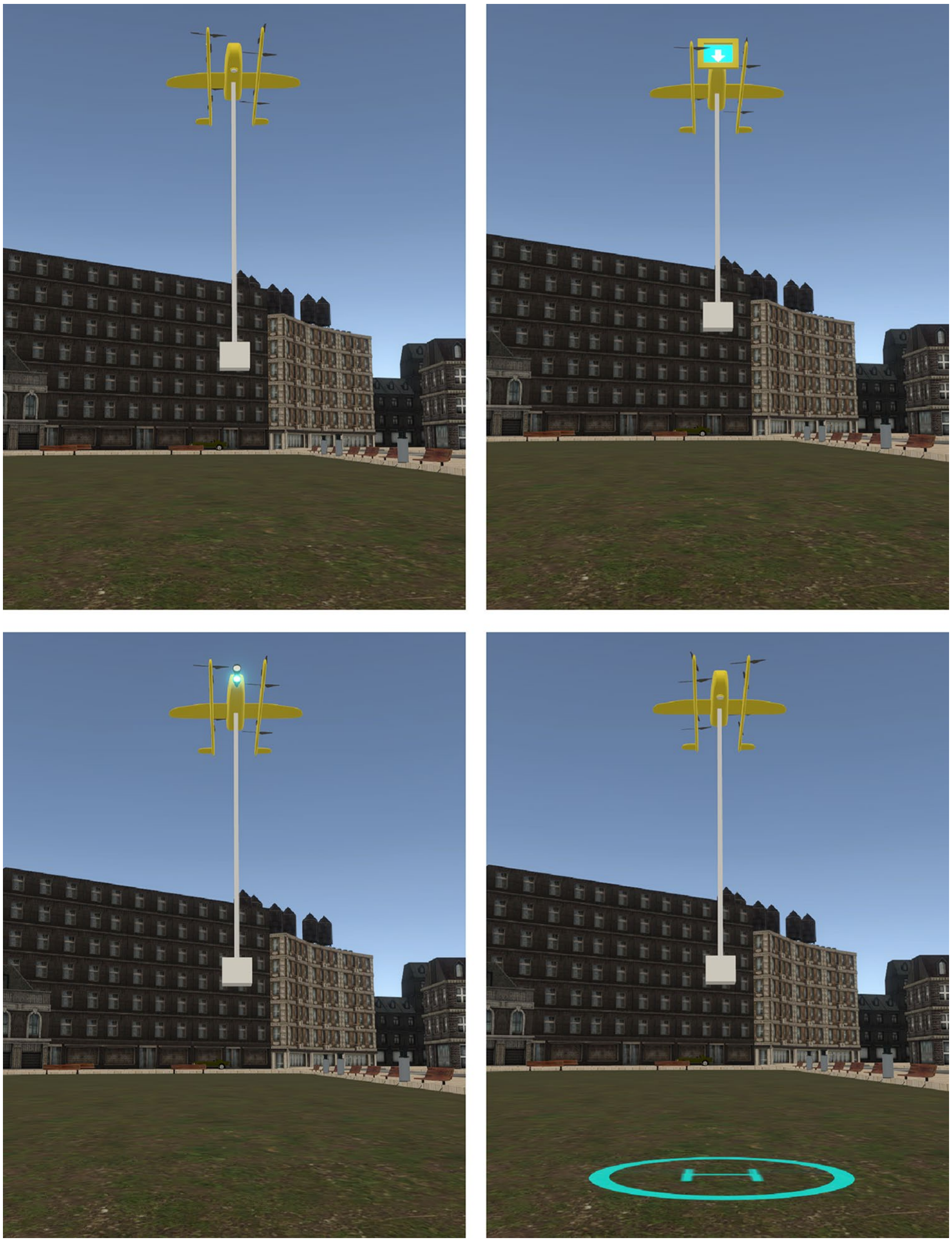

Fig. 2 Illustration of 4 interface conditions, namely Baseline (top-left), Display (top-right), Lights (bottom-left), and Projection (bottom-right) when the drone is hovering and using a cable to drop-off the package

a height of 7 m and hovering (Lingam et al. 2025b). This behavior signaled the drone's intention to prepare for delivery and to scan the surroundings for a safe drop-off (Lingam et al. 2025b).

Following the preparation stage, the drone performed the package drop-off either by descending and placing the package on the ground (Land) or by hovering and lowering the package via a rope (Cable). After the drop-off stage, the drone signaled readiness to depart by activating its propellers while on the ground (Land) or by remaining in hover (Cable) and scanning the surroundings for a safe departure. During the take-off stage, the drone either ascended (Land) or retracted the rope (Cable) before lifting off and exiting the area. The preparation stage lasted 5 s, whereas the drop-off and take-off stages lasted 10 s each. The total duration of each video is 35 s. The duration of each stage was adjusted based on feedback from pilot studies.

3.2.2 Procedure

The online study began with an overview of the study objective. Participants were recruited through the Prolific platform (https://www.prolific.com/), with eligibility criteria including at least 100 previously approved submissions, an approval rate of 97% or higher, native proficiency in English, and residency in the United States (Fartook et al.

2025; Herdel et al. 2025). The study context involved a brief introduction to the concept of delivery drones operating in a public park, followed by a role-specific briefing adapted from an interview and focus group study on delivery drones (Lingam et al. 2025c). Participants were instructed to envision themselves in the role of a bystander: "Imagine you are in a public park, and you hear a distant hum that gradually grows louder. You then see a drone descending nearby to deliver a package ordered by someone else. Although you weren't expecting it, you become aware of the drone's presence in your vicinity." Participants were then informed that drones may use visual interfaces and delivery mechanisms to communicate their intentions. Participants were informed about delivery stages and the use of lights or signals to convey drone intentions, but specific meanings of visual elements were not explained to promote intuitive interpretation and avoid bias.

Participants signed an informed consent form and completed a demographic questionnaire that included items on age and gender. They also reported their prior experience with drones. Each questionnaire page featured a video stimulus followed by assessment questions based on the measures detailed in the next section. To minimize order effects, the presentation order of questionnaire pages was randomized. At the end of the study, participants ranked the visual cues in order of preference. Reliability check questions were incorporated to assess participants' contextual understanding and attention (Dey et al. 2020). The entire experiment took approximately 30 min, with participants receiving £4.25 as compensation. The study method was approved by the Ethical Review Board of Eindhoven University of Technology.

3.2.3 Measures

The study employed a combination of quantitative and qualitative measures. After viewing each video, participants evaluated the corresponding visual cue using a series of questions (see Table 1) adapted from prior HRI research on uncertainty (Lingam et al. 2025b), understandability, predictability, trust (Körber 2018; Lingam et al. 2025b), and convincingness (Bazilinskyy et al. 2020; Tabone et al. 2023). Participants responded to each item using a seven-point Likert scale (1 = strongly disagree to 7 = strongly agree).

Following the Likert-scale items, participants were shown images representing different stages of the delivery process and asked to indicate the stage at which they would feel certain approaching the drop-off spot before crossing (referred to as participant crossing intention). Response options included: 'scanning before drop-off', 'drop-off', 'scanning before take-off', 'take-off', 'after the drone exits the scene', or 'none of the above'. While the convincingness measure evaluated how effectively the cues captured participants' attention and prompted thoughts of crossing the landing spot, the crossing intention measure complemented by identifying when participants deemed it appropriate to approach the drop-off spot. Additionally, participants were encouraged to elaborate on their evaluations and preferences through open-ended responses after each video.

Participants were presented with images of all eight visual cues at the end of the study. They were asked to rank the cues in order of preference, from 1 (least preferred) to 8 (most preferred) and to provide textual elaborations for the most and least preferred cues.

3.2.4 Participants

A total of 173 individuals responded to the questionnaire. Following the exclusion of 23 participants due to technical difficulties and multiple reliability check failures, the final sample included 150 participants (75 men, 74 women, 1 non-binary). The participants aged between 18 and 64 years ($M = 40.2$, $SD = 11.3$). Nearly all participants ($n = 149$) had encountered drones in some form, either through media or direct observation, with 25 indicating that they owned a drone. Specifically, 142 participants had seen a drone from a distance, 120 had seen one flying nearby, and 41 had piloting experience. Only 8 reported never having seen a drone in real life.

