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Social Acceptance of Autonomous Food Delivery Robots: An Analysis of Public Commentaries

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Abstract
Although autonomous delivery robots (ADRs) offer a feasible solution for last-mile delivery, there is still limited research on how individuals outside direct users, such as other road users, community residents, and the public, perceive ADRs. This study aims to understand the social acceptance of ground-based food ADRs used for grocery delivery in Finland, where long distances and harsh winter conditions pose challenges for robotic delivery services. An analysis of publicly available reader comments on news articles about food ADRs revealed four categories of contextual factors related to their use, including aspects of the robots' appearance, operations, and safety and security. This study contributes to our understanding of factors influencing public opinion and social acceptance of service robots and offers practical implications for those designing or deploying autonomous delivery robots.

Keywords: Social acceptance, robots, service robots, autonomous delivery robots, food delivery robots

Type: Article

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1. Introduction

The growth of e-commerce has been accompanied by the need for quicker deliveries, a shortage of drivers, and increasing fuel costs, pushing firms to develop robotic last-mile delivery technologies (Bakach et al., 2020; Simoni et al., 2020; Law et al., 2021; Camprisi et al., 2023). Traditional delivery methods are challenged by parking availability issues, fuel and fleet management costs, and narrow drop-off time windows (Srinivas et al., 2022). In contrast, robotic delivery offers numerous benefits, including reduced manpower requirements, improved efficiency, lower operational costs, and faster deliveries (Graetz & Michaels, 2018; Bogue, 2019; Hossain, 2023). Furthermore, public interest in robotic delivery increased during the pandemic due to its lack of interpersonal contact (Bogue, 2020; Seyitoğlu & Ivanov, 2020; Zeng et al., 2020; Bhattacharya et al., 2021; Byrd et al., 2021; Meidute-Kavaliauskiene et al., 2021).

Nonetheless, limitations related to capacity, performance, regulations, safety, legality, and societal aspects have slowed the adoption of autonomous delivery robots (ADRs) and drones (Bogue, 2019; Rubio et al., 2019; Simoni et al., 2020; Bachofner et al., 2022; Ostermeier et al., 2022). Current airspace traffic regulations restrict the widespread application of autonomous drones (Sharma et al., 2020), and drone noise can be disruptive in urban environments (Bakach et al., 2021). Furthermore, the load capacity of drones is suboptimal compared to ground-based robots (Simoni et al., 2022), and drones must find safe drop-off spots while being sensitive to weather conditions (Ostermeier et al., 2022; Ganjipour & Edrisi, 2023). As a result, multi-wheeled mobile robots operating on sidewalks provide a more effective option for robotic parcel delivery (Rubio et al., 2019; Jiang et al., 2022). Users' opinions on ADRs are generally positive, making them a promising option for last-mile deliveries (Bakach et al., 2021; Ostermeier et al., 2022).

In line with the observation by Ivanov et al. (2019) that service robot research has largely adopted an engineering perspective, previous studies have focused on the design and functionality of ADRs (Liemhetcharat et al., 2015; Quan et al., 2020; Simoni et al., 2020; Srinivas et al., 2022). Hossain (2023) identified key factors affecting ADR acceptance, including user concerns (perception, costs, service faults, safety, and efficiency) and supportive elements (regulation, infrastructure, and city characteristics). However, research on social acceptance, particularly regarding secondary users like drivers, bicyclists, and pedestrians, remains scarce (Law et al., 2021). More studies are needed to understand public perceptions and reactions to ADRs (Naneva et al., 2020; Pani, 2020; Tussyadiah et al., 2020; Yuen et al., 2022; Merdin-Uygur & Ozturkcan, 2023) as their use increases. This is crucial since perceptions vary by robot type, application, and location, and public opinion evolves with greater exposure and awareness of robot capabilities (Naneva et al., 2020; Nomura & Tanaka, 2022).

This study aims to identify the factors influencing the social acceptance of food ADRs. Social acceptance is defined as a favorable or positive response to a technology by members of a given social unit (e.g., country, region, city, or neighborhood) (Gaede & Rowlands, 2018). It refers to the extent to which a new and potentially controversial technology is accepted or tolerated by a community, rather than solely focusing on individual users' intention to adopt it, which falls under the concept of technology acceptance (Savela et al., 2018). Wolsink (2018) argues that social acceptance encompasses perceptions related to the promotion of and opposition to new technology. This study analyzes reader comments on news articles about the introduction of food ADRs by Alepa, a Finnish retailer. By doing so, the study identifies and categorizes factors that reflect the social acceptance of ADRs by community members who may be affected by these service robots.

2. Literature review

2.1. Social acceptance as a perspective to public opinion

The adoption of technologies can be examined through different theoretical lenses. For instance, technology acceptance focuses on an individual's intention and decision to use, or continue using, a technology (de Jong et al., 2019; Cha, 2020; Song & Kim, 2022; Yuen et al., 2022; Ganjipour & Edrisi, 2023). It emphasizes technological factors such as usefulness and ease of use that influence a person's decision regarding adoption or non-adoption.

Non-adoption is distinct from resistance, as the technology may simply not be useful enough for the intended purpose (Bao, 2009). In contrast, social acceptance reflects community members' support or tolerance for a technology whose use affects the community (Savela et al., 2018; Westerlund, 2020). Therefore, social acceptance is often also understood as public acceptance (Gupta et al., 2012), public acceptability (Baur et al., 2022), or community acceptance (Nielsen et al., 2022).

Both technology acceptance and social acceptance are influenced by positive or negative beliefs and attitudes toward a new technology (de Graaf et al., 2019; Belanche et al., 2020). Baur et al. (2022) note that even positive attitudes do not necessarily reflect a person's complete opinion on the matter. Social acceptance also encompasses social rejection, indicating the extent to which a technology is opposed due to its perceived harmful effects on the community (DeWall & Bushman, 2011). Technologies such as cloning, nuclear power, artificial intelligence (AI), and robotics have been associated with societal controversies, leading to resistance and rejection (Gupta et al., 2012; Baur et al., 2022; Hübner et al., 2023). However, understanding the factors that hinder social acceptance can help facilitate the introduction of controversial technologies in society (Hübner et al., 2023). Taebi (2017) argues that social acceptance should also encompass ethical acceptance, which considers the moral issues that arise with the introduction of new technologies.

