Hey, Robot! Don't Cut in Line: Designing Queuing Behaviors of Delivery Robots with Multiple Stakeholders

Nayoung Kim[1], Hyochang Kim[2], Sunok Lee[3], and Changjoo Nam[1,4,*]

***Abstract*—In situations where a delivery robot shares limited resources with people who are incidentally copresent in the same space, its behavior affects both those individuals and customers awaiting delivery. In this paper, we refer to such individuals as incidentally copresent persons (InCops). Most prior studies focus on a single stakeholder, leaving a gap for deployment in shared environments. We examined how robot behavior influences customers' perceived waiting time and the impressions formed by both InCops and customers, using a multi-stakeholder perspective. A key scenario involves a robot and an InCop meeting at an elevator door, where the robot performs a queuing behavior. We compared yielding, cutting in line, and first-in-first-out, along with four information types shown to customers. User journey maps captured qualitative insights. Results revealed that preferences for robot queuing behavior differed by stakeholder, with InCops responding primarily to norm compliance and customers relying more on system transparency to interpret waiting experiences. These findings suggest that socially aligned, humble conduct and visible intent are critical for delivery robots operating in resource-limited environments that balance fairness with efficiency.**

***Index Terms*—Social HRI, Service Robotics, Acceptability and Trust**

I. INTRODUCTION

DELIVERY robots are being introduced to improve efficiency of everyday human life [1]. However, their coexistence with humans does not always guarantee efficiency. The rise of delivery robots has introduced a new kind of delay — customers now find themselves waiting not for human delivery drivers, but for delivery robots. This delay is especially evident in dense urban areas where delivery robots, valued for economic efficiency, are rapidly deployed [1]. In such environments, robots must often share limited resources with people, including narrow alleys, building entrances.

Elevators represent a particularly critical case of resource sharing because they are essential for vertical mobility in multi-story buildings. During peak hours such as lunch and dinner, people queue for elevators, and delivery robots must also wait to complete deliveries. In this context, robots compete with *incidentally copresent persons (InCops)*[1] for elevator access. Tensions already exist among people during these peak hours, and the presence of delivery robots introduces an additional layer of tension. Moreover, the queuing behaviors influence not only InCops but also the customers who ultimately receive the service. We therefore frame elevator use as a representative scenario of resource contention in robotic delivery.

What matters in these shared queues is not only the actual waiting time but also the perceived duration of the wait [2]. Previous research has shown that perceived waiting time strongly shapes user satisfaction [3]. This relationship between perceived waiting time and satisfaction applies not only to individual users but also to both group stakeholders. Specifically, a robot's behavior in line creates implicit social interactions with InCops, which in turn influence how customers evaluate delivery efficiency and sociability [4].

To fully understand these effects of robot behaviors, it is necessary to take a multi-stakeholder perspective (e.g., InCops and customers) [5]. Prior studies have focused on InCops, who engage in implicit interactions with robots in shared spaces [6], [7]. However, these studies do not consider customers who are the primary beneficiaries of the service provided by the robots. In real-world settings, delivery robots act as a service medium rather than an agent or recipient. Most of their operational time is spent in transit, and during this time, they frequently encounter InCops in public spaces [4]. As a service medium, delivery robots must mediate between potentially conflicting stakeholder expectations, such as customers prioritizing delivery speed and InCops expecting courteous, norm-compliant behavior. These tensions are particularly salient in shared and resource-constrained environments. Although such encounters are brief, they can shape the social impression of the robot [4].

This incidental impression may influence both the InCop and the customer. For example, if a delivery is delayed because the robot yields at an elevator, the customer may perceive this interaction as either respectful or inefficient. This indirect link between InCop interaction and customer evaluation highlights the need to examine both parties together [5]. However, prior human–robot interaction (HRI) research has rarely considered both groups in a single study. Our study addresses this gap by including InCops and customers as stakeholders shaped by the same robot behavior.

We investigate how delivery robots' queuing behaviors influence both InCops and customers. Specifically, we examined

Manuscript received: November 19, 2025; Revised: February 16, 2026; Accepted: April 4, 2026.

This paper was recommended for publication by Editor Angelika Peer upon evaluation of the Associate Editor and Reviewers' comments. This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. RS-2024-00411007) and by the Korea Planning & Evaluation Institute of Industrial Technology (KEIT) grant funded by the Korea government (MOTIE) (No. RS-2024-00444344).

[1] Department of Electronic Engineering, Sogang University, Seoul, Korea.

[2] Stanford Center at the Incheon Global Campus, Stanford University, Incheon, Korea.

[3] Department of Art & Technology, Sogang University, Seoul, Korea.

[4] Vertical Labs, Co., Ltd., Seoul, Korea.

[*] Corresponding author: `cjnam@sogang.ac.kr`

Digital Object Identifier (DOI): see top of this page.

---

[1] In this study, we use the term InCops instead of bystanders to highlight the unintentional and non-persistent nature of human–robot co-presence in public settings.

three robot queuing behaviors—cutting in line, yielding, and First-In, First-Out (FIFO)—and four information conditions for customers—behavior-visible yielding, behavior-visible cutting in line, behavior-visible FIFO, and behavior-invisible progress UI. We examine how robot queuing behavior and information type influence perceived waiting time, perceived sociability, and acceptance to the customer and InCop. Based on our findings, we provide practical guidelines for robot queuing behavior design and customer interface strategies in resource-constrained delivery contexts.

The contributions of this work are as follows:

- We introduce a multi-stakeholder framework for evaluating the queuing behaviors of delivery robots. Unlike prior work that treated InCops and customers as separate evaluation targets, we examine both groups together. By conceptualizing the robot as a service medium, we capture the impressions of direct and indirect stakeholders.
- We provide empirical and design-level insights into perceived transparency during last-mile delivery. Our user journey maps revealed that participants experienced emotional fluctuations during the mid-delivery stage, particularly due to uncertainty about the robot's status.
- Our findings demonstrate a normative consensus across stakeholders. Regardless of stakeholder type, participants evaluated robots more positively when they yielded or followed FIFO. Although the idea that "Robots should not cut in line." may appear intuitive, our results empirically demonstrate the relationship between efficiency and acceptance in last-mile delivery contexts. While cutting in line could maximize efficiency, both InCops and customers evaluated yielding and FIFO as more acceptable and sociable, indicating that social acceptance can outweigh speed optimization.