Table 1 Questions on uncertainty, understandability, predictability, trust and convincingness toward the visual cues

Scale	Item
Uncertainty	The cues made me feel uncertain about the drone's action
Understandability	The cues, intended to show the drone's actions, were clear to me
	I was able to understand the drone's actions based on the cues
Predictability	The cues I received acted unpredictably[a]
	It was difficult to identify what the cues would show next about the drone's actions[a]
Trust	I trust the cues to inform me of the drone's actions
	I relied on the cues to inform me of the drone's actions
Convincingness	The cues made me feel certain to approach the drop-off spot (for crossing)

[a] Inverse statement

3.3 Analyses

3.3.1 Quantitative data analysis

The Likert-scale data violated the normality assumption for all the measures: convincingness ($W = 0.9$, $p < 0.001$), predictability ($W = 0.9$, $p < 0.001$), preference ($W = 0.93$, $p < 0.001$), trust ($W = 0.91$, $p < 0.001$), uncertainty ($W = 0.86$, $p < 0.001$), and understandability ($W = 0.89$, $p < 0.001$). The data were analyzed using nonparametric methods. The Likert-scale responses were analyzed using Aligned Rank Transform ANOVA (ART-ANOVA; Wobbrock et al. 2011), a statistical approach previously adopted in HCI and HDI research (Bretin et al. 2025; Villa et al. 2022; Wang et al. 2024). The procedure includes aligning and ranking the data first and then conducting a two-way repeated-measures ANOVA (henceforth referred to as ANOVA) on the transformed values (Wobbrock et al. 2011). Post hoc pairwise comparisons (hereafter referred to as post hoc tests) were then conducted using the extended ART-Contrasts procedure with Bonferroni correction (Elkin et al. 2021). Spearman correlations were conducted to investigate how uncertainty relates to other Likert scales and how these scales can help with the interpretation of uncertainty. The significance level for all statistical tests is $\alpha = 0.05$. Only significant results were reported for the sake of brevity.

The data on participant crossing intention, excluding "none of the above" responses, were analyzed using a Chi-square test to examine the distribution of responses across different delivery stages for diverse visual cues. The dataset comprised 149 and 148 observations for the Cable and Land methods in the Projection, and 147 and 148 observations for the Cable and Land methods in the Baseline, respectively.

3.3.2 Qualitative data analysis

A total of 1,500 textual responses were collected across eight scenarios, as well as from the end-of-questionnaire questions regarding participants' most and least preferred cues. The data were analyzed using reflexive thematic analysis (Braun and Clarke 2022) by the first author to explore participants' subjective perspectives. This approach acknowledges the interpretative role of the researcher and the relevance of domain expertise in HDI. The analysis process was inspired by prior HDI research (Herdel et al. 2021, 2024).

The first author began by familiarizing himself with the data through reading responses and taking notes. Using MaxQDA software (https://www.maxqda.com/), the researcher conducted a bottom-up and inductive coding process, allowing codes (with sub-codes where applicable) to emerge from the data (i.e., participant quotes) without applying pre-existing categories. Themes were developed iteratively, with axial coding employed to identify relationships between codes. Related codes were grouped into themes based on patterns of similarity and difference. Codes and themes were continually reviewed and refined against the original dataset. In total, 15 codes were identified across three themes (see Table 2). A content analysis (White and Marsh 2006) was conducted to quantify the frequency of codes within the final themes. Each time a quote aligned with a specific code, its frequency count was incremented by one, enabling the transformation of qualitative insights into quantifiable data (i.e., count data).

4 Results

4.1 Likert scales

Figure 3 shows mean and standard deviation for all the six measures across the four interface conditions and two delivery methods. Baseline, particularly for the Land method, received higher uncertainty scores and exhibited greater variability compared to the interface conditions. Baseline-Land received lower ratings for understandability, predictability, trust, and convincingness, and higher variance in ratings compared to the interface conditions.

ANOVA was performed to examine the effects of interface and delivery method on the six Likert scales. The interface had significant main effects with large effect sizes across all six measures: uncertainty, $F(3, 149) = 187.15$, $p < 0.001$, $\eta_p^2 = 0.35$; understandability, $F(3, 149) = 242.55$, $p < 0.001$, $\eta_p^2 = 0.41$; predictability, $F(3, 149) = 211.03$, $p < 0.001$, $\eta_p^2 = 0.38$; trust, $F(3, 149) = 218.88$, $p < 0.001$, $\eta_p^2 = 0.39$; convincingness, $F(3, 149) = 165.84$, $p < 0.001$, $\eta_p^2 = 0.32$; and preference, $F(3, 149) = 565.37$, $p < 0.001$, $\eta_p^2 = 0.62$. The delivery method showed a main effect on uncertainty, $F(1, 149) = 14.98$, $p < 0.001$, $\eta_p^2 = 0.01$ and understandability, $F(1, 149) = 3.98$, $p = 0.046$, $\eta_p^2 < 0.01$. However, the effect sizes were small and had no significant impact on the remaining four measures. Interaction effects between interface and delivery method were statistically significant for five measures, but with small effect sizes: uncertainty, $F(3, 149) = 6.35$, $p < 0.001$, $\eta_p^2 = 0.02$; predictability, $F(3, 149) = 5.83$, $p < 0.001$, $\eta_p^2 = 0.02$; and trust, $F(3, 149) = 7.71$, $p < 0.001$, $\eta_p^2 = 0.02$.

Post hoc tests revealed that Baseline received the highest uncertainty ratings and the lowest scores for understandability, predictability, trust, convincingness, and preference compared to the three interfaces. The mean, standard errors, and p values for significant pairs are reported in Fig. 4. Among the interfaces, Lights were associated with significantly higher uncertainty scores and lower understandability, predictability, trust, and convincingness scores than Display. Projection received significantly lower uncertainty

Table 2 Themes corresponding to the codes quantified from the open-ended responses

Themes	Codes	Description with example quotes	Code frequency
Bystander needs for HDI	Crossing behavior	Bystander intention to approach and cross the landing spot (e.g., when to approach/cross the spot)	89
	Attention capture	The need to capture the bystander's attention (e.g., draw awareness)	70
	Drone state awareness	Information on changes in drone behavior (e.g., landing, retracting, preparation stages)	110
	Landing spot	Clarity on landing spot information (e.g., where it was going to drop-off)	21
	Additional information	Desire for additional information beyond the above needs (e.g., drone's presence, progress bar)	50
Effects of cues	Explainability	Clarity of cues in conveying and predicting drone behavior (e.g., clear way for the drone to indicate its actions). Contains sub-codes on cues as clear or not, and predictable or not	597
	Bystander intentions	Influence of cues on bystander decisions or actions (e.g., to approach)	60
	Uncertainty	Uncertainty experienced by bystanders regarding the cues (e.g., blinking light is too confusing)	63
	Perceived safety	Feelings of safety with a given cue during the interaction (e.g., felt unsafe)	136
	Intuitiveness	Ease of understanding and interpreting the cues (e.g., simple, intuitive)	124
	Likeability	Overall likability and comfort associated with the cues (e.g., good, comfort, prefer)	311
Concerns and improvements with cues	Safety	Safety concerns regarding the delivery method (e.g., cable would get stuck, hit someone in face)	85
	Visibility	Concerns about the visibility or clarity of the interface cues (e.g., hard to see from other people's location)	130
	Role transition	Change of bystander role to recipient (e.g., receive the package)	32
	Improvements	Suggestions to further enhance the cues (e.g., combining interfaces)	112

and higher understandability, predictability, and convincingness scores than Lights. Projection was rated as the most preferred interface, followed by Display and Lights, respectively.

Post hoc tests for the delivery methods showed that Land ($M = 3.12$, SE = 0.08) was rated significantly higher in uncertainty than Cable ($M = 2.93$, SE = 0.07), $p < 0.001$. Land ($M = 4.86$, SE = 0.07) received significantly lower understandability scores than Cable ($M = 4.94$, SE = 0.07), $p = 0.046$. For the interaction between interface and delivery method, Baseline–Land ($M = 5.11$, SE = 0.14) received significantly higher uncertainty scores than Baseline–Cable ($M = 4.44$, SE = 0.15), $p = 0.03$. Baseline–Cable ($M = 3.67$, SE = 0.13) was rated significantly higher in predictability than Baseline–Land ($M = 3.09$, SE = 0.12), $p = 0.03$. Similarly, Baseline–Cable ($M = 3.57$, SE = 0.14) received significantly higher trust scores than Baseline–Land ($M = 2.99$, SE = 0.13), $p = 0.02$.