2.2. Social acceptance factors of autonomous delivery robots

Last-mile logistics account for much of the overall cost and delivery inefficiencies (Bogue, 2019; Belanche et al., 2020; Bachofner et al., 2022; Camprisi et al., 2023), prompting food businesses to seek alternative solutions (Bhattacharya et al., 2021). Robotic deliveries are argued to provide significant savings in operational costs compared to conventional delivery methods (Bakach et al., 2020). Consequently, ADRs have begun to replace manual food deliveries, which are constrained by human limitations such as time and availability (Law et al., 2021). They travel along sidewalks to consumers' specified destinations at low speeds (Koh & Yuen, 2023). However, they can still help meet delivery deadlines, particularly during high-traffic hours, while achieving greater routing efficiency and delivery density (Plank et al., 2022; Camprisi et al., 2023).

Service automation is argued to become increasingly influential on service experience (Buhalis et al., 2024). While people react differently to service automation like ADRs (Huang & Rust, 2021), they must adapt to today's high-tech service environment and learn to use such service robots (Seyitoğlu & Ivanov, 2020). Seyitoğlu and Ivanov (2020) also note that the introduction of automation technologies may create potential service failures and frustrations for other members of society, making it important to understand their perceptions of delivery robots. According to Naneva et al. (2020), cognitive attitudes reflect an individual's thoughts or evaluations, such as the perceived usefulness of ADRs, while affective attitudes reflect their feelings or emotions toward robots. Robot acceptance is influenced by cognitive and emotional responses, both actively and passively (i.e., unconsciously) (Castro et al., 2020; de Graaf et al., 2019). Table 1 lists key categories and subcategories regarding the social acceptance of delivery robots.

Table 1. *Key categories of social acceptance of delivery robots*

Contextual	**Appearance**	**Operations**	**Safety & Security**
Sensitivity	Familiarity	Usefulness	Traffic safety
Suitability	Cuteness	Functionality	Liability
Exposure	Adaptability	Reliability	Food safety
	Interaction	Sustainability	Cybersecurity
		Usability	

2.2.1. Contextual factors

Three distinct contextual factors (sensitivity, suitability, exposure), which refer to specific use contexts and characteristics unique to particular communities, are discussed below.

Sensitivity. Contactless delivery using ADRs gained popularity during the pandemic (Pani et al., 2020; Meidute-Kavaliauskiene et al., 2021; Zeng et al., 2020; Aymerich-Franch & Ferred, 2022; Merdin-Uygur & Ozturkcan, 2023). Upon arrival at the customer's doorstep, an ADR notifies the customer and allows them to self-collect items from the robot's freight compartment (Koh & Yuen, 2023). Pitardi et al. (2022) found that some people prefer robotic delivery for purchasing 'embarrassing products' online, as it allows them to avoid potentially uncomfortable interactions with delivery employees (Pitardi et al., 2022). Customers feel less embarrassed interacting with a service robot, as robots cannot make moral or social judgments and lack feelings (Pitardi et al., 2022). Moreover, robotic delivery can streamline the service process, providing customers with a smooth, safe, and uninterrupted experience (Huang & Rust, 2021).

Suitability. Previous research has found that the suitability of a technology for its use environment is an important factor in its acceptance (Tussyadiah et al., 2020; Chi et al., 2023). ADRs are equipped with wheels, allowing easy movement within their designated "workspace" (Cha, 2020; Gehrke et al., 2023; Ganjipour & Edrisi, 2023; Koh & Yuen, 2023). They can self-navigate in various environments, avoiding obstacles on roads (Rubio et al., 2019; Law et al., 2021), and are well-suited for urban environments characterized by high densities of stops and short delivery distances (Simoni et al., 2020). However, ADRs operate at low speeds (Sharma et al., 2020; Simoni et al., 2020), which imposes limitations on the types of fresh food items that can be delivered. Additionally, weather conditions can vary by geographical location, meaning that temperature and road conditions may unexpectedly impact ADR performance (Plank et al., 2022).

Exposure. Visibility, i.e., the increasing presence of ADRs on roads, can enhance people's intention to adopt robotic delivery (Kaur et al., 2021b; Pitardi et al., 2022). Populated urban areas, such as cities and university campuses, are environments where people are most likely to observe ADRs (Bogue, 2020; Gehrke et al., 2023). For instance, Starship Technologies' mobile ADR is highly visible when in use; it weighs 20 kilograms, has a payload capacity of 10 kilograms, and can travel up to 15 kilometers between charges (Bogue, 2019; Bogue, 2020), making it suitable for last-mile distribution of small parcels, groceries, and food (Simoni et al., 2020). This robot moves at a slow speed (4 mph, 6 km/h) and uses a chirping proximity alert sound that can attract the attention of other road users (Gehrke et al., 2023; Mishra et al., 2023).

2.2.2. Appearance factors

The following sections discuss familiarity, cuteness, adaptability, and interaction as factors that pertain to the robot's appearance and its interaction characteristics when engaging with people.

Familiarity. People form impressions of robots by assessing their physical familiarity (Song & Kim, 2022). Robots can be categorized into two primary types—humanoids and non-humanoids—based on the degree of their resemblance to humans (Naneva et al., 2020). Non-humanoid robots include 'zoomorphic' designs, which feature an animal-like appearance, and 'functional' designs, characterized by a task-specific form that may appear unfamiliar (Seyitoğlu et al., 2021). Anthropomorphizing—i.e., giving a robot a human-like appearance, name, or behavior—may lead to discomfort compared to a more machine-like appearance (Lu et al., 2019; Mende et al., 2019; Odekerken-Schröder et al., 2022). Service robots are often designed to appear and interact in a less threatening manner, distinguishing them from industrial robots (Zeng et al., 2020).