II. RELATED WORK

Research on queuing emphasizes that fairness and uncertainty shape waiting experiences more than objective time. In the context of delivery robots, prior studies have focused on robot feedback and behavior from the perspective of InCops, overlooking how such actions affect customers. As delivery robots increasingly operate in shared spaces, their behaviors impact multiple stakeholders at the same time. This section reviews foundational work on queuing psychology, explores fairness dilemmas in multi-stakeholder interactions, and examines transparency as a design strategy for managing expectations and reducing perceived waiting burdens.

A. Psychology of Queuing

Humans inherently dislike waiting in line [8]. However, as emotions color experiences, the same queuing can be perceived differently depending on the mode of interaction and the impressions of the robot [9]. Prior research shows that perceived time is more influential than objective duration in shaping waiting [9], [2]. People evaluate waiting negatively not only because of its length but also due to unexpected delays, lack of control, and fairness violations [2]. Perceived time has been repeatedly confirmed as a stronger predictor of service satisfaction than actual time [10].

The rise of delivery robots has introduced a new kind of delay. People no longer wait for delivery workers but for robots to complete deliveries or access elevators. Research on waiting with robots has focused on robot behaviors and feedback provision [11], [12]. Previous research found that robots providing human-like or machine-like feedback are evaluated more positively than silent robots, even when actual waiting time remains the same [12]. Other studies show that when robots use conflict resolution strategies including appeals or commands in resource-constrained public spaces, people evaluate their acceptability differently [11]. These feedback mechanisms also alter perceived waiting time.

However, these studies focus only on the perspective of InCops [11], [13]. Delivery robots spend most of their operational time in transit, where they engage in implicit interactions with InCops [4]. At the same time, customers remain the direct beneficiary of the service. A robot's queuing behavior directly shapes the experience of InCops while indirectly influencing customer satisfaction. Yet, research that considers both perspectives together remains scarce.

The psychology of queuing identifies fairness and uncertainty as critical determinants of waiting experiences [2]. providing a lens for understanding delivery robot behavior in multi-stakeholder contexts. Building on this background, we ask the following research question (RQ).

RQ_1. How do robot queuing behaviors influence perceived waiting time for InCops and customers in shared-resource environments?

B. Fairness in Multi-Stakeholder Perspectives

Unfair waits feel longer than fair ones [9]. In human interactions, fairness is guided by norms such as FIFO or yielding to elderly individuals or those in urgent situations. A central question is whether people hold similar expectations for robots. Prior research shows mixed findings. Some view robots as social actors that should follow norms [7], whereas others see them as subordinate tools that should perform efficiently without asserting autonomy [11], [14].

Studies on service robots also reflect this tension. People often respond to robots socially and expect polite and respectful behavior [15]. At the same time, they tend to assign robots a lower social status [11]. Assertive or dominant behaviors often lead to rejection. For example, robots commanding or threatening receive negative evaluations [11], [16] whereas robots yielding or apologizing are viewed positively [11], [17]. These findings suggest that yielding is not evaluated merely as a functional behavior, but as a morally interpretable action. Prior work on moral reasoning in HRI shows that people attribute intentions, responsibilities, and moral expectations to robots, even when recognizing their limited agency [18]. From this perspective, yielding can be interpreted as a signal of moral alignment, indicating respect for social norms and consideration for others. Such moral expectations help explain why robots that violate norms (e.g., cutting in line) are evaluated more negatively than robots that act inefficiently but politely.

These tensions become even more complex when viewed from a multi-stakeholder perspective. The behaviors of delivery robots such as cutting in line or yielding affect both customers and InCops. A single robot action influences multiple groups at the same time. Prior studies focusing on a single user fail to capture this broader dynamics [11], [13]. In addition, these tensions become more complex in resource-limited contexts, such as when robots and humans wait for an elevator. This conflict is evident in robot queuing behaviors. Cutting in line increases efficiency but reduces perceived fairness, whereas yielding supports fairness but delays delivery. This situation resembles a coordination game. The robot acts under a payoff structure that requires balancing efficiency and fairness. Some users may want robots to always yield [11]. Others may accept norm violations for the sake of faster service. Some may prefer a compromise, where robots follow norms but also offer transparency to reduce user discomfort [19].

Research has rarely examined robot behavior in resource-limited contexts from a multi-stakeholder perspective. To fill this gap, we examine how different stakeholder groups perceive and evaluate delivery robot behavior in a shared resource environment, leading to the following questions:
RQ_2. How do customers and InCops evaluate robot behaviors during shared waiting situations?

C. Transparency as a Strategy to Reduce Uncertainty and Stakeholder Tension

Uncertain waits feel longer than known and finite waits. Waiting is shaped not only by fairness but also by uncertainty [2]. From the moment an order is placed, customers enters a waiting state. Higher uncertainty increases perceived waiting time and psychological discomfort [20]. Transparency reduces this uncertainty [21]. Prior work shows that displaying delivery progress or offering real-time feedback helps customers perceive shorter waits [22], [23].

Delivery robots introduce additional layers of uncertainty. Customers may worry not only about the arrival time but also about whether the robot is functioning properly [7]. These concerns are stronger during early-stage deployments [24]. Unexpected technical issues or delays can make the experience more stressful [25]. In last mile environments, the robot must complete complex sub-tasks. Passing through narrow hallways, waiting for elevators, boarding them, and locating the correct room increase the customer's anxiety.

Transparency addresses more than just usability. Prior research shows that merely informing the user that the process is ongoing improves satisfaction and reduces perceived waiting time [22]. Beyond this functional role, transparency contributes to trust formation in HRI by making the robot's actions, status, and intentions more predictable and interpretable [26]. Providing information about the robot's current location, delivery status, and expected arrival time enables customers to anticipate what will happen next, supporting appropriate trust in the system [27]. By reducing uncertainty about system performance, transparency increases service acceptance [27]. This study does not treat transparency only as a solution for uncertainty. Instead, we examine its role in reducing tension between multiple stakeholders. We posit that informing the customer about the robot's situation can reduce friction with other people in the shared environment. Thereby, we derive a question on transparency if it can be a design strategy that balances efficiency and fairness.
RQ_3. Does providing transparency about delivery status reduce perceived waiting time in last-mile delivery?