Uncertainty was strongly and negatively correlated with understandability ($r = -0.85$, $p < 0.001$), predictability ($r = -0.87$, $p < 0.001$), trust ($r = -0.78$, $p < 0.001$), and convincingness ($r = -0.76$, $p < 0.001$).

4.2 Participant crossing intention

The proportion of participants indicating their crossing intention significantly differed across delivery stages depending on the interface condition, $\chi^2(12, N = 150) = 61.05$, $p < 0.001$, but not across delivery methods, $\chi^2(4, N = 150) = 5.62$, $p = 0.23$. These findings indicate that the timing of participants' intent to cross the drop-off spot was influenced by the presence of an interface (see Fig. 5). Although most participants indicated an intention to cross after the drone exits the scene, interfaces encouraged earlier crossing intentions compared to the Baseline. The Projection elicited the highest proportion of participants willing to cross before the package drop-off, followed by Display, Lights, and Baseline. During the drone's take-off, more participants indicated the intent to cross for the Display, followed by Lights, Projection, and Baseline. In the Baseline, most participants reported feeling certain to approach only after the drone had exited the scene.

4.3 Textual responses

This section presents the themes and codes identified from the qualitative analysis, supported by quotes. Participant quotes are denoted by 'P' followed by their ID number.

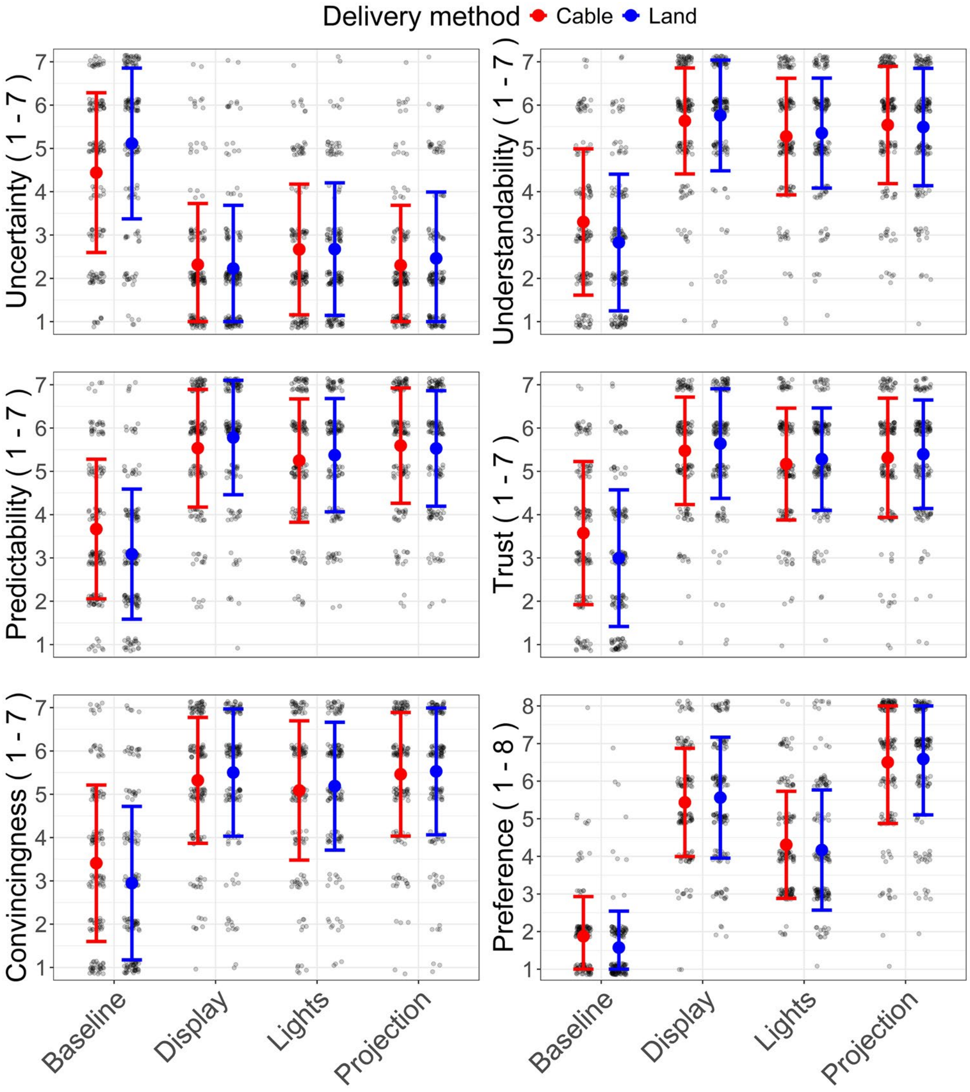

Fig. 3 Mean and standard deviation of uncertainty, understandability, predictability, trust, convincingness, and preference ratings for the eight visual cues, with overlaid individual data points. Likert-scale items ranged from 1 (strongly disagree) to 7 (strongly agree), while preference was assessed using a rank-based scale from 1 (lowest preference) to 8 (highest preference)

4.3.1 Bystander needs for HDI

Participants highlighted the need for clear information regarding landing spot location, when to approach/cross the drop-off spot, how to capture bystander attention, awareness of drone states, and additional information. Drone state awareness (33.3%) was the most frequently mentioned code, followed by crossing behavior (27%), landing spot information (18.2%), additional information (15.1%), and attention capture (6.4%).

4.3.1.1 Drone state awareness Most mentioned the need to raise bystander awareness by clearly communicating different drone states (e.g., drop-off and take-off) and the transitions between these states (e.g., scanning), rather than waiting for clarity about "what the drone is doing until after the package is dropped" (P126). Participants suggested using interfaces to create drone state awareness to reduce uncertainty about the timing of drone actions and improve predictability: "Was it [drone] going to hover for 2 s or 5 s after dropping the package, for example, or just fly away immediately?" (P32).

4.3.1.2 Landing spot information Participants expressed the need to receive information about the drop-off location before the drone initiates the delivery action. The absence of such information made participants feel uncertain about the drone's actions, contributing to anxiety and a sense of lack of safety: "I would be very apprehensive of the drone's actions. I would be unsure of the landing spot and when the drone would exit the scene" (P136).

4.3.1.3 Crossing behavior Participants expressed confusion about deciding when it was safe to approach and cross the drop-off spot. Intentions varied as some preferred to approach before the package was dropped off or before the

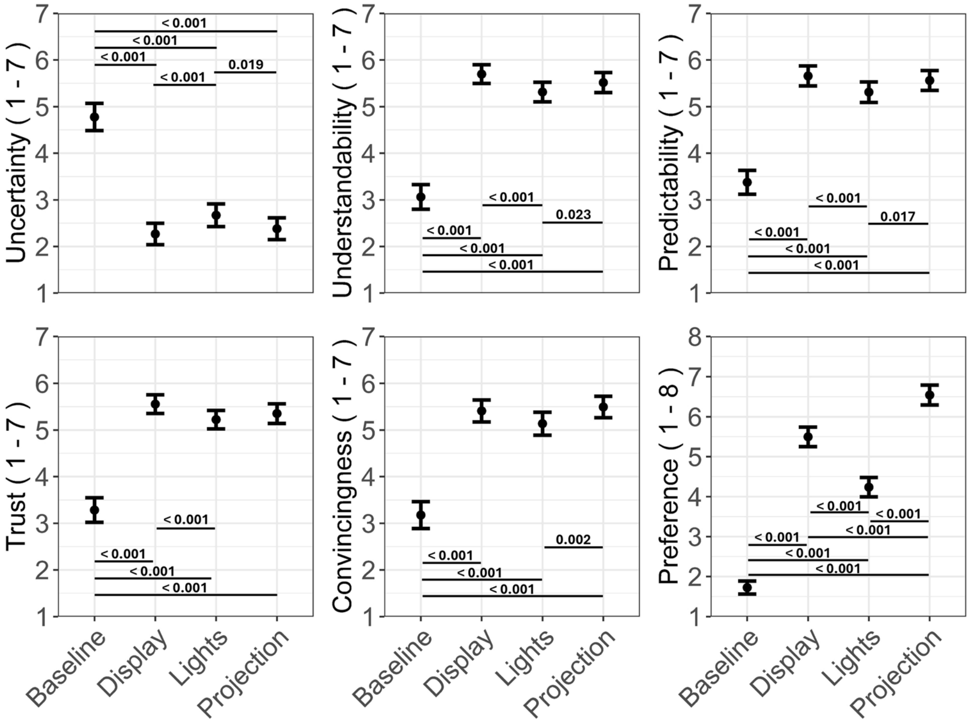

Fig. 4 Mean and error bars of the four interfaces across the six scales: uncertainty, understandability, predictability, trust, convincingness, and preference, combined for the two delivery methods. The Likert-scale measures ranged from 1 (strongly disagree) to 7 (strongly agree), while preference was assessed on a rank-based scale from 1 (lowest preference) to 8 (highest preference). The error bars represent standard errors. Pairwise comparisons with significant *p* values are reported