Cuteness. A robot's cuteness plays an important role in human-robot interactions (Lv et al., 2022). For instance, non-humanoid robots with a 'cute babyface' are well-perceived (Chen & Jia, 2023), and people react emotionally when they observe cute robots being petted or mistreated (de Graaf et al., 2019). Thus, the design of a robot's appearance, vocal features—such as tone of voice, speed of speech, and language style—can significantly impact people's perceptions (Huang et al., 2021; Seyitoğlu et al., 2021). Some robots can even enhance their likeability through nonverbal cues, including socially responsive gaze, gestures (e.g., nodding, head tilting), and sounds (Wang et al., 2019; Maggi et al., 2022; Chen & Jia, 2023). A cute appearance can mask a robot's potentially

intimidating capabilities as a networked, smart, and autonomous device (Caudwell & Lacey, 2020; Yoganathan et al., 2021) and may increase user tolerance of service failures (Huang et al., 2021).

Adaptability. A robot's ability to integrate into the surrounding social structures and activities of a given context is crucial for its acceptance (Gaudiello et al., 2016). While virtual robots like chatbots can easily alter their appearance, physical robots can primarily adjust interaction characteristics such as voice and language style (Lv et al., 2022). In such cases, adaptation might involve selecting a gendered voice, like male or female, based on user preferences (de Jong et al., 2019) or greeting users in a culturally adapted manner (Trovato et al., 2015). That said, vacuum robots tend to be more readily accepted than social robots, regardless of vocal characteristics or other adaptive features (Nomura & Tanaka, 2022), possibly because robots performing functional tasks are more easily accepted than those engaging in social tasks (Gaudiello et al., 2016).

Interaction. Delivery robots can communicate with people using lights to indicate changes in direction (Aymerich-Franch & Ferrer, 2022). While voice- and gesture-based interaction capabilities can promote robot acceptance (Maurtua et al., 2017), the lack of true social communication may frustrate some users (Seyitoğlu & Ivanov, 2020). Robots with natural-language capabilities can better engage users through "feeling intelligence" (Huang & Rust, 2021). In human-robot interaction, feeling intelligence refers to the emotions a person experiences toward the robot, enabling robotic responses to be adapted based on those emotions (Huang & Rust, 2021). This can enhance the perceived positive "warmth"—a sense of the robot's intent to do good rather than harm—which influences acceptability (Yoganathan et al., 2021). Additionally, a robot's perceived personality during interactions has been found to impact acceptability (Park et al., 2012).

2.2.3. Operational factors

Previous research emphasizes five factors associated with ADR operations: usefulness, functionality, reliability, sustainability, and usability.

Usefulness. Robot acceptance is influenced by utilitarian and hedonic values (de Graaf & Allouch, 2013). The former refers to the usefulness of a robot, while the latter pertains to the enjoyment associated with the robotic service experience (de Graaf & Allouch, 2013; de Graaf et al., 2019; Lu et al., 2019; Odekerken-Schröder et al., 2022). Usefulness is linked to performance, i.e., the robot's ability to effectively carry out its intended actions (Yoganathan et al., 2021), particularly regarding efficiency, timesaving, and convenience (Song & Kim, 2022; Mishra et al., 2023). Convenience, in terms of reducing the physical effort required from customers, has been shown to increase the use of food ADRs (Byrd et al., 2021). However, perceived usefulness is not always a positive factor; it can also lead to "technophobia," a fear associated with novel technologies (Tussyadiah et al., 2020; Subero-Navarro et al., 2022). People may experience "robot anxiety" and feel uncomfortable when seeing robots at work or interacting with them (Saari et al., 2022).

Functionality. A robot's smooth movement is associated with its acceptability (Savela et al., 2018; Song & Kim, 2022). Cha (2020) notes that people often describe service robots as "cool," a term that reflects their functionality and the benefits they provide. Huang et al. (2021) suggest that a robot's unexpected ability to perform complex functions during service may even prompt people to view themselves as out of touch with the latest technological advancements. However, a robot's functionality and ability to deliver intended benefits may not be essential for its social acceptance; psychological factors, such as individual attitudes, also play a role (Gaudiello et al., 2016; Castro et al., 2020). Some studies (e.g., de Graaf & Allouch, 2013; de Graaf et al., 2019) link perceived usefulness to general attitudes toward autonomous technology. Utilitarian values, such as the benefits of use, are often associated with cognitive evaluations of technology.

Reliability. Perceived reliability is a significant precursor to ADR acceptability, as people may hesitate to adopt them due to potential malfunctions (Bhattacharya et al., 2021). Indeed, mechanical or software malfunctions

can expose robots to risks, such as traffic accidents. Therefore, fault tolerance is a key design aspect, particularly given that ADRs rely on internet connectivity to replace many crucial on-board sensors and data processing tasks, leaving the robot vulnerable in case of connectivity issues (Simoens et al., 2018). Simoens et al. (2018) argue that reliability encompasses the robot's hardware and software components, as well as various safety guarantees in human-robot interaction, and reflects the extent to which a robot's systems can continue their mission amid failures or unforeseen events. Reliability also includes the robot's capacity to anticipate faults and initiate necessary preemptive measures (Simoens et al., 2018).

Sustainability. The benefits of delivery robots also include environmental sustainability (Pandey et al., 2021). As sustainability increasingly influences consumers' purchasing decisions, they may favor options with lower environmental impacts in terms of energy consumption, air pollution, and sustainable packaging (Byrd et al., 2021; Mohammad et al., 2023). ADRs run on electricity, with significantly lower noise levels and CO_2 emissions compared to traditional delivery methods (Srinivas et al., 2022; Ganjipour & Edrisi, 2023). They can, in fact, reduce inner-city traffic and support initiatives toward emission reduction, zero-emission goals, and climate change mitigation, positioning them as a green approach to last-mile delivery (Pani et al., 2020; Plank et al., 2022; Ganjipour & Edrisi, 2023; Ostermeier et al., 2023). ADRs are not only economical but also provide a sustainable alternative to truck-based delivery, especially in cases of scattered demand points, inconvenient delivery times, and higher urban air pollution risks (Mishra et al., 2023).