III. METHODOLOGY

To examine how delivery robots' queuing behaviors affect multi-stakeholder experiences, we conducted a within-subjects design that examined three robot behaviors from the perspective of InCops and four conditions from the perspective of customers. Specifically, to assess how different interfaces influence customers' perceived processing time and overall user experience, we implemented a within-subjects design involving four conditions (customer information condition: behavior-visible vs. behavior-hidden with delivery progress UI only). In addition, to explore how stakeholders form expectations about robot queuing behavior, we adopted a qualitative approach using user journey maps. The study were approved by the Sogang University Institutional Review Board (SGUIRB-A-2505-30).

A. Participants

A total of 30 participants over the age of 19 participated in the study, including 18 males ($M = 26.72$, $SD = 3.06$) and 12 females ($M = 27.42$, $SD = 3.06$). The sample size was determined using G*Power. For the one-way repeated-measures ANOVA (effect size: Cohen's $f = 0.25$, α-error: 0.05, power: 0.80, number of tested predictors: 1), an *a priori* power analysis indicated that a minimum of 24 participants was required for the customer perspective and 28 participants for the InCops perspective. Accordingly, we determined that at least 28 participants were required and recruited 30 participants to account for potential dropouts. Participants who reported no significant visual or auditory impairments were eligible to participate. All participants received \$7 as compensation for their participation.

B. Delivery Robot

The experiment used a mobile delivery robot, Neubie, that is currently deployed in a commercial delivery service in South Korea. It has a footprint of 56 × 67 cm and a height of 69 cm. In this study, the robot was manually controlled by a researcher using a controller, which enabled operation of both its movement and the opening and closing of its delivery container. We set the speed to 0.8 m/s to ensure safety when waiting with users in front of the elevator, in accordance with industrial safety standards [28]. The front of the robot displayed a face with two eyes, and the orange lighting band at the bottom remained illuminated at all times without changing across situations.

This article has been accepted for publication in IEEE Robotics and Automation Letters. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/LRA.2026.3686647

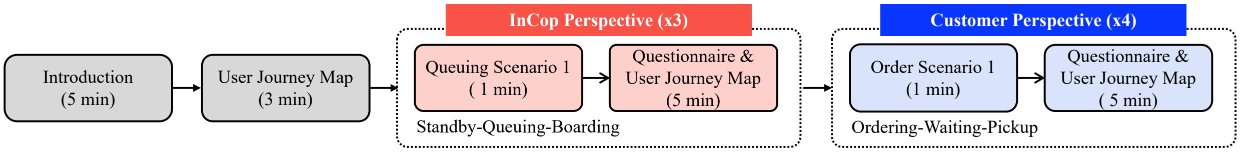


Fig. 1. Overall experiment procedure. Participants completed an introduction and initial journey map, followed by three InCop-perspective scenarios and four customer-perspective scenarios, each followed by a questionnaire and journey map.

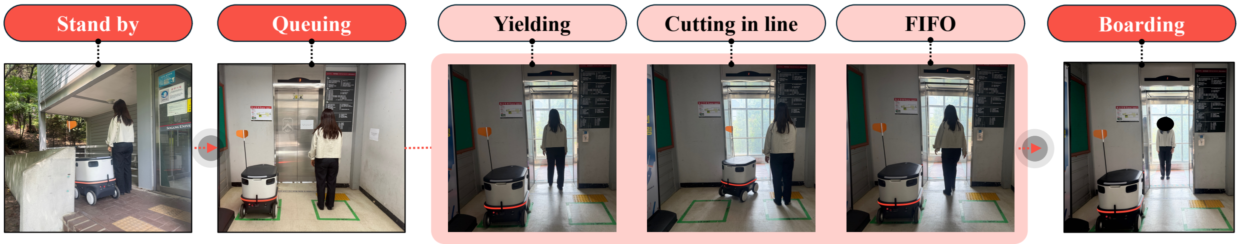
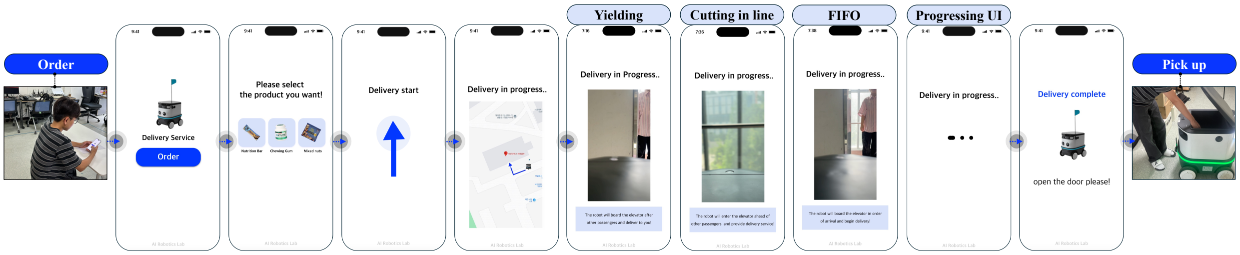


Fig. 2. Experimental procedure from the InCops' perspective with three robot queuing conditions (Yielding, Cutting in Line, FIFO).



The robot will board the elevator after other passengers and deliver to you!

The robot will enter the elevator ahead of other passengers and provide delivery service!

The robot will board the elevator in order of arrival and begin delivery!

Fig. 3. Experimental procedure from the customer perspective with four information types. After placing an order, a delivery starts with a map view. Upon arrival at the building, one of four interface conditions in the blue shade is shown (Visible: Yielding, Cutting in Line, FIFO; Invisible: Progress UI).