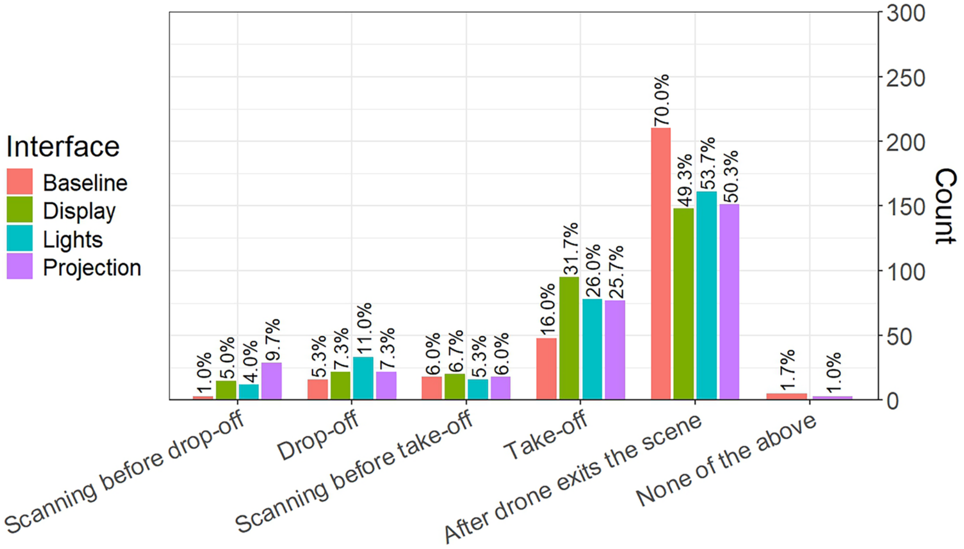

Fig. 5 Proportion of participants indicating the stage at which they felt certain to cross the drop-off spot, shown across the four interface conditions (Baseline, Display, Lights, and Projection)

drone took off, while others felt that it was safer to wait until the drone had exited the scene. Participants highlighted the need to clearly advise on the time to approach or cross for safety: “The danger must be more pronounced after dropping the package to wait for an ‘all clear’ signal or [a] danger signal with a cross (X) symbol.” (P100).

4.3.1.4 Attention capture

As the drone entered the public space from the sky, requiring participants to look upward, participants expressed the necessity to capture their attention. A failure to do so, particularly under poor lighting conditions, posed safety risks. Participants noted that the presence of an interface “makes it easier to spot [the drone]” (P94) and decide “if it was safe [to be in the vicinity of the drone]” (P27).

4.3.1.5 Additional information

Additional needs mentioned by participants included communication of recipient-

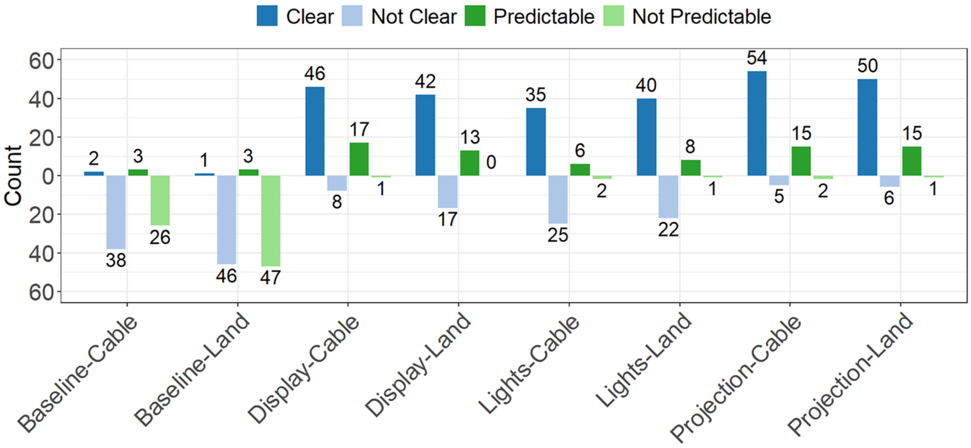

Fig. 6 Frequency of sub-codes, namely clear/not clear and predictable/not predictable, associated with visual cues under the explainability code

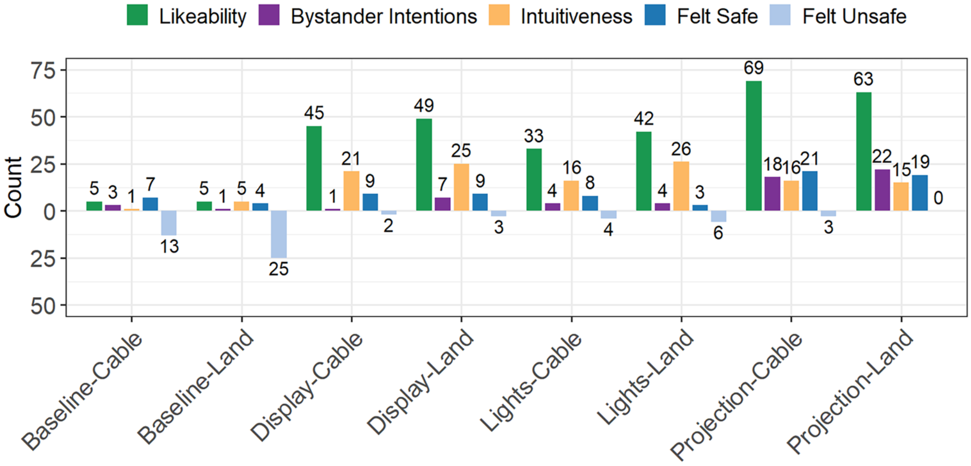

Fig. 7 Frequency of selected codes, namely likeability, bystander intentions, intuitiveness, and perceived safety (i.e., felt safe/unsafe), associated with visual cues

related information such as "who it came for" (P66), verification mechanisms to restrict bystander interaction, and safety warnings such as "extra blinker lights" (P80).

4.3.2 Effects of cues

The results of the content analysis (as described in Sect. 3.3.2) on the effects of the visual cues are presented in Figs. 6 and 7. These figures show that the visual cues influenced participants' perceptions and behavioral intentions during interactions with the delivery drone. Participants reflected on the cues' explainability (Fig. 6), as well as their likeability, intuitiveness, perceived safety, and bystander intentions (Fig. 7).

4.3.2.1 Effects due to the visual interfaces The absence of a visual interface reduced clarity and led to difficulty in trusting the drone: "With no indication of what's going on, it would be hard to trust the drone" (P5). The interfaces were considered important for capturing bystander attention and conveying explicit information, thereby improving the clarity and predictability of the drone's actions. This was observed when compared to the Baseline, where participants frequently cited a lack of clarity and predictability (see Fig. 7). Moreover, the interfaces were perceived as safe and intuitive, and were associated with higher likeability ratings than the Baseline (see Fig. 7).

Projection: Among the three interfaces (see Figs. 6, 7), Projection was frequently associated with greater clarity and predictability of drone actions, as well as higher likeability and perceived safety, followed by Display and Lights. Ground projection conveyed both drone action and safety zone information (via a circular ring) and was reported to require less visual effort than drone-mounted interfaces (i.e., Display and Lights), as participants did not need to look upward. Among the three interfaces, Projection helped participants decide on crossing intention (see Fig. 7) by implying "(…) where to go [or wait] when I am approaching [the spot]" (P39).

Display: Participants found the Display (of arrows) more intuitive than the other two interfaces (see Fig. 7), appreciating the large directional cues for their potential to be easily visible from a distance: "I like the directional cues and the larger screen displaying them. I believe this makes it clear and obvious while also being visible from a further distance" (P86).

Lights: Lights were described as intuitive (see Fig. 7). Participants appreciated the simplicity of two separated LED lights. However, Lights were criticized for lacking clarity compared to the other two interfaces (see Fig. 6). The lack of clarity was associated with distinguishing between the top and bottom LEDs and interpreting the drop-off and take-off intentions: "I think in the real world, it would be super hard to tell which light was blinking" (P52).