Usability. Robots can perform complex tasks tirelessly, at a lower cost, and with fewer errors and greater accuracy (Sheridan, 2016; Meidute-Kavaliauskiene et al., 2021; Song & Kim, 2022). However, the usability of ADRs depends on factors such as the number and size of compartments, carrying capacity, speed, operational range, and the quality of routing and navigation algorithms (Liemhetcharat et al., 2015; Quan et al., 2020; Simoni et al., 2020; Bakach et al., 2021). These factors can be enhanced through the "mothership model," where human driver transports goods by truck to a drop-off area and then deploys a fleet of robots to deliver parcels to customers' doors (Yoganathan et al., 2021; Ostermeier et al., 2022; Srinivas et al., 2022; Ostermeier et al., 2023). This approach shortens delivery times, as the average length of delivery routes is reduced, enabling a few robots to deliver many parcels (Sharma et al., 2020; Ostermeier et al., 2021). Additionally, usability includes accessibility when picking up orders from the ADR, which can be challenging for users with mobility disabilities (Sipetas et al., 2023).

2.2.4. Safety and Security

Finally, four factors are associated with safety and security: traffic safety, liability, food safety, and cybersecurity.

Traffic safety. The safety of humans around the robot can be enhanced by limiting its speed and improving pre-collision strategies to avoid causing harm (Maurtua et al., 2017). ADRs typically move slowly and quietly on pedestrian pathways, minimizing interference with residents, pedestrians, and other road users, such as cyclists (Ostermeier et al., 2022). However, Law et al. (2021) found that many people perceive ADRs as too slow, overly cautious, and prone to abrupt stops when encountering pedestrians. Additionally, Saari et al. (2022) suggest that some individuals fear injury from a robot. Therefore, robots must maintain constant awareness of their surroundings to adjust speed and trajectory as needed, and their design should avoid sharp edges (Maurtua et al., 2017). The use of route markers, for example, to alert others to potential collisions, may be challenging in urban environments where ADRs operate on public sidewalks and seldom follow pre-programmed routes due to the high number of customers and varied drop-off locations.

Liability. Many people tend to hold autonomous robots, like ADRs, accountable for their actions and blame them in the event of negative outcomes (Westerlund, 2020b; Pitardi et al., 2022). This is because such robots are expected to perform their services flawlessly, independently, and without user control (Gaudiello et al., 2016). ADRs are anticipated to operate smoothly throughout service interactions, prioritizing the user's

interests over others' (Merdin-Uygur & Ozturkcan, 2023). Consequently, Belanche et al. (2020) suggest that food delivery companies should focus on increasing customers' perceived control over ordering, delivery tracking, and other app functions, especially among older consumers who may be more hesitant to adopt such technology. ADRs operating on public roads can cause or be involved in various traffic incidents, and Sheridan (2016) notes that collision avoidance and liability remain ongoing concerns for robot manufacturers.

Food safety. Another safety concern relates to the items being carried, especially groceries. Customers value the cleanliness of food containers and the excellent condition of received orders, along with affordable delivery costs (Ray et al., 2019). Byrd et al. (2021) argue that food ADRs face several challenges, particularly in terms of food safety (e.g., maintaining food temperature) and food quality (e.g., appearance, freshness, and prevention of spills or leaks). However, robotic delivery users tend to have lower expectations compared to human delivery. Nonetheless, ADRs must keep hot food warm in winter and cold food cool in summer, and they must ensure food packaging remains clean and dry, even in rain or snow (Byrd et al., 2021). According to Belanche et al. (2020), food safety also involves the security of the delivery; for instance, the robot must prevent tampering (i.e., intentional food contamination) by external parties (Byrd et al., 2021).

Cybersecurity. Although connectivity enables the robot to inform the retailer and customer of its current location and estimated arrival time (Huang & Rust, 2021), and even provide real-time video feed in case of theft attempts, it also introduces potential cybersecurity risks (Byrd et al., 2021). A cyber attacker could reprogram the ADR to cause unexpected or rogue behavior (Oravec, 2023). Such behavior would harm the reputation of robotic delivery services; therefore, the security of carried items and the protection of sensitive customer information are essential (Belanche et al., 2020). ADR designers should work to enhance the information security of their apps and robots, implementing data protection measures and barriers against malware and hacking, as well as providing transparent information about their security measures and privacy policies (Belanche et al., 2020). Su et al. (2022) notes that investing in security to protect sensitive customer data is crucial to ensuring privacy and increasing acceptance of food delivery services.

3. Method

3.1. Data collection and approach

While most studies on the acceptance of food delivery services and robots rely on quantitative research (e.g., de Graaf et al., 2019; Saari et al., 2022), a qualitative approach can better address contextual nuances and therefore provide a deeper understanding of people's attitudes toward the technology (Pandey et al., 2021). Although qualitative studies frequently use interviews (Pandey et al., 2021), this study focuses on textual data collected from the comment sections of publicly available online news articles. This approach aligns with previous studies on human-robot public perception (e.g., Huang et al., 2021), which recognize user-generated content—such as text, pictures, or videos on online platforms—as valuable data for understanding public opinions about robots. A total of 401 "reader comments" were collected from online newspapers in Finland, a sparsely populated Northern European country with relatively long distances between locations. In April 2022, Alepa, a major Finnish retailer, launched a robotic grocery delivery service for customers in Espoo, the country's second-largest city. Comments submitted by readers in response to 16 online news articles about the launch were collected from April to August 2022.