C. Experiment Design

Participants were briefed about the study and provided informed consent, after which they completed an initial user journey map. The experiment was conducted from two perspectives: the InCop and the customer. Each participant experienced three conditions from the InCop perspective and four conditions from the customer perspective, as illustrated in Figure 1. In the InCop conditions, the experiment was conducted in front of an elevator on the first floor of a building, whereas in the customer conditions, it was conducted inside an office. The order of perspectives was randomized, and participants moved between locations according to the assigned order. For each perspective, the order of conditions was also randomized to minimize order effects [29]. After completing each condition, participants filled out a questionnaire. At the end of each perspective, after experiencing all corresponding conditions, they completed an additional user journey map. The entire experiment lasted approximately one hour, with the detailed timing of each phase shown in Figure 1.

1) InCop perspective: The InCop condition consisted of three phases: standby, queuing, and boarding, and the detailed procedure is illustrated in Figure 2. Participants were instructed as follows. Due to the elevator's weight limit, only one person or one robot could board at a time. When the robot moved, participants were asked to wait until the robot finished moving before proceeding. The experimenter operated the elevator button. From that point onward, the experimenter directly controlled the robot to manipulate the elevator boarding order, while participants were free to move and board the elevator. The exact verbal instruction used in the experiment was as follows: "If the robot starts moving first, please wait until the robot stops moving and then stand in front of the elevator. After the experimenter presses the elevator button, please board the elevator freely."

In the standby phase, the participants waited in a specific spot in front of the building entrance. To clearly mark the beginning of perceived waiting, they were asked to turn around while waiting. This procedure was used to distinguish perceived waiting time from the preparatory phase of the experiment, and participants were instructed that the experiment would begin once they turned toward the entrance. During the queuing phase, either the participant or the robot moved first to the spot in front of the elevator, depending on the assigned condition. In the yielding condition, the robot moved first and waited in front of the elevator; in the cutting in line condition, the participant moved first and waited; and in the FIFO condition, the participant moved first and waited. Afterward, the remaining agent (participant or robot) outside the building joined at the elevator front. To control for external variables, the waiting positions of both the participant and the robot were marked on the floor [13].

In the boarding phase, once both were in position, the experimenter pressed the elevator button. In the yielding condition, the robot was waiting but remained still, allowing the participant to board first. In the cutting in line condition, the participant arrived and was waiting first. However, the robot, which came later, moved ahead when the elevator arrived and boarded before the participant. In the FIFO condition, the participant, who was waiting first, boarded the elevator first. Each trial ended when either the participant or the robot boarded the elevator and the doors closed.

2) Customer perspective: The customer condition consisted of three phases: ordering through a mobile application, waiting in the office, and picking up the order once the robot arrived at the office. To control variability in the delivery robot's movement time, a Wizard-of-Oz (WoZ) methodology was employed [30]. Before the interface indicated the robot's arrival, the researcher placed the delivered item inside the robot outside the participant's door. When the interface displayed a notification indicating that the robot had arrived, the participant opened the door and retrieved the item from the robot, experiencing the interaction as if the robot had autonomously completed the delivery. The mobile application used in the study was prototyped in Figma for interface design, and interactions were implemented using Protopie.

The interface was structured as a sequence of screens – ordering, item selection, preparation, delivery initiation, delivery in progress, the last-mile delivery (inside the building), and delivery completion. At the final stage, participants opened the container of the robot and retrieved the item. The detailed procedure is illustrated in Figure 3.

Four interface conditions were implemented. In the behavior-visible conditions, the last-mile delivery was shown in the app using prerecorded robot ego-view video clips, covering the standby, waiting, and elevator-boarding phases. The video showed one of three behaviors: yielding, cutting in line, or FIFO. The video duration was 35 seconds, ending as the elevator doors closed. In the behavior-hidden condition, participants viewed only a delivery progress display for the same 35 seconds, without any robot behaviors.

D. Measures

In this study, we employed distinct measurement scales for each stakeholder. From the InCop perspective, we assessed perceived processing time (3 items, Cronbach's $\alpha = .96$), perceived sociability (3 items, Cronbach's $\alpha = .81$), and acceptance (9 items, Cronbach's $\alpha = .93$) in response to the robot's queuing behaviors [3], [31], [32]. For perceived processing time, participants responded to items such as "Your waiting to board the elevator was" and "Your request for delivery was" on a scale anchored by the terms fast, speedy, and quick. Higher scores indicated that participants perceived the process as faster. From the customer perspective, we used the same three scales as in the InCop perspective and included service evaluation (3 items, Cronbach's $\alpha = .95$) [33]. All items were assessed using a 7-point Likert scale, where 1 represents strongly disagree and 7 represents strongly agree. Because the within-subjects design was implemented separately for each perspective, we analyzed the data using one-way ANOVAs for each perspective.

To complement the quantitative measures, we also collected user journey maps [34], [35], [36]. Each participant recorded the delivery robot usage scenario, and their expectations for the service. They then illustrated the service process step by step, describing their actions, thoughts, and emotions through both written notes and an emotional trajectory graph. Finally, they identified problems or discomfort they experienced and suggested possible improvements.

TABLE I
MEAN AND STANDARD DEVIATION OF INCOPS' EVALUATION

	Cutting in line	Yielding	FIFO
Perceived processing time	3.07 (1.71)	4.94 (1.67)	5.51 (1.35)
Perceived sociability	3.46 (1.57)	4.84 (1.45)	5.00 (1.53)
Acceptance	4.10 (1.40)	5.20 (1.32)	5.31 (1.14)

IV. RESULTS

A. Questionnaire

For the InCops, significant main effects were observed for perceived processing time [$F(2, 58) = 20.81, p < .001, \eta_p^2 = .418$], perceived sociability [$F(2, 58) = 23.11, p < .001, \eta_p^2 = .443$] and acceptance [$F(2, 58) = 12.85, p < .001, \eta_p^2 = .307$]. Bonferroni post hoc tests showed that perceived processing time was rated significantly higher in the yielding compared to the cutting in line (95% CI [-3.01, -0.68], $p < .01$), and also significantly higher in the FIFO compared to the cutting in line (95% CI [-3.48, -1.41], $p < .001$). Similarly, perceived sociability was rated significantly higher in the yielding than in the cutting in line (95% CI [-2.04, -0.74], $p < .001$), as well as in the FIFO compared to the cutting in line (95% CI [-2.25, -0.78], $p < .001$). Acceptance followed the same pattern, with higher ratings in both the yielding (95% CI [-1.80, -0.41], $p < .01$) and FIFO (95% CI [-2.01, -0.40], $p < .01$) compared to the cutting in line. No significant differences were observed between the yielding and FIFO conditions for any of these measures. The means and standard deviations for the InCop perspective are presented in Figure 4 and Table I.