4.3.2.2 Effects of delivery methods Figure 6 indicates that participants found the Land method less clear to interpret the drop-off task and more difficult to predict than the Cable method, particularly in the Baseline. The drone's descent directly to the ground, without the use of interfaces, was perceived as "dangerous" (P79) and unsafe (see Fig. 7). The Display of arrows and Lights on the drone was considered more intuitive than in the Cable method (see Fig. 7), as the animated symbols were seen to align with the drone's descending actions rather than those of the package: "The down-pointing arrow could be misconstrued as [drone] landing [rather than for package descent]" (P96). The differentiation between the top and bottom LEDs became more noticeable during descent for the Lights-Land, contributing to higher likeability and intuitiveness than the Lights-Cable (see Fig. 7).

4.3.3 Concerns and improvements with cues

Participants identified several potential concerns regarding the implementation of visual cues in dynamic public spaces. Among the concerns raised, visibility issues related to the interfaces were most frequently mentioned (52.6%), followed by safety concerns regarding the delivery methods (34.4%), and the potential for role transitions from bystander to recipient (13%).

4.3.3.1 Visibility concerns A major concern was the visibility of interfaces in dynamic public environments. Participants noted potential issues such as reduced visibility of the Projection on varying landscapes and light conditions (e.g., effectiveness under "bright daylight" (P50)), limited readability of the Display and Lights from different angles (e.g., "It [lights] is only visible from the front of the drone, which could be problematic for pedestrians at other angles" (P98)), and difficulty viewing drone-mounted cues from different heights and distances. Such visibility concerns were reported to contribute to uncertainty about interpreting drone intentions and deciding when to approach.

4.3.3.2 Safety concerns Participants expressed potential risks associated with both the delivery methods in public spaces. For the Cable method, concerns primarily centered on the weather and wind conditions that could "cause instability" (P140) during the delivery process. This raised uncertainties related to the package safety: "Would it make the package sway and not land properly?" (P11), and "get stuck or swing around" (P56). In contrast, concerns with the Land method focused on safety risks to humans and animals, due to the drone's propellers potentially operating "dangerously close to the ground, people, or animals" (P96). Despite the concerns, some participants highlighted advantages of the Cable method, including "less risk of vandalism" (P46) and safer interactions with bystanders: "The cable avoids having the drone's blades/wings hitting anyone accidentally" (P52).

4.3.3.3 Concerns due to role transitions Although a majority of participants reported an intention to stay away from the drop-off spot, concerns arose when some participants expressed a willingness to approach and retrieve the package. This was particularly observed during the drone's take-off stage when equipped with visual interfaces. This highlights the potential for role ambiguity, where a bystander may unintentionally transition into a recipient role.

4.3.3.4 Improvements to visual cues based on identified concerns Participants suggested improvements for the visual cues to further reduce uncertainty, clarify intent, support crossing decisions, and improve safety of HDI. A key recommendation was to combine interfaces to convey different types of information, while also improving the visibility of the information from various angles. For instance, participants proposed using the Display and Projection together to communicate directional intentions and drop-off location. Another suggestion was to combine Lights [placed around the drone] with Projection: using Lights "to catch the attention of people who are not paying attention" (P111), and using projection to indicate where the package would land and the area to avoid.

5 Discussion

This online study investigated how visual cues can be used to communicate a delivery drone's intentions and reduce bystanders' uncertainty, with the goal of improving trust and safety of drones in public environments. Specifically the research question was: *How do visual cues, in terms of delivery methods (i.e., drone landing and cable drop) and visual interfaces (i.e., display, lights, and projection), affect bystanders' uncertainty during drone delivery in public spaces?* Uncertainty was measured through qualitative feedback and Likert scales on uncertainty, understandability, predictability, trust, and convincingness. A strong negative correlation between uncertainty and the other scales indicates that these measures can be used to understand the implications of uncertainty. The mixed-methods analysis showed that visual interfaces communicating drone intentions significantly reduced uncertainty and also improved understandability, predictability, trust, and the convincingness of the cues, compared to having no interface. Specifically, the quantitative findings showed that the display and projection interfaces significantly reduced uncertainty more than the lights. Among the three interfaces, projection was rated as the most preferred interface. Furthermore, qualitative feedback highlighted the benefits of projection interface and emphasized the need for clear approach cues and visibility concerns with the cues in public spaces.

5.1 Recommending visual interfaces to improve certainty and trust

The use of visual interfaces not only reduced uncertainty about the drone's intentions but also increased trust and made bystanders feel more certain about crossing the drop-off spot compared to conditions without interfaces. When the interfaces clarified what the drone was doing (e.g., drop-off, take-off, and preparation states) and what it would do next, bystanders experienced less ambiguity and expressed higher trust. Without interfaces, however, bystanders felt uncertain and had difficulty interpreting and predicting intentions solely from the delivery method. We suggest the use of visual interfaces to communicate the drone intentions in order to reduce uncertainty and improve bystander trust on delivery drones in public spaces. Below, we discuss the findings for each of the interfaces and provide tailored recommendations.

5.1.1 Use projection to indicate drop-off spot and safety boundary

The helipad-like projection on the ground, which was the most preferred interface, reduced uncertainty about the drone's intentions and improved the understandability and predictability of the drone actions compared to the light-based interface. The qualitative findings further supported this result, with participants describing the projected cues as clear and predictable and reporting that they felt safer around drones equipped with projection cues than those using displays or lights. An explanation is that the helipad-like projection has conveyed not only the drone's drop-off and take-off intentions but also communicated the precise drop-off location and a visible boundary around the drop-off area. This safety boundary helped bystanders feel more certain and supported their decision-making regarding where to cross. The findings add novelty by extending the prior use of projections in HRI, such as to mark garbage pickup zones (Obaid et al. 2015) and to display directional symbols (Hetherington et al. 2021). We recommended the use of projection to clearly indicate drop-off spots and safety zones, helping bystanders feel safe and decide where to cross.

Participants further noted that ground projection lies within the human line of sight, making it easier to capture attention than the drone-mounted cues. The need to visually identify both the robot and its separate interface may divide attention and reduce the intuitive interpretation of the cues (Aleva et al. 2024; Peereboom et al. 2024). This may increase uncertainty in cluttered environments, such as due to the presence of pets, or vegetation, where users must shift their attention between the robot, surrounding elements, and the visual interface. Future research is recommended to examine bystander's gaze behavior and uncertainty when interacting with delivery drones equipped with projection-based interfaces in cluttered public environments.

5.1.2 Use display to signal drone motion and direction

The on-board display reduced uncertainty, improved the understandability and predictability of drone actions, and was associated with higher trust scores than the lights. An explanation, based on the qualitative feedback, is that the directional arrows are found to be the most intuitive among the three interfaces to interpret the drone movements. These findings extend the functional role of displays on drones that conveyed 'emotions' using facial features in the previous HDI studies (Bretin et al. 2025; Herdel et al. 2021, 2025; Yeh et al. 2017).

The predictability and intuitiveness of arrows on the drone were evident especially for the landing method compared to the cable drop method. Participants perceived the arrows to be more suitable for conveying the drone's own motion than the movement of the package. The findings have implications for HRI and aerial manipulation (e.g., drones with arms or grippers). Drone mounted displays are recommended to prioritize communicating the robot's intent rather than the status of the manipulator (e.g., gripper) or carried objects (e.g., packages).

When the drone was taking off, participants expressed an intention to approach the drop-off area upon seeing the animated upward directional arrow, more so than with the projection or light-based interfaces. An explanation is that the upward arrow may have been interpreted as an instruction to approach the drop-off area, similar to the forward directional arrows marked on roads to instruct traffic to drive ahead (Ministry of Infrastructure and Water Management 2025). Future research is recommended to further explore arrow-based designs and to clearly differentiate between cues that communicate the drone's intended motion and cues that instruct bystanders on how to act during each interaction stage. For instance, adding a cross (X) symbol to the animated upward arrow during take-off could clarify that bystanders should not approach.