3.2. Relevance of contextual factors in data

According to Pandey et al. (2021), contextual factors such as geography and weather may increase the adoption of food delivery services, while limited financial resources may prevent consumers from using these services (de Graaf et al., 2019). Some people prefer to shift the inconveniences associated with long distances, traffic jams, and adverse weather conditions (e.g., snow, rain) to intermediaries like the Uber Eats delivery service. Mohammad et al. (2021) note that ground-based ADRs are less affected by weather conditions than drones. However, since food ADRs are smaller than cars and delivery trucks, factors like weather and physical distance

can influence people's evaluations of ADR usefulness and performance, as well as their perceptions of ADRs navigating traffic. Therefore, this study considers weather and geographical factors as relevant contextual influences on food ADR adoption. In addition to long distances, Finland's long, cold, and snowy winters pose challenges to the operation and performance of battery-operated technology (e.g., reduced battery life) and ADRs driving on snowy and icy roads during winter.

3.3. Data analysis of the corpus

Unstructured qualitative data, such as text, is often analyzed using software like NVivo. However, in this study, the coding and analysis of reader comments were conducted manually to allow for deeper immersion in the data and to enhance interpretative depth. Following the method used by Pandey et al. (2021), the collected data were compiled into a corpus file and analyzed using a thematic coding technique. A "coding manual" with a predefined set of coding categories was developed based on the literature review. In line with Pandey et al. (2021), this coding manual was created by identifying and labeling relevant coding categories from prior studies. Throughout the process, multiple rounds of revision were conducted to refine the coding categories by merging, adding, or removing redundant and overlapping categories. The coding manual facilitated the identification of new and previously unrecognized categories within the data, thereby contributing to existing literature. Each comment was analyzed and categorized according to the coding manual. For comments that aligned with multiple categories, segments were split into shorter text passages following the manual's guidelines. During analysis and interpretation, reflective keywords and phrases were highlighted and selected as illustrative examples when reporting the results.

4. Findings

4.1. Contextual factors

Suitability. Numerous comments discussed the suitability of food ADR use in Finland, particularly during the winter months: "I'm not really convinced of the suitability of the technology to where we live, especially in these weather conditions." "During the winter, there is a lot of snow and ice on the ground due to neglected or poor maintenance," and thus, "ADR use is impossible without tracks or snow chains and ice removal." However, issues with suitability were not limited to winter conditions: "Sandblasting sand, snow in winter, leaves in autumn, torrential rains in summer, and various construction sites and barriers for road constructions" were considered to hinder ADR use. Some comments suggested that "when the weather conditions deteriorate and at the latest in the beginning of winter, the unsuitability of ADRs will be noticed." Consequently, there would be a need for costly "plowing robots or melting robots" or extended snow clearing and road maintenance to enable robotic delivery. On the other hand, winter was seen as a season when one "could really enjoy not having to go to the store but use robotic delivery instead." Accordingly, some comments argued that the delivery model should follow "a mixed work model, i.e., a person in the winter and a robot at other times, but one price.".

Societal impact. Multiple comments criticized the negative impact of robots on the labor force. Food ADRs are replacing humans who work in home delivery jobs by "taking the job of someone who could transport food safely to the customer," and companies using delivery robots "are trying to reduce the ever-smaller number of existing jobs." Furthermore, while each ADR "takes the work of at least one person," some comments questioned, "how will the society of the future, completely unemployed, survive?" The consequences of ADR adoption were seen as particularly harmful for young people seeking their first jobs: "The future is that stores/warehouses will not have staff, but robots will take care of everything," and people expressed a preference to "see retail owners hire young people with an electric scooter to deliver food orders, a perfect summer job or part-time job." An associated concern was the reduction in tax revenue due to job losses: "These robots don't bring any more tax revenue." Additionally, with the adoption of ADRs for food delivery, "profits are privatized, but the costs of accidents or changes in the infrastructure such as ADR-compatible traffic lights go to society." Although ADRs provide cost benefits to businesses by reducing their labor needs, some

suggested that "the benefits brought by automation should flow through society." Notably, some comments argued that "the design, manufacturing, and maintenance of ADRs provide employment.".

4.2. Appearance factors

Cuteness. Many comments noted that ADRs look "cute," "amusing," or "nice and sympathetic." Only one comment argued that "children will be frightened… could they make a face for these robots? Cute, big eyes at the minimum!" That said, someone mentioned that their children really enjoyed "these little robots that look as scary as a trash bin." Observing the cute robots made people "feel good," "have positive vibes," and "laugh in excitement." In one comment, "seeing these cute robots from the office window improves my well-being at work." Some associated cuteness with robotic behavior: "I enjoy watching them roaming around," "they look cute going ups and downs all alone," and "a fleet of them looks wildly funny, all lined up and then getting stuck at the traffic lights." Additionally, observing ADR behavior sparked an urge to help them: "seeing a robot getting stuck in the queue was so cute and aroused a strong desire to help," and "I saw two robots on the road and felt that I should protect them somehow… they are like toddlers in traffic." Regarding interaction, one comment noted that the robots "do not look sympathetic to me and do not attract my positive attention even if they greet you kindly," while another emphasized that it is important "the robot can communicate in Finnish, rather than only English.".

4.3. Operations

Usefulness. Perceptions of the usefulness of food ADRs were positive. Robotic delivery was seen as more reliable and dependable than human-operated delivery: "Doesn't a machine perform better than a human? A robot is not dangerous or dishonest," and "these [robots] do not strike and demand a monthly payment of 4000€, they do not get sick, and they do not harass customers." That said, some perceived humans as "the fastest, safest, and most reliable." Nonetheless, many comments pointed out that there are people with disabilities, illnesses, or injuries, as well as seniors who may have mobility issues that "complicate [their] movement," meaning they "may not be able to walk to the store." For them, ADRs are "sure to bring a lot of joy and benefit." Given the timeframe of the study, it is unsurprising that self-isolation due to COVID-19 was mentioned as a particular situation where food ADRs added value. Overall, robotic delivery was seen as "easy and convenient," and "customers can save time and effort," thus making "people's everyday lives easier." Some suggested additional value-creating tasks that the robots could perform, including "postal mail delivery," "returning customer's empty bottles to the store for a deposit refund," and "help with parking control" by reporting observed parking violations to police.