For the customers, significant main effects were also found for perceived processing time [$F(3, 87) = 9.77, p < .001, \eta_p^2 = .252$], perceived sociability [$F(3, 87) = 4.61, p < .05, \eta_p^2 = .137$], acceptance [$F(3, 87) = 2.71, p < .05, \eta_p^2 = .085$] and service evaluation [$F(3, 87) = 3.18, p < .05, \eta_p^2 = .099$]. Bonferroni post hoc tests showed that, for perceived processing time, the cutting in line was rated significantly higher than the loading (95% CI [0.40, 2.29], $p < .01$). In addition, both the yielding (95% CI [0.23, 1.49], $p < .01$) and the FIFO (95% CI [0.23, 1.83], $p < .01$) were rated significantly higher than the loading. For perceived sociability, the yielding was rated significantly higher than the loading (95% CI [0.08, 1.30], $p < .05$). For service evaluation, the yielding was rated significantly higher than the loading (95% CI [0.00, 1.15], $p < .05$). Across all measures, all remaining pairwise comparisons were not statistically significant. The means and standard deviations for the customer perspective are presented in Figure 4 and Table II.

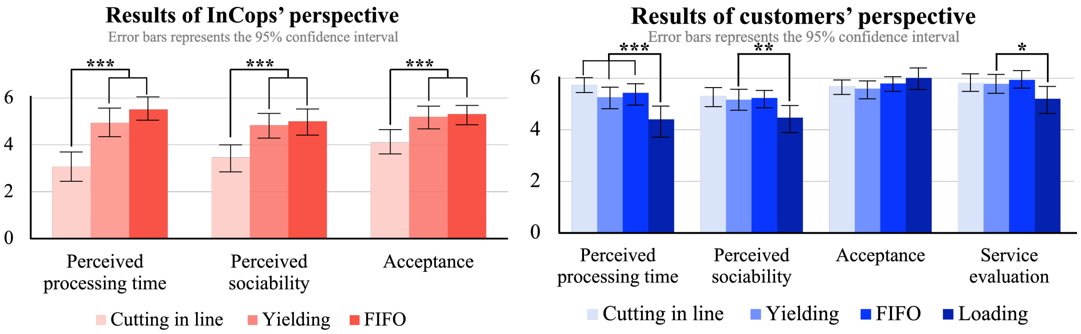


Fig. 4. Results for InCops (left) and customers (right) across queuing behavior and transparency conditions. InCops evaluated yielding and FIFO more positively than cutting in line across perceived processing time, perceived sociability, and acceptance. Customers perceived shorter waiting times under behavior-visible conditions compared to the progress UI, while perceived sociability and service evaluation were higher for yielding.
* $p < .05$, ** $p < .01$, *** $p < .001$.

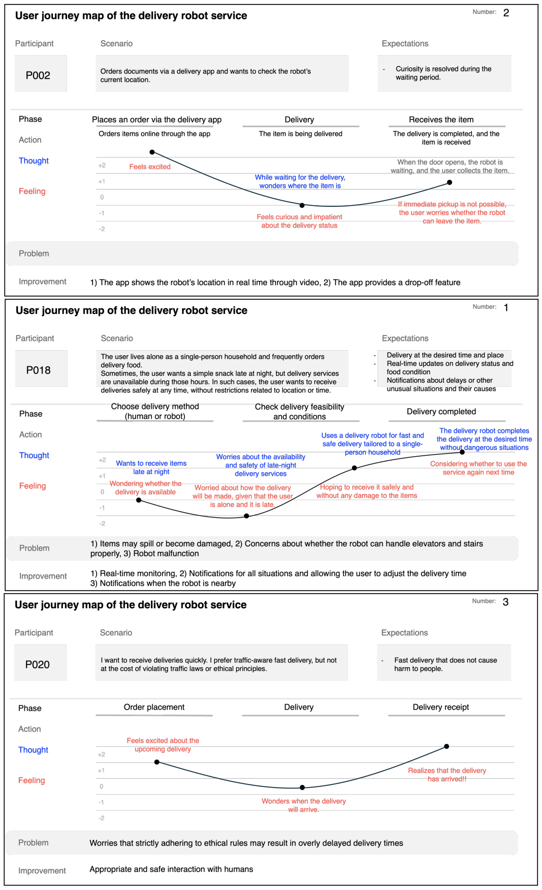
TABLE II
MEAN AND STANDARD DEVIATION OF CUSTOMERS' EVALUATION

	Cutting in line	Yielding	FIFO	Progress UI
Perceived processing time	5.74 (0.81)	5.26 (1.18)	5.43 (1.15)	4.40 (1.67)
Perceived sociability	5.30 (1.01)	5.16 (1.13)	5.23 (0.94)	4.47 (1.46)
Acceptance	5.69 (0.78)	5.59 (0.97)	5.79 (0.81)	6.23 (1.18)
Service evaluation	5.81 (0.95)	5.78 (1.02)	5.93 (0.94)	5.20 (1.48)

B. User Journey Map

User journey maps were recorded item by item and analyzed using thematic analysis [37]. To support systematic analysis, the journey map data were first organized as raw entries across predefined dimensions, including perspective (initial, InCop, and customer), scenario, expectations, service stage, behavior, thoughts, emotional ratings, perceived problems or discomfort, and suggested improvements. Two coders with expertise in HCI independently analyzed the structured entries and refined codes through comparison and discussion. The coding scheme was refined through multiple rounds of comparison and discussion, during which discrepancies were resolved and overlapping codes were consolidated. This process resulted in a set of themes capturing stage-specific emotional patterns and their causes.