5.1.3 Use lights to signal direction on a landing drone

The on-board lights were perceived as intuitive due to their similarity to motor-vehicle signaling. However, lights received the highest rating for uncertainty and lowest ratings for understandability and predictability, among the three interfaces. Participants reported that the light cues were not clear, made it difficult to anticipate the drone's actions, and left them feeling less safe and more uncertain when deciding whether to cross the drop-off spot. An explanation, based on the qualitative feedback, is that the participants find it difficult to distinguish between the top and bottom LEDs when drones are positioned higher than eye level. This limited the benefits of familiarity typically associated with light-based signaling as seen for motor vehicles on roads. The issue was particularly evident in the cable drop condition, where the drone hovered above eye level, making it harder and less intuitive to interpret the signals. As the drone descended to land, the lights became more distinguishable and their meaning more intuitive. We recommend using lights on a drone that descends to the ground. Instead of using only two LEDs, future research should investigate employing multiple LEDs animated in the direction of motion (Shin et al. 2024) to improve the interpretability of drone movements, especially in vertical planes.

5.2 Integrate explicit approach cues into the visual interfaces to guide bystander safety

The projection and display interfaces not only reduced uncertainty but also influenced bystanders to express an intention to approach the drone and cross prematurely (i.e., before drop-off or take-off). This aligns with prior work on proxemics around drones, which found that individuals tend to approach closer to drones when they feel comfortable (Yeh et al. 2017). However, HDI research (Bretin et al. 2025; Yeh et al. 2017) has focused primarily on design recommendations that encourage humans to approach drones, with a lack of attention given to communicating when individuals should not approach the drone. Attempts by bystanders to approach the drone during a (delivery) operation raise concerns, including the risk of interrupting the delivery process and the potential for collisions. For example, participants reported an intention to cross the drop-off spot once it was communicated by the drone, while landing. Participants expressed intent to retrieve the package from drones equipped with interfaces. These findings broaden existing discussions on HRI breakdowns in public settings (Nielsen et al. 2023; Pelikan et al. 2024; Yu et al. 2024) by highlighting safety concerns not just for the bystanders, but also for the robot and its carried contents.

Among the three interfaces, the projection interface showed the greatest potential to provide guidance on how to act, as the design of the circular safety boundary was perceived as encouraging bystanders to not enter the boundary. The current design requires further development as some participants expressed an intention to approach the drop-off spot even before the drone had taken off, raising potential safety concerns. Participants expressed the need for explicit cues to guide bystanders on when it is safe or not to cross the drop-off spot. For example, drone designs could project a cross symbol (X) when it is not safe to approach. Future research is recommended to adapt and validate the current projection interface to communicate not only drone intentions and safety boundaries but also instructions on when bystanders should or should not approach the drone or the drop-off area. This has implications for service drones operating for purposes beyond delivery, such as firefighting drones, which must assist firefighters while keeping bystanders at a safe distance from the incident.

5.3 Recommending cable-drop method for delivering packages

Differences were observed between the two delivery methods across uncertainty, understandability, predictability, and trust, particularly when no interfaces were present. An implication of this finding is that, in the absence of interfaces communicating drone intentions, bystanders rely significantly on the delivery method to infer the intentions. The cable-drop method was associated with feelings of safety and certainty, as the drone hovers above human height while releasing the package. The landing approach was perceived as less clear, less predictable, less safe, less trustworthy, and significantly more uncertain than the cable-drop approach. Based on the textual responses, an explanation is that participants are concerned about potential collisions involving a descending drone operating in close proximity to bystanders or animals in public environments (e.g., parks). These findings align with Lingam et al. (2025b) and Bevins and Duncan (2021), who reported that humans feel uncertain around landing drones and often step back when drones change altitude. To reduce uncertainty and improve trust of the bystanders, we recommend that designers implement cable-drop mechanisms allowing the drone to hover above humans rather than descend to the ground when delivering packages in public spaces.

5.4 Addressing practical concerns with visual interfaces and delivery methods

Participants raised practical concerns regarding the visibility and safety of visual cues. Visibility issues are caused by varying lighting conditions, uneven ground surfaces, and proximity to the drone. These issues could affect the readability of information and increase bystander uncertainty. Suggested solutions included using omni-directional or multimodal interfaces (e.g., combining projection with lights attached around the drone) to quickly attract bystander attention, and improve awareness of drone intentions and drop-off locations. Future research should empirically investigate whether the proposed solutions attract bystander attention by examining the gaze behavior when bystanders are interacting with the drone's visual cues.

While the package is being delivered, participants expressed concerns about the stability and safety of the drone and package in strong winds. This may cause the drone to deviate from its planned behavior and reduce trust. Kox et al. (2024, 2025) found that trust can be maintained when behavioral deviations or errors of a robot are communicated transparently. Future research should conduct focus groups to involve bystanders in refining interface designs for clearly communicating intentions of drones under uncertain conditions (e.g., package or drone sway due to strong winds). Next, the research should empirically evaluate the designs while maintaining ecological validity.

5.5 Limitations and considerations

Although video-based online studies provide greater repeatability and experimental control, there could be other factors affecting the bystander perception. For instance, the environmental factors, such as weather, and presence of animals and trees, have been previously discussed to affect human perception and uncertainties (Lingam et al. 2025c). Excluding such factors limits the ecological validity of the findings and reduces the perceived risk for participants (Tabone et al. 2023). This highlights the need to validate the results through real-world field experiments. Current regulations do not allow delivery drones weighing more than 500 g from operating near people, requiring a horizontal distance of at least 50 m (Netherlands Enterprise Agency 2025). Research should continue to explore clear communication methods in HDI, evaluate in simulated environmental conditions, and contribute to improving interaction safety. Such efforts could inform revision of regulations to allow closer interactions with drones in the real-world public spaces.

Potentially due to the regulations (Netherlands Enterprise Agency 2025), among other factors, the current state of bystander-drone interactions is less frequent than the bystander interactions with ground robots such as automated vehicles. We expect the bystander-drone interactions to increase in future when AI and automation advance the drone technologies to safely enter public spaces and potentially interact with bystanders. Beyond the role of bystanders, humans may interact with drones as recipients in public spaces (Lingam et al. 2025b). These are the primary users who typically order packages to be delivered to public locations. Recipients possess prior information (e.g., drone specifications and delivery method) that may affect uncertainty differently compared to bystanders (Lingam et al. 2025c). Future research should complement our research by examining the effect of visual cues on recipients in the context of delivery services.

To ensure experimental control and replicability, the videos were presented from a bystander's viewpoint, with the drone positioned at a fixed distance of 7 m horizontally and descending from a height of 7 m. In real-world settings, however, bystanders may move and place themselves at varying distances or viewing angles. Such changes in proxemic behavior potentially influence uncertainty. For example, a bystander observing a descending drone might feel unsafe and step further away, which in turn could reduce the visibility and clarity of visual interfaces such as LED lights. Future research should examine how bystanders naturally position themselves relative to drones when visual cues are present and how the bystander movements shape their uncertainty about visual cues.

6 Conclusion

This online study investigated how visual cues, such as delivery methods (i.e., cable drop and landing) and interfaces (i.e., lights, display, and projection), communicating a drone's intentions affect bystanders' uncertainty during a delivery process in a public space. Understanding these effects is essential for enabling trustworthy and safe interactions with drones, as bystanders will engage with delivery drones in public environments. Quantitative and qualitative findings suggest that conveying explicit information about drone intentions with visual interfaces reduces uncertainty and improves bystanders' ability to predict drone behavior and decide where to cross with greater certainty and trust. While the placement of lights presents clarity challenges, display of directional arrows is perceived as intuitive and useful for predicting drone motion and direction. Projection of landing location and safety zones is the most preferred, and is appreciated for easily capturing attention without requiring upward gaze. Although intent communication reduces uncertainty, it may encourage premature crossing or package retrieval, raising safety concerns for both bystanders and the drone. We recommend that drone designers use interfaces not only to communicate motion of the drone and drop-off spots in public spaces, but also to instruct bystanders on how to act (e.g., whether or not to cross) during the drone operations. Such efforts have the potential to improve public safety and trust in drones operating in public spaces.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00146-026-02903-3.

Acknowledgements This research was supported by the Dutch Research Council—NWO (Grant Number: NWA.1292.19.298) through the project “Safety Solutions for Autonomous Vehicle Integration in Urban Mobility: Efficient and Reliable Acting in an Uncertain and Unreliable World”. Mohammad Obaid is partially funded by CHAIR at Chalmers University of Technology for the project "AI + Social Drones: Towards Autonomous and Adaptive Social Drones" under the CHAIR X + AI funding. ChatGPT was used to improve the language and grammar of the text but not to create content.