Functionality. Compared to usefulness, perceptions of food ADRs' functionality were more negative. Many comments emphasized the limitations of robotic functionality. The fact that users must go outside to collect their food items was criticized; unlike human-operated delivery, "the delivery robot cannot open doors, use the staircase or the elevator to go to the upper floors, or ring the doorbell." Instead, "the customer has to go out in the sleet and rain to collect their purchases," and "there are a lot of seniors who move poorly, who are too weak to carry a bag, and who cannot get to the front door of their apartment buildings to pick up a delivery." Additionally, various errors and malfunctions were mentioned. One comment stated, "the robot found its way [to my home] but did not open the lid." Many comments highlighted the impact of harsh winter conditions on robotic delivery: "I doubt those robots will operate properly in slush and snow," as their "wheels are too small" and "potholes, sand, snow, puddles, anything can be a hindrance." Furthermore, "under Finnish climate conditions, nothing should be introduced that relies on the markings on the road for navigation.".

Sustainability. Perceptions of food ADRs' environmental sustainability and green implications were mixed. On one hand, delivery robots were seen as contributing to reduced traffic and emissions, for example, "a very welcome development that will reduce the need for private cars" and "great idea, it also saves nature in terms of my motoring." On the other hand, some comments were more skeptical, suggesting that environmental

sustainability should not be used as an argument to promote food delivery robots, or at the very least, "using such an argument would be dubious." For example, some comments raised concerns that "the real carbon footprint of the robot is a question mark," noting that "battery materials and the electricity [used to charge a robot's battery] are not environmentally sustainable," and thus, "electric robots are not zero-emission technologies." Additionally, concerns were raised that robotics could lead to "pushing more plastic and battery waste into the world." It was also argued that "it would be more environmentally sustainable if the consumer walked or cycled to a convenience store." Notably, sustainability was mentioned in only a few comments.

4.4. Safety and Security

Traffic safety. Numerous comments argued that ADRs will inevitably be involved in accidents: "there's no doubt that accidents with these [robots] will happen at some point." Reasons why such accidents are unavoidable include that "these robots perform unexpected movements," "they take 90 degree turns," and "first they stand still and then start moving without a warning." Additionally, the robots have been observed to "go against the red traffic lights," causing near misses: "when the light turned red, the robot seemed to hesitate for a moment and then narrowly crossed the lane before getting hit by a car." ADRs are seen as potentially hazardous to other users of the road or sidewalk, such as children, bicyclists, motorists, and people with disabilities, because an ADR has "no lights or a turn signal, so you cannot predict where it is about to turn." One commenter reported seeing a pedestrian "dodge the robot onto the roadway… be careful when these [robots] are on the move, as pedestrians can unexpectedly leap to the front [of your car]." As a result, some argued, "we don't need any more obstacles or dangerous toys in the traffic." Additionally, a few comments suggested that the robots' coloring should be "yellow like a safety vest," because "in the winter, you don't notice them in the snow." That said, some comments were positive: "the robots seem to immediately slow down when they are approached by another road user and wait until the road user has passed… so they seem to anticipate the environment very well." Other comments argued that "you can't run into it unless you want to" and that the robot "moves so slowly that it doesn't make me worried at all.".

Liability. People are uncertain about liabilities in robot-involved traffic accidents or incidents, such as when food is stolen, lost, delayed, or damaged due to malfunction or sabotage. Some comments asked, "who is liable for road accidents caused by them?" and others suggested that liability should fall on the robot's manufacturer and/or the grocery store that owns the robot. Various types of incidents were described, including "direct impact" when a robot collides with another road user and "indirect impact" when a driver hits pedestrians while attempting to avoid a collision with an unexpectedly moving robot. Many comments questioned whether food ADRs need traffic insurance: "How do the Road Traffic Act and the Vehicle Act view them? Are they even required to have traffic insurance?" and "Are they vehicles [like cars]? They don't have features listed under the Vehicle Act. I guess their insurance matters are on the back burner." Some comments also addressed liabilities if the robots were to violate traffic laws: "When a robot violates the Road Traffic Act, then to whom to write a fine?" Suggestions included recommendations such as, "It is a matter of urgency to update the legislation so that it becomes clear who or what is a road user… and clarify if robots could be treated as road users who do not follow traffic rules intended for humans, similarly to animals such as elks and deer." This was seen as relevant from the perspective of financial liability for damages. A mandatory traffic insurance requirement for robots was considered important, as otherwise "companies make money, but taxpayers pay the costs like treatment of skull injuries." Updated traffic laws should also outline a robot's "correct use and penalties for traffic violations."

Food safety, cybersecurity, and robot safety. Many comments addressed concerns about food safety (e.g., the food may get stolen), cybersecurity (e.g., the robot may be hacked), and robot safety (e.g., the robot may face vandalism and violence). "Anyone can steal, topple or break the robot, or otherwise just make trouble for it." Another comment stated, "It's just a matter of time when someone throws a robot into a river/sea or takes a robot home and forcibly opens the lid, breaks the GPS and takes the food from the inside." Incidents like these could erode public trust in ADRs. One commenter mentioned, "[These robots] are a hacker's dream target."

The connectivity of food ADRs indeed makes them vulnerable to hacking and potential takeover, allowing a hacker to change delivery routes. On the other hand, people were largely unaware of the robots' security features, such as the requirement for a passcode to open the container lid and collect the food items. Finally, several comments highlighted concerns about robot safety: "It will be interesting to see how ADRs will cope with pranking, vandalism, and theft." The robot "tempts scythes to commit evil," and "all those people have to do is kick the robot on its side." Violence and vandalism could occur simply for amusement: "I saw a boy under 10 years old bullying the robot by constantly stepping in front of it, even though the robot was trying to get around. The boy used a cell phone to take a video of his antics."