Participants reported expectations and needs regarding the functions and information provided by delivery robots. Specifically, they emphasized fast and safe delivery and the ability to check the robot's location during service. The overall structure of the journey maps was consistent across participants, with most dividing the service into three phases: ordering, delivery in progress, and pickup. Emotional trajectories showed a clear pattern. In 49 out of 90 journey maps, the delivery phase was associated with more negative emotions than the ordering and pickup phases, forming a V-shaped curve (see Figure 5). Written reflections indicated that these negative emotions arose not only from waiting but also from uncertainty about the robot's capabilities in performing the delivery task. Participants sought reassurance through GPS- or camera-based tracking and expressed concerns about whether the robot could reliably navigate complex buildings.


User journey map of the delivery robot service Number: 2

Participant: P002

Scenario: Orders documents via a delivery app and wants to check the robot's current location.

Expectations:
- Curiosity is resolved during the waiting period.

Phase	Places an order via the delivery app	Delivery	Receives the item
Action	Orders items online through the app	The item is being delivered	The delivery is completed, and the item is received

Feels excited
While waiting for the delivery, wonders where the item is
Feels curious and impatient about the delivery status
When the door opens, the robot is waiting, and the user collects the item.
If immediate pickup is not possible, the user worries whether the robot can leave the item.

Problem

Improvement: 1) The app shows the robot's location in real time through video, 2) The app provides a drop-off feature

User journey map of the delivery robot service Number: 1

Participant: P018

Scenario: The user lives alone as a single-person household and frequently orders delivery food.
Sometimes, the user wants a simple snack late at night, but delivery services are unavailable during those hours. In such cases, the user wants to receive deliveries safely at any time, without restrictions related to location or time.

Expectations:
- Delivery at the desired time and place
- Real-time updates on delivery status and food condition
- Notifications about delays or other unusual situations and their causes

Phase: Choose delivery method (human or robot) | Check delivery feasibility and conditions | Delivery completed

Wants to receive items late at night
Wondering whether the delivery is available
Worries about the availability and safety of late-night delivery services
Worried about how the delivery will be made, given that the user is alone and it is late.
Uses a delivery robot for fast and safe delivery tailored to a single-person household
Hoping to receive it safely and without any damage to the items
The delivery robot completes the delivery at the desired time without dangerous situations
Considering whether to use the service again next time

Problem: 1) Items may spill or become damaged, 2) Concerns about whether the robot can handle elevators and stairs properly, 3) Robot malfunction

Improvement: 1) Real-time monitoring, 2) Notifications for all situations and allowing the user to adjust the delivery time
3) Notifications when the robot is nearby

User journey map of the delivery robot service Number: 3

Participant: P020

Scenario: I want to receive deliveries quickly. I prefer traffic-aware fast delivery, but not at the cost of violating traffic laws or ethical principles.

Expectations:
- Fast delivery that does not cause harm to people.

Phase: Order placement | Delivery | Delivery receipt

Feels excited about the upcoming delivery
Wonders when the delivery will arrive.
Realizes that the delivery has arrived!!

Problem: Worries that strictly adhering to ethical rules may result in overly delayed delivery times

Improvement: Appropriate and safe interaction with humans

Fig. 5. These figures present examples of user journey maps for a delivery robot service created by participants. The journey maps, originally written in Korean, were translated into English. Color coding distinguishes actions, thoughts, and feelings across phases.

V. FINDINGS AND DISCUSSION

In this section, we interpret the results from a multi-stakeholder perspective. We first show that InCops and customers hold asymmetric expectations toward robot queuing behavior, differing in both what they expect and how strongly those expectations shape their evaluation. We then demonstrate that interface transparency helps bridge these asymmetric waiting experiences by reducing uncertainty.

A. Asymmetric Expectations of Robot Behavior

Stakeholders showed different expectations toward robot behavior, and the strength of these expectations varied by perspective. InCops did not require the robot to yield. Instead, InCops expected the robot to preserve social order and avoid fairness violations. This pattern indicates that InCops based their evaluations primarily on whether the robot explicitly violated social norms, rather than on whether the robot actively prioritized humans. Research on the psychology of queuing shows that unfair waiting experiences amplify perceived time regardless of objective duration [2], [9]. The findings demonstrate that this fairness-based mechanism also operates in robot-mediated queuing interactions. This evidence refines prior work that argues robots should prioritize humans by showing that the degree of expected prioritization depends on stakeholder role [11].

The influence of robot behavior was weaker from the customer perspective. For perceived sociability and service evaluation, significant differences appeared only between the yielding and the loading. No significant differences emerged among yielding, FIFO, and cutting in line behaviors. This pattern suggests that customers did not interpret robot behaviors through fine-grained social norms. Customer evaluations reflected a more holistic assessment of the delivery service [38]. In customer perspective, participants focused on whether the service felt smooth and considerate, rather than on how the robot resolved queuing situations.

Effect sizes further clarify this asymmetry. Effect sizes were consistently larger for InCops than for customers. This difference reflects a structural contrast in interaction. InCops directly shared physical space with the robot and coordinated movement in real time. Customers interacted with the robot indirectly through a delivery interface. Direct physical interaction amplified the psychological and social impact of robot behavior for InCops, whereas interface-mediated interaction reduced the salience of robot behavior [39]. This intentional asymmetry may also have contributed to the difference in effect sizes.

Taken together, the results show that robot behavior does not carry a uniform meaning across users. Stakeholder roles shape both the content of expectations toward robot behavior and the strength with which those expectations influence evaluation. A single-stakeholder approach would obscure these differences and risk oversimplifying user expectations. Designing robot behavior for shared spaces therefore requires a multi-stakeholder perspective that explicitly accounts for asymmetric expectations and their varying strengths.

B. Bridging Asymmetric Waiting Experiences

From the customer perspective, perceived processing time was influenced more by system transparency than by the robot's specific queuing behavior. Negative emotions increased particularly when participants could not understand what the robot was doing. These reactions were most pronounced in situations involving vertical mobility, such as elevators or stairs, or uncertainty about whether the robot could locate the correct destination inside a building. This pattern indicates that, for customers, the visibility and interpretability of system-provided information played a more critical role than the robot's behavioral strategy itself.