Author contribution Conceptualisation: S.N.L., S.M.P., M.O., M.M.; Data curation: S.N.L.; Formal analysis and software: S.N.L.; Funding acquisition: S.M.P., M.O., M.M.; Investigation: S.N.L.; Methodology: S.N.L., S.M.P., M.O., M.M.; Resources and Supervision: S.M.P., M.O., M.M.; Validation and Visualisation: S.N.L.; Writing—original draft: S.N.L.; Writing—review and editing: S.N.L., S.M.P., M.O., M.M.

Data availability The video scenarios presented to participants and the data supporting the online study’s findings are available in the supplementary material.

Declarations

Conflict of interest The authors declare no competing interests.

References

Aleva TK, Tabone W, Dodou D, de Winter JC (2024) Augmented reality for supporting the interaction between pedestrians and automated vehicles: an experimental outdoor study. Front Robot AI 11:1–14. https://doi.org/10.3389/frobt.2024.1324060

Bazilinskyy P, Dodou D, De Winter J (2020) External human–machine interfaces: which of 729 colors is best for signaling ‘Please (do not) cross’?. In: 2020 IEEE international conference on systems, man, and cybernetics (SMC), pp 3721–3728. https://doi.org/10.1109/SMC42975.2020.9282998

Bevins A, Duncan, BA (2021) Aerial flight paths for communication: how participants perceive and intend to respond to drone movements. In: Proceedings of the 2021 ACM/IEEE international conference on human–robot interaction, pp 16–23. https://doi.org/10.1145/3434073.3444645

Bhat P, Zhao Y (2022) "I was confused by it; it was confused by me:" exploring the experiences of people with visual impairments around mobile service robots. In: Proceedings of the ACM on human–computer interaction. 6(CSCW2), pp 1–26. https://doi.org/10.1145/3555582

Boll S, Koelle M, Cauchard J (2019) Understanding the socio-technical impact of automated (aerial) vehicles on casual bystanders. In: Extended abstracts of the CHI conference on human factors in computing systems, pp 1–8

Braun V, Clarke V (2022) Conceptual and design thinking for thematic analysis. Qual Psychol 9(1):3–26. https://doi.org/10.1037/qup0000196

Bretin R, Khamis M, Cross E, Obaid M (2025) The role of drone’s digital facial emotions and gaze in shaping individuals’ social proxemics and interpretation. ACM Trans Hum Robot Interact 14(3):1–34. https://doi.org/10.1145/3714477

Brock AM, Chatain J, Park M, Fang T, Hachet M, Landay JA, Cauchard JR (2018) FlyMap: interacting with maps projected from a drone. In: Proceedings of the 7th ACM international symposium on pervasive displays, pp 1–9. https://doi.org/10.1145/3205873.3205877

Dey D, Habibovic A, Pfleging B, Martens M, Terken J (2020) Color and animation preferences for a light band eHMI in interactions between automated vehicles and pedestrians. In: Proceedings of the 2020 CHI conference on human factors in computing systems, pp 1–13. https://doi.org/10.1145/3313831.3376325

Dragan AD, Lee KC, Srinivasa SS (2013) Legibility and predictability of robot motion. In: 2013 8th ACM/IEEE international conference on human-robot interaction (HRI), pp 301–308. https://doi.org/10.1109/HRI.2013.6483603

Duncan BA, Beachly E, Bevins A, Elbaum S, Detweiler C (2018) Investigation of communicative flight paths for small unmanned aerial systems. In: 2018 IEEE international conference on robotics and automation (ICRA), pp 602–609. https://doi.org/10.1109/ICRA.2018.8462871

Dutta D (2024) Beyond ground transportation: the rise of drone logistics. The robot report. https://www.therobotreport.com/beyond-ground-transportation-the-rise-of-drone-logistics/. Accessed 7 July 2025

Elkin LA, Kay M, Higgins JH, Wobbrock, JO (2021) An aligned rank transform procedure for multifactor contrast tests. In: The 34th annual ACM symposium on user interface software and technology (UIST '21), pp 754–768. https://doi.org/10.1145/3472749.3474784

Fartook O, McKendrick Z, Oron-Gilad T, Cauchard JR (2025) Enhancing emotional support in human–robot interaction: implementing emotion regulation mechanisms in a personal drone. Comput Hum Behav Artif Hum. https://doi.org/10.1016/j.chbah.2025.100146

Fink F, Paulicke D, Grünthal M, Jahn P (2023) Of course, drones delivering urgent medicines are necessary. But i would not use them until…” Insights from a qualitative study on users’ needs and requirements regarding the use of medical drones. PLoS ONE 18(5):1–20. https://doi.org/10.1371/journal.pone.0285393

Franssen M, Dong H, Verstegen R, Martens MH (2024) Exploring the effects of interior design elements on the uncertainty of passengers of fully automated cars. In: Accelerating open access science in human factors engineering and human-centered computing, pp 213–223. https://doi.org/10.54941/ahfe1005211

Hedayati H, Gross MD, Szafir D (2021) What information should a robot convey?. In: 2021 IEEE/RSJ international conference on intelligent robots and systems (IROS), pp 6232–6239. https://doi.org/10.1109/IROS51168.2021.9635999

Herdel V, Kuzminykh A, Parmet Y, Cauchard JR (2024) Anthropomorphism and affective perception: dimensions, measurements, and interdependencies in aerial robotics. IEEE Trans Affect Comput 15:1463–1474. https://doi.org/10.1109/TAFFC.2024.3349858

Herdel V, Kuzminykh A, Hildebrandt A, Cauchard JR (2021) Drone in love: emotional perception of facial expressions on flying robots. In: Proceedings of the 2021 CHI conference on human factors in computing systems, pp 1–20. https://doi.org/10.1145/3411764.3445495

Herdel V, Yamin LJ, Cauchard, JR (2022) Above and beyond: a scoping review of domains and applications for human–drone interaction. In: Proceedings of the 2022 CHI conference on human factors in computing systems, pp 1–22. https://doi.org/10.1145/3491102.3501881

Herdel V, Parmet Y, Cauchard JR (2025) Exploring the effects of emotion appropriateness on user perception: a delivery drone case study. In: Proceedings of the 2025 ACM/IEEE international conference on human–robot interaction, pp 747–756. https://doi.org/10.1109/HRI61500.2025.10974116

Herse S, Vitale J, Tonkin M, Ebrahimian D, Ojha S, Johnston B, Judge W, Williams MA (2018) Do you trust me, blindly? Factors influencing trust towards a robot recommender system. In: 2018 27th IEEE international symposium on robot and human interactive communication (RO-MAN), pp 7–14. https://doi.org/10.1109/ROMAN.2018.8525581

Hetherington NJ, Croft EA, Van der Loos HM (2021) Hey robot, which way are you going? Nonverbal motion legibility cues for human–robot spatial interaction. IEEE Robot Autom Lett 6(3):5010–5015. https://doi.org/10.1109/LRA.2021.3068708

Jane LE, Ilene LE, Landay JA, Cauchard JR (2017) Drone and Wo: cultural influences on human–drone interaction techniques. In: Proceedings of the 2017 CHI conference on human factors in computing systems (CHI '17), pp 6794–6799. https://doi.org/10.1145/3025453.3025755

Khan MNH, Neustaedter C (2019) An exploratory study of the use of drones for assisting firefighters during emergency situations. In: Proceedings of the 2019 CHI conference on human factors in computing systems, pp 1–14. https://doi.org/10.1145/3290605.3300502

Körber M (2018) Theoretical considerations and development of a questionnaire to measure trust in automation. In: Proceedings of the 20th congress of the International Ergonomics Association (IEA 2018), pp 13–30. https://doi.org/10.1007/978-3-319-96074-6_2

Kox ES, Van den Boogaard J, Turjaka V, Kerstholt JH (2024) The journey or the destination: the impact of transparency and goal attainment on trust in human–robot teams. ACM Trans Hum Robot Interact 14(2):1–23. https://doi.org/10.1145/3702245

Kox ES, Hennekens M, Metcalfe JS, Kerstholt JH (2025) Trust violations due to error or choice: the differential effects on trust repair in human-human and human–robot interaction. ACM Trans Hum Robot Interact 14(4):1–27. https://doi.org/10.1145/3743694

Krämer S, Ginosar E, Koelle M, Müller H, Boll S, Cauchard J (2025) I have a package for Mr. and Mrs. Smith, can you point me to their house? ACM Trans Hum Robot Interact 14(3):1–29. https://doi.org/10.1145/3724131