Privacy. The introduction of AI-based traffic surveillance systems was noted somewhat positively: "The city is engaged in a pilot where AI monitors traffic, including pedestrians and cyclists. When a traffic jam forms on one of the lanes, it is eased by giving the green light to the entire lane in a fraction of a second. It should be easy for the system to consider the street crossing needs of these small four-wheelers." However, other comments expressed growing concerns about the privacy of users and residents in the area due to the robot's digital surveillance systems. ADRs are equipped with several sensors, such as cameras and microphones, which allow them to collect and store sensitive data from users and their living environments for undisclosed purposes. Such data includes, for example, photos, videos, or audio recordings of customers and area residents, as well as visuals of private roads and property not open to the public. While taking photos and videos in public areas is legal, doing so on private property without consent is illegal in many countries, including Finland. Accordingly, one comment asked, "What do the cameras of these robots see and record? We must demand strict ethical moral rules and transparency from algorithms, AI, robots, automation, and programmers before it is too late."

Table 2. *Identified categories of social acceptance for food ADRs in the corpus*

Contextual	**Appearance**	**Operations**	**Safety & Security**
Sensitivity	Familiarity	**Usefulness**	**Traffic safety**
Suitability	**Cuteness**	**Functionality**	**Liability**
Exposure	Adaptability	Reliability	**Food safety**
Societal impact	Interaction	**Sustainability**	**Cybersecurity**
		Usability	***Robot safety***
			Privacy

Table 2 displays in bold text the factors identified in the data, while regular text shows those identified in previous literature. Italicized text highlights factors that were identified in the data but not in the literature review. These "new" factors include "societal impact," which falls under the category of contextual factors, and "robot safety" and "privacy," which belong to the category of safety- and security-related factors.

5. Discussion and Conclusions

This study aimed to identify factors influencing the social acceptance of food ADRs by analyzing readers' comments on Finnish news articles about their use. The following sections summarize key findings and discuss their implications for the service robot literature.

5.1. Key findings and their contributions to theory and practice

The findings of this study revealed the categories of factors underlying social acceptance of ADRs. While all four categories were present in the comments, most of the specific factors identified in the literature review also appeared, along with some "new" factors not previously identified. These "new" factors—namely, societal impact, robot safety, and privacy—have been discussed in general literature on robots but not specifically in the context of social acceptance of delivery robots. In this regard, the findings contribute to the literature on robots for last-mile delivery by highlighting that the public has ample concerns about service robots for delivery. The study context of Finland, with its long distances and harsh winter weather, was evident in several categories,

suggesting that societal context—such as country and climate type—may be essential when trying to understand social acceptance of autonomous delivery service robots. In the following sections, five key areas of findings are discussed, along with their contributions to scholarship.

5.1.1. The cuteness of ADRs encourages people to help them, fostering social acceptance

Firstly, the appearance of food ADRs seems to play an important role in their social acceptance. Although non-humanoid and designed primarily for function, resembling space rovers, people still found them cute. The findings suggest that the robots' cuteness stems not only from their small size and harmless appearance but also from a perceived "helplessness" in the way they operate on roads. The aspect of delivery robots "looking cute and sympathetic" was frequently mentioned in the comments. This finding contributes to existing literature on public sentiments toward robotics (e.g., Quick, 2022) by suggesting that people tend to feel sympathy for robots due to their uncanny, helpless, and endearing behaviors. Additionally, people seem to anthropomorphize food delivery robots, expressing a strong willingness to help them when they encounter difficulties in traffic. Interestingly, some previous research suggests that anthropomorphizing service robots may cause discomfort (e.g., Mende et al., 2019; Odekerken-Schröder et al., 2022). This was hardly the case with the food ADRs in this study, as only one comment mentioned the "scary looks" of ADRs. However, as a practical implication, food ADR designers should emphasize a cute and friendly appearance to enhance public reception of autonomous service robots. A robot's friendly look can be further enhanced by avoiding features that overly reduce its sense of helplessness.

5.1.2. The safety of food ADRs is a recognized concern for social acceptance in society

Secondly, public concerns about robot safety, particularly regarding food ADRs facing acts of vandalism and violence, emerged as an important theme. Robot abuse has been discussed in social robotics; for example, Cooney et al. (2023) note that, although people tend to treat social robots with empathy—giving them nicknames, feeling bad when they get stuck or need repairs, and even removing a robot's battery to spare it from "pain" after significant damage—there are increasing reports of robot abuse. Mamak (2022) argues that violence against robots reflects public morality rather than the robots themselves, suggesting that such acts stem not from the robots' characteristics but from their public performance. Cooney et al. (2023) speculate that abuse of robots may be partly due to their "helplessness" against human actions, such as their slow speed and inability to defend themselves. In public spaces, children and youth are more likely than adults to abuse robots, often by blocking their paths, teasing, kicking, or damaging them (Yamada et al., 2023). Children may engage in such behavior out of curiosity about the robot's reactions or simply for enjoyment (Nomura et al., 2016). This study's findings confirm that robot abuse is a recognized concern regarding food ADRs, with recent news reports supporting this notion by highlighting increased vandalism and theft of food ADRs due to social media trends (e.g., Adarlo, 2023). Since a robot's helplessness is also a driving factor for social acceptance, a practical implication is that companies using food ADRs should avoid making them overly helpless. Instead, they should promote robotic food delivery in a way that encourages people to view ADRs more as tools, like cars, rather than as autonomous beings. Furthermore, combating social media trends that showcase abuse of food ADRs may require visible legal action against influencers associated with such incidents.