Conditions that visualized the robot's movement reduced this uncertainty. Although actual waiting time was identical across conditions, perceived processing time was shorter when movement information was provided. In contrast, conditions that presented only a simple loading bar without movement information produced consistently longer perceived processing times and lower ratings of sociability and service quality, regardless of the robot's queuing behavior. These results align with prior work showing that transparency supports trust formation and reduces uncertainty [21], [22], [26]. The present findings further suggest that transparency functions as a key design mechanism for aligning heterogeneous expectations in multi-stakeholder environments.

The results indicate that robot behavior should not be designed as a single fixed social norm. Instead, robot behavior and interface design should jointly address differences in expectation strength and interpretation across stakeholders. These findings suggest that social acceptance and service efficiency are not necessarily opposing goals. By satisfying minimal norm compliance requirements in shared physical spaces and simultaneously supporting customers' understanding of the delivery process through transparent interface design, delivery robots can address the expectations of both stakeholder groups without sacrificing efficiency. Therefore, from a real-world business perspective, designing delivery robots for shared spaces requires moving beyond single-user optimization. Such designs adopt strategies that account for multi-stakeholder tensions and asymmetries.

VI. FUTURE DIRECTIONS

Our evaluations demonstrated the value of examining delivery robot queuing behaviors from multiple perspectives, and raised several directions for future research. First, the experiment modeled a 1:1 interaction, which does not reflect the social density of many real-world environments. Future studies should evaluate robot behavior in multi-human scenarios to understand how crowding and time pressure influence human judgments of queuing behaviors. Second, we focused on customers and InCops as the primary stakeholders. Real-world service ecosystems also include business operators such as restaurants and robot service providers. Incorporating these stakeholders will help reveal how queuing behaviors affect operational efficiency and service outcomes. Third, the progress UI used in this study was simplified to control for interface design effects on perceived waiting time. However, real-world delivery systems often present progress through more granular and context-rich stages. Future research should examine how ecologically valid progress interfaces interact with robot queuing behaviors.

VII. CONCLUSION

We conducted an empirical study using a real delivery robot to examine how its queuing behaviors influence perceived waiting time, perceived sociability, acceptance, and service

This article has been accepted for publication in IEEE Robotics and Automation Letters. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/LRA.2026.3686647

quality. The study adopted a multi-stakeholder perspective by including both customers and InCops. We collected questionnaire responses and user journey maps to analyze how different robot behaviors shape user impressions across stakeholder roles in shared spaces. Our findings reveal a shared expectation across stakeholders: delivery robots should not cut in line to humans and provide transparent information about their actions. These results suggest that complying with social norms may be more important than optimizing for speed alone.

REFERENCES

[1] D. Jennings and M. Figliozzi, "Study of sidewalk autonomous delivery robots and their potential impacts on freight efficiency and travel," *Transportation Research Record*, vol. 2673, pp. 317–326, 2019.

[2] D. H. Maister *et al.*, *The psychology of waiting lines*. Boston, MA: Harvard Business School, 1984.

[3] A. N. Chen, Y. Lee, and Y. Hwang, "Managing online wait: Designing effective waiting screens across cultures," *Information & Management*, vol. 55, pp. 558–575, 2018.

[4] N. Kim and S. S. Kwak, "Investigating behavioral and cognitive changes induced by autonomous delivery robots in incidentally copresent persons," in *Proc. of the IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*. IEEE, 2024, pp. 2514–2519.

[5] B. Lin, W. Lee, R. Yang, and E. Lim, "Examining the effects of values and risks on outdoor food delivery robot adoption using mixed methods: different stakeholders' perspectives," *Information Technology & Tourism*, vol. 27, pp. 157–188, 2025.

[6] S. Kim, S. Bak, and K. Kim, "Which robot do you prefer when boarding an elevator: Fast vs. considerate," in *Extended Abstracts of the CHI Conf. on Human Factors in Computing Systems*. New York, NY, USA: Association for Computing Machinery, 2024, pp. 1–7.

[7] X. Yu, M. Hoggenmüller, T. T. M. Tran, Y. Wang, and M. Tomitsch, "Understanding the interaction between delivery robots and other road and sidewalk users: A study of user-generated online videos," *ACM Trans. Human-Robot Interaction*, vol. 13, no. 4, pp. 1–32, 2024.

[8] M. Van Hagen, *Waiting Experience at Train Stations*. Delft, Netherlands: Eburon Uitgeverij BV, 2011.

[9] D. A. Norman, "The psychology of waiting lines," *Excerpt of*, vol. 3, pp. 1–21, 2008.

[10] D. A. Thompson, P. R. Yarnold, D. R. Williams, and S. L. Adams, "Effects of actual waiting time, perceived waiting time, information delivery, and expressive quality on patient satisfaction in the emergency department," *Annals of Emergency Medicine*, pp. 657–665, 1996.

[11] F. Babel, R. Welsch, L. Miller, P. Hock, S. Thellman, and T. Ziemke, "A robot jumping the queue: Expectations about politeness and power during conflicts in everyday human-robot encounters," in *Proc. of the CHI Conf. on Human Factors in Computing Systems*. New York, NY, USA: Association for Computing Machinery, 2024, pp. 1–13.

[12] D. Kang, C. Nam, and S. S. Kwak, "Robot feedback design for response delay," *Int. Journal of Social Robotics*, pp. 341–361, 2024.

[13] D. Gallo, P. L. Bioche, J. K. Willamowski, T. Colombino, S. Gonzalez-Jimenez, H. Poirier, and C. Boulard, "Investigating the integration of human-like and machine-like robot behaviors in a shared elevator scenario," in *Proc. of the ACM/IEEE Int. Conf. on Human-Robot Interaction*. New York, NY, USA: Association for Computing Machinery, 2023, pp. 192–201.

[14] P. Salvini, C. Laschi, and P. Dario, "Design for acceptability: improving robots' coexistence in human society," *Int. Journal of Social Robotics*, vol. 2, pp. 451–460, 2010.