Lee JD, See KA (2004) Trust in automation: designing for appropriate reliance. Hum Factors 46(1):50–80. https://doi.org/10.1518/hfes.46.1.50_30392

Lindley DV (2014) Understanding uncertainty (revised edition). Wiley, New York

Lingam SN, Franssen M, Petermeijer SM, Martens M (2025a) Challenges and future directions for human–drone interaction research: an expert perspective. Int J Hum Comput Interact 41(12):7905–7921. https://doi.org/10.1080/10447318.2024.2400756

Lingam SN, Petermeijer SM, Torre I, Bazilinskyy P, Ljungblad S, Martens M (2025b) Behavioral effects of a delivery drone on feelings of uncertainty: a virtual reality experiment. ACM Trans Hum Robot Interact 14(4):1–27. https://doi.org/10.1145/3729538

Lingam SN, Verstegen R, Petermeijer SM, Martens M (2025c) Human interactions with delivery drones in public spaces: design recommendations from recipient and bystander perspectives. Front Robot AI 12:1–18. https://doi.org/10.3389/frobt.2025.1580289

Lingam SN, Petermeijer SM, Obaid M, Martens M (2025d) DroDelivery: user-centered concepts for intent-based communications of a delivery drone in public spaces. In: Adjunct Proceedings of the 27th international conference on mobile human–computer interaction (MobileHCI '25 Adjunct), pp 1–9. https://doi.org/10.1145/3737821.3749600

Ministry of Infrastructure and Water Management (2025) Road Traffic Signs and Regulations in the Netherlands. Government.nl. https://www.government.nl/documents/reports/2024/02/09/road-traffic-signs-and-regulations-in-the-netherlands. Accessed 9 Dec 2025

Netherlands Enterprise Agency (2025) Rules for flying drones. Business.gov.nl. https://business.gov.nl/regulation/drones/?gad_source=1&gclid=CjwKCAjw68K4BhAuEiwAylp3ktRHcDphMcDlHhX2-bs5Dv3rW7qmfGIBJdtJiKgoz28CZhDIhrDQBoCs44QAvD_BwE. Accessed 13 June 2025.

Nielsen S, Skov MB, Hansen KD, Kaszowska A (2023) Using user-generated YouTube videos to understand unguided interactions with robots in public places. ACM Trans Hum Robot Interact 12(1):1–40. https://doi.org/10.1145/3550280

Nunkoo R, Pillai R, Sivathanu B, Rana NP (2024) Drivers and inhibitors of consumers' adoption of AI-driven drone food delivery services. Int J Hosp Manag 123:1–12. https://doi.org/10.1016/j.ijhm.2024.103913

Obaid M, Mubin O, Basedow CA, Ünlüer AA, Bergström MJ, Fjeld M (2015). A drone agent to support a clean environment. In: Proceedings of the 3rd international conference on human–agent interaction, pp 55–61. https://doi.org/10.1145/2814940.2814947

Peereboom J, Tabone W, Dodou D, de Winter J (2024) Head-locked, world-locked, or conformal diminished-reality? An examination of different AR solutions for pedestrian safety in occluded scenarios. Virtual Reality 28(2):1–19. https://doi.org/10.1007/s10055-024-01017-9

Pelikan HR, Reeves S, Cantarutti MN (2024) Encountering autonomous robots on public streets. In: Proceedings of the 2024 ACM/IEEE international conference on human–robot interaction, pp 561–571. https://doi.org/10.1145/3610977.3634936

Puig-Pey A, Zamora JL, Amante B, Moreno J, Garrell A, Grau A, Yolanda B, Santamaria A, Sanfeliu A (2023) Human acceptance in the human–robot interaction scenario for last-mile goods delivery. In: 2023 IEEE international conference on advanced robotics and its social impacts (ARSO), pp 33–39. https://doi.org/10.1109/ARSO56563.2023.10187432

Rosenthal-von Der Pütten A, Sirkin D, Abrams A, Platte L (2020) The forgotten in HRI: incidental encounters with robots in public spaces. In: Companion of the 2020 ACM/IEEE international conference on human–robot interaction, pp 656–657. https://doi.org/10.1145/3371382.3374852

Sanfridsson J, Sparrevik J, Hollenberg J, Nordberg P, Djärv T, Ringh M, Claesson A (2019) Drone delivery of an automated external defibrillator—a mixed method simulation study of bystander experience. Scand J Trauma Resusc Emerg Med 27(40):1–9. https://doi.org/10.1186/s13049-019-0622-6

Shankland S (2023) Zipline's new drone brings aerial delivery closer for millions more of us. CNET. https://www.cnet.com/tech/computing/new-zipline-drone-brings-aerial-delivery-closer-for-millions-more-of-us/. Accessed 6 Feb 2025.

Shapira S, Cauchard JR (2022) Integrating drones in response to public health emergencies: a combined framework to explore technology acceptance. Front Public Health 10:1–14. https://doi.org/10.3389/fpubh.2022.1019626

Shin H, Choi J, Oh C (2024) Delivering the future: understanding user perceptions of delivery robots. In: Proceedings of the ACM on human–computer interaction, 8(CSCW1), pp 1–24. https://doi.org/10.1145/3653687

Szafir D, Mutlu B, Fong T (2015) Communicating directionality in flying robots. In: Proceedings of the Tenth Annual ACM/IEEE international conference on human–robot interaction, pp 19–26. https://doi.org/10.1145/2696454.2696475

Tabone W, Happee R, García J, Lee YM, Lupetti ML, Merat N, de Winter J (2023) Augmented reality interfaces for pedestrian–vehicle interactions: an online study. Transport Res F Traffic Psychol Behav 94:170–189. https://doi.org/10.1016/j.trf.2023.02.005

Villa S, Mayer S, Hartcher-O'Brien S, Schmidt A, Machull, TK (2022) Extended mid-air ultrasound haptics for virtual reality. In: Proceedings of the ACM on human–computer interaction (ISS), pp 1–24. https://doi.org/10.1145/3567731

Wang Z, Wu Y, Yang S, Chen X, Rohles B, Fjeld M (2024) Exploring intended functions of indoor flying robots interacting with humans in proximity. In: Proceedings of the 2024 CHI conference on human factors in computing systems (CHI '24), pp 1–16. https://doi.org/10.1145/3613904.3642791

White MD, Marsh EE (2006) Content analysis: a flexible methodology. Libr Trends 55:22–45. https://doi.org/10.1353/lib.2006.0053

Windschitl PD, Wells GL (1996) Measuring psychological uncertainty: verbal versus numeric methods. J Exp Psychol Appl 2:343

Wing (2025) Learn about how Wing delivery works. https://wing.com/technology. Accessed 29 Mar 2025

Wobbrock JO, Findlater L, Gergle D, Higgins JJ (2011) The aligned rank transform for nonparametric factorial analyses using only anova procedures. In: Proceedings of the SIGCHI conference on human factors in computing systems (CHI '11), pp 143–146. https://doi.org/10.1145/1978942.1978963

Yeh A, Ratsamee P, Kiyokawa K, Uranishi Y, Mashita T, Takemura H, Fjeld M, Obaid M. (2017) Exploring proxemics for human–drone interaction. In: Proceedings of the 5th international conference on human agent interaction (HAI '17), pp 81–88. https://doi.org/10.1145/3125739.3125773

Yu X, Tran TTM, Wang Y, Mah K, Cao Y, Johansen SS, Johal W, Lupetti ML, Rose M, Rittenbruch M, Zsolczay RG, Hoggenmüller M (2024) Out of place robot in the wild: envisioning urban robot contextual adaptability challenges through a design probe. In: Extended abstracts of the CHI conference on human factors in computing systems, pp 1–7. https://doi.org/10.1145/3613905.3651002

Zègre-Hemsey JK, Grewe ME, Johnson AM, Arnold E, Cunningham CJ, Bogle BM, Rosamond WD (2020) Delivery of automated external defibrillators via drones in simulated cardiac arrest: users' experiences and the human–drone interaction. Resuscitation 157:83–88. https://doi.org/10.1016/j.resuscitation.2020.10.006

Zeng Y, Low KH, Schultz M, Duong VN (2020) Future demand and optimum distribution of droneports. In: 2020 IEEE 23rd international conference on intelligent transportation systems (ITSC), pp 1–6. https://doi.org/10.1109/ITSC45102.2020.9294283