5.1.3. Privacy concerns with ADRs can be mitigated through greater benefits and appropriate robot behavior

Thirdly, perceptions of privacy were twofold. On one hand, the introduction of AI-based traffic surveillance systems that monitor traffic and help ADRs navigate in busy urban environments was viewed positively, suggesting that privacy-invoking surveillance prompted by ADRs may offer benefits to all road users. On the other hand, a robot's built-in surveillance capacity—such as cameras and other sensors capable of recording events in its operational environment—was viewed negatively. The demand for privacy-preserving robotic design, including transparent system architecture, sensor visibility, and fair data-handling practices, has been highlighted in previous literature (e.g., Schafer & Edwards, 2017), and the findings of this study reinforce this call. Additionally, people have been found to feel more comfortable in privacy-sensitive human-robot

interactions when they observe robots exhibiting behaviors that respect user privacy. Such behaviors can be as simple as turning away from a person to show the robot's back, informing the person that video recording is paused, moving away, or redirecting the robot's navigational camera—or "gaze"—in another direction (Yang et al., 2022). That said, Lutz and Tamó-Larrieux (2020) found that although people often express significant concerns over social robots' data protection and privacy, the perceived benefits of robots generally tend to outweigh these concerns. As a practical implication, manufacturers of food ADRs should be more transparent about the data recorded by the robots in their operational environment and how privacy concerns are addressed.

5.1.4. Workforce replacement by ADRs is a major concern for social acceptance

Fourthly, the findings highlighted the societal impacts of ADRs, including negative effects on the labor force (as human delivery workers are replaced by ADRs) and the uneven distribution of benefits (where profits from automation are privatized by robotics manufacturers and delivery providers, while taxpayers bear the costs of adapting urban infrastructure for robots). This study found particular concern over youth seeking part-time jobs and future retail workers being replaced by ADRs. Westerlund (2020b) observed that job displacement by robots was a prominent concern in public online discussions around smart robots. This concern is not unfounded, as robotics has been argued to disrupt business models and lead to significant job losses, especially in industries with a high proportion of low-skilled, routine tasks (Lambert, 2019). Conversely, Zhang et al. (2023) argue that robotics can, in fact, increase rather than replace human labor and that corporate adoption of robots to assist human employees can enhance fairness, for instance, by supporting active hiring of female employees. A practical implication of this notion is that companies using food ADRs should view robots as assistants that enhance the efficiency of human employees, rather than as replacements aimed at cost savings. Firms should design their service processes to integrate service robots, such as food ADRs, in a way that demonstrates the company's appreciation for both employees and customers as individuals, even as robots enhance the service.

5.1.5. Sustainability remains an under-addressed area in the social acceptance of service robots

Finally, sustainability is an important yet under-researched and largely overlooked area in robotics. Previous literature has highlighted the potential of robotic applications to advance sustainability, such as promoting pro-recycling behavior (Lo et al., 2022) and designing sorting robots for waste management (Friedrich et al., 2021). However, these perspectives often omit the fact that robots themselves eventually become e-waste, posing environmental burdens. The data in this study included only a few comments on environmental sustainability, consistent with prior studies on public perceptions of smart robots (e.g., Westerlund, 2020b). This limited focus is concerning given the rapid increase in the number of robots in society. While delivery robots can operate on green energy, challenges related to the production and recycling of robotics components remain unresolved. For example, mining for battery materials is environmentally harmful and raises ethical concerns: raw material extraction demands significant energy and water, and mining workers frequently face unsafe conditions (Nature, 2021). These findings support the view, echoed in some prior studies (e.g., Westerlund, 2020b; Nature, 2021), that future research should address the recycling and reuse potential of robotics materials and components. Similarly, practitioners could collaborate with autonomous vehicle manufacturers to design net-zero production processes for food ADRs and to increase the returnability and recyclability of robotic components at the end of their life cycle.

6. Limitations and Future research

Although this study, based on the analysis of online comments, provided ample insights into the social acceptability of food ADRs, there are limitations that future studies could address. One limitation is the lack of metadata, such as information on commenters' gender, age, occupation, and general attitudes toward technology. These factors have been found to influence robot acceptance (de Graaf & Allouch, 2013; de Jong et al., 2019; Cha, 2020; Seyitoğlu et al., 2021; Nomura & Tanaka, 2022). This remains a persistent challenge

when using data from publicly available news comments, as these platforms typically do not require users to provide their (real) name or any demographic or sociographic information. Notably, some online news sites require commenters to use their real name or social media profile, which may allow for rough estimates of commenters' gender or other demographics. While this would not yield highly accurate or reliable data, it could support some research purposes related to examining associations between robot acceptance and demographic factors such as gender. Alternatively, future research could investigate the social acceptance of food ADRs through methods such as focus group interviews within residential communities where people can encounter autonomous service robots.

Another limitation relates to commenters' prior exposure to food ADRs. Previous literature suggests that people's attitudes toward robots may be influenced by whether they have previously interacted with a robot, either directly or indirectly (Naneva et al., 2020; Saari et al., 2022). People with no exposure to robots tend to rely on imagined and socially constructed representations of robots, often resulting in negative attitudes (Savela et al., 2018). While some commenters in our data indicated prior exposure to food ADRs, this information could not be systematically included in the analysis. We acknowledge that some themes in our analysis might be associated with prior exposure and encourage further research on how direct or indirect exposure impacts acceptability. Additionally, our data only covered the early days after the introduction of food delivery robots in the community. Previous research (e.g., Windemer, 2023) suggests that community support for new technology is shaped by ongoing experiences with that technology over time. Future studies could thus investigate how the social acceptance of food ADRs evolves over one or several years.

A third limitation is that this study focused on a single country—a small, technologically advanced nation with Western cultural values. Public attitudes toward robots are known to vary based on cultural factors (Chi et al., 2023), and a nation with Eastern cultural values, like Japan, could provide an interesting comparison. In Japan, the population is familiarized with robots from childhood, and robots are often viewed as positive and helpful, whereas Western cultures tend to see robots as a potential threat, with fears of them turning against humanity (Westerlund, 2020a; Subaru-Navarro et al., 2022). As such, factors like societal impact in Eastern cultures may focus less on the threats robots pose to human employment and more on the benefits of advanced robotics in society. Additionally, Chi et al. (2023) suggest that Western cultures may value a robot's novelty and entertainment value over the performance value that is more emphasized in Eastern cultures. Future research should thus broaden the geographical and cultural scope of studies on the social acceptance of food ADRs.

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