[15] W.-t. Law, K.-s. Li, K.-w. Fan, T. Mo, and C.-k. Poon, "Friendly elevator co-rider: An hri approach for robot-elevator interaction," in *Proc. of the ACM/IEEE Int. Conf. on Human-Robot Interaction (HRI)*. Sapporo, Japan: IEEE, 2022, pp. 865–869.

[16] J. Złotowski, K. Yogeeswaran, and C. Bartneck, "Can we control it? autonomous robots threaten human identity, uniqueness, safety, and resources," *Int. Journal of Human-Computer Studies*, pp. 48–54, 2017.

[17] S. Choi, A. S. Mattila, and L. E. Bolton, "To err is human (-oid): how do consumers react to robot service failure and recovery?" *Journal of Service Research*, vol. 24, no. 3, pp. 354–371, 2021.

[18] B. F. Malle and M. Scheutz, "Moral competence in social robots," in *Machine ethics and robot ethics*. Routledge, 2020, pp. 225–230.

[19] L. Yu and Y. Li, "Artificial intelligence decision-making transparency and employees' trust: The parallel multiple mediating effect of effectiveness and discomfort," *Behavioral Sciences*, p. 127, 2022.

[20] K. Sweeny, "Waiting well: Tips for navigating painful uncertainty," *Social and Personality Psychology Compass*, pp. 258–269, 2012.

[21] U. Bhatt, J. Antorán, Y. Zhang, Q. V. Liao, P. Sattigeri, R. Fogliato, G. Melançon, R. Krishnan, J. Stanley, O. Tickoo *et al.*, "Uncertainty as a form of transparency: Measuring, communicating, and using uncertainty," in *Proc. of the AAAI/ACM Conf. on AI, Ethics, and Society*. New York, NY, USA: Association for Computing Machinery, 2021, pp. 401–413.

[22] Y. G. Lee, A. N. Chen, and T. Hess, "The online waiting experience: Using temporal information and distractors to make online waits feel shorter," *Journal of Association for Information Systems*, p. 1, 2017.

[23] C.-H. Chen and W. Zhai, "The effects of dynamic prompt and background transparency of hover feedback design on the user interface of shopping websites," *Asia Pacific Journal of Marketing and Logistics*, vol. 35, pp. 809–827, 2023.

[24] S. N. Lingam, S. M. Petermeijer, I. Torre, P. Bazilinskyy, S. Ljungblad, and M. Martens, "Behavioral effects of a delivery drone on feelings of uncertainty: a virtual reality experiment," *ACM Trans. Human-Robot Interaction*, 2025.

[25] K. E. Weick and K. M. Sutcliffe, *Managing the Unexpected: Resilient Performance in an Age of Uncertainty*. San Francisco, CA: John Wiley & Sons, 2011, vol. 8.

[26] J. B. Lyons and P. R. Havig, "Transparency in a human-machine context: Approaches for fostering shared awareness/intent," in *Int. Conf. on Virtual, Augmented and Mixed Reality*, ser. Lecture Notes in Computer Science, vol. 8525. Heraklion, Crete, Greece: Springer, 2014, pp. 181–190.

[27] M. M. De Graaf, B. F. Malle, A. Dragan, and T. Ziemke, "Explainable robotic systems," in *Companion of the ACM/IEEE Int. Conf. on Human-Robot Interaction*, 2018, pp. 387–388.

[28] *Industrial trucks – Safety requirements and verification – Part 4: Driverless industrial trucks and their systems*, Int. Organization for Standardization Std. ISO 3691-4:2020, 2020.

[29] J. L. Brooks, "Counterbalancing for serial order carryover effects in experimental condition orders." *Psychological methods*, vol. 17, no. 4, p. 600, 2012.

[30] N. Dahlbäck, A. Jönsson, and L. Ahrenberg, "Wizard of oz studies: why and how," in *Proc. of the 1st Int. Conf. on Intelligent user interfaces*, 1993, pp. 193–200.

[31] Y.-H. Wu, J. Wrobel, M. Cornuet, H. Kerhervé, S. Damnée, and A.-S. Rigaud, "Acceptance of an assistive robot in older adults: a mixed-method study of human–robot interaction over a 1-month period in the living lab setting," *Clinical interventions in aging*, pp. 801–811, 2014.

[32] J. D. Van Der Laan, A. Heino, and D. De Waard, "A simple procedure for the assessment of acceptance of advanced transport telematics," *Transportation Research Part C: Emerging Technologies*, 1997.

[33] M. K. Lee, S. Kiesler, J. Forlizzi, S. Srinivasa, and P. Rybski, "Gracefully mitigating breakdowns in robotic services," in *Proc. of ACM/IEEE Int. Conf. on Human-Robot Interaction*, 2010, pp. 203–210.

[34] A. Lisetschko, S. van Ledden, A. D. Mäder, N. Jansen, and A. Dogangün, "Innovative solutions for libraries: A user-centric cumulative study on the requirements analysis for the use of social robots," in *Proc. of Australasian Conf. on Human-Computer Interaction*, 2024, pp. 431–441.

[35] S. Khan and C. Germak, "Reframing hri design opportunities for social robots: Lessons learnt from a service robotics case study approach using ux for hri," *Future internet*, vol. 10, no. 10, p. 101, 2018.

[36] T. Howard, "Journey mapping: A brief overview," *Communication Design Quarterly Review*, vol. 2, no. 3, pp. 10–13, 2014.

[37] G. Terry, N. Hayfield, V. Clarke, V. Braun *et al.*, "Thematic analysis," *The SAGE handbook of qualitative research in psychology*, vol. 2, no. 17-37, p. 25, 2017.

[38] J. Chepur and R. Bellamkonda, "Examining the conceptualizations of customer experience as a construct," *Academy of Marketing Studies Journal*, vol. 23, no. 1, pp. 1–9, 2019.

[39] W. A. Bainbridge, J. W. Hart, E. S. Kim, and B. Scassellati, "The benefits of interactions with physically present robots over video-displayed agents," *Int. Journal of Social Robotics*, pp. 41–52, 2011.