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Research paper

Piloting a joint delivery system of droids and cargo bikes at the JRC Ispra campus: A service design approach

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ABSTRACT

In recent years, the levels of e-commerce in the modern commercial environment have significantly increased, necessitating the adoption of measures and policies capable of complementing each other to achieve a sustainable urban freight transport system. Beyond traditional approaches, a new array of automation-based technologies has been developed offering dynamic, and reliable solutions. This research designs a next-generation multimodal last-mile delivery system of lunch boxes at the JRC campus, in Ispra, Italy, based on a service design approach that embraces three dimensions of engagement in participatory design for sustainable change; scoping, developing and scaling. Analytically, the "scoping" phase focuses on establishing and operating a living lab as a platform for co-design, fostering dialogue, shared understanding, and iterative learning among stakeholders. The "developing" phase involves mapping the service through user journeys and service blueprints while integrating digital practices. The "scaling" phase focuses on co-developing cooperative business models that generate value, manage resources effectively, and foster sustainable, community-driven networks. The pilot demonstrated significant operational improvements (droids navigated 77 % autonomously and sender waiting time averaged 5.17 % of the total journey), while 90 % of users rate the service as satisfactory or very satisfactory. However, the financial viability remains highly dependent on sponsorships and grants.

1. Introduction

In recent years, the importance of Urban Freight Transport (UFT) in the modern commercial environment has significantly increased. The COVID-19 pandemic acted as a catalyst for this change (Beckers et al., 2021), with levels of e-commerce nearly doubling globally between 2019 and 2024 (Statista, 2023). Trends indicate continued growth; in 2023, global retail e-commerce sales reached an estimated 5.8 trillion U.S. dollars, while projections indicate a 39 percent growth in this figure over the coming years, with expectations to surpass eight trillion dollars by 2027 (Statista, 2023). This rapid increase brings challenges related to the continuous provision of home delivery services for a large volume of orders and is often accompanied by new "desires" from end-users, such as faster, more reliable, secure, and sustainable deliveries, placing significant pressure on courier companies (Allen et al., 2018; Gatta et al., 2023, chap. 21; Polydoropoulou et al., 2022). According to the World Economic Forum (2024), if the current situation continues to meet the projected demand for online shopping, the number of delivery vehicles in the top 100 global cities will need to increase by 36 % by 2030. The consequences are significant, as it is estimated that emissions from delivery vehicle traffic will increase by 32 %, and congestion will rise by over 21 %, adding approximately 11 min to the daily commute travel time for each passenger.

The challenges and the need for adopting new solutions (measures and policies) in the field of UFT are well recognized within the European Union (EU) (Prencipe et al., 2024). In line with the Paris Agreement, the EU has set the ambitious goal of becoming the first climate-neutral continent by 2050. In the context of UFT, this will be achieved with a

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dual approach designed to reduce CO2 emissions by 55 % by 2030 at the latest, through the "Fit-for-55″ package and paving the way for zero emissions in freight transport, including UFT and passenger transport (European Commission, 2024).

In the course of selecting and implementing suitable solutions, numerous methodologies have emerged to address the myriad challenges of applicability (Galambos et al., 2024; Janjevic & Ndiaye, 2014; Klose et al., 2022). Most studies acknowledge that horizontal approaches are ineffective and emphasize the necessity of local adaptation to the specificities of urban areas and engagement with the local ecosystem considering multi-stakeholder approaches (Marcucci et al., 2017; Nathanail et al., 2018). In this light, this research outlines the steps undertaken to pilot an innovative city logistics solution consisting of a joint system of ground delivery robots (named onwards "droids") and cargo bikes, implemented at the Joint Research Centre (JRC) Ispra Campus, located in the Province of Varese, Italy. The JRC campus serves solely as a testbed, selected for its specific characteristics, as detailed in the first subsection of the "BACKGROUND AND METHODOLOGY" section.

While previous research has evaluated alternative last-mile delivery solutions at the same JRC campus, including scenarios involving (i) an automated delivery droid coupled with a Euro 4 Light Commercial Vehicle (LCV), (ii) a delivery droid coupled with a depot station, and (iii) a delivery droid coupled with an electric LCV (Garus et al., 2022), these studies did not focus on the co-design or operationalization of a last-mile service. It is important to acknowledge that a broader Living Lab (LL) framework - the JRC Future Mobility Solutions LL - has been in place at the campus since 2019 (European Commission, 2021). However, this study establishes a thematic LL specifically aimed at co-creating, piloting, and scaling a joint food delivery service using droids and cargo bikes. Distinctively, it integrates a service design methodology, applying tools such as stakeholder journey mapping, blueprinting, and participatory business modeling. This contribution represents the first attempt at the JRC campus to systematically design and test the operational feasibility of such a delivery system through a co-creation lens.

The motivation for piloting such a joint system is based on the notion that vans are inefficient in urban contexts, multiple bikers are expensive for completing the last mile of delivery, while droids are too slow to drive all the way from a distribution hub. Another driving factor for conducting this study, is that, excluding research focused on the technical design of droids (Hutter et al., 2017; Law, Fan, Li, & Mo, Jun. 2023; Plank et al., 2022; Udoh et al., 2024) or the development of mathematical routing algorithms (Alfandari et al., 2022; Chen et al., 2021; Simoni et al., 2020; Yu et al., 2022), the body of literature addressing the integration of droids in last-mile delivery systems is very limited. According to Alverhed et al. (2024), who systematically reviewed delivery droids as part of delivery systems, research is predominantly focused on (i) operations, (ii) infrastructure, (iii) regulations, and (iv) public acceptance, while service design - preceding implementation - and business value creation remain out of the literature radars.

To fill in these research gaps, the objective of this research is to design a next-generation multimodal last-mile delivery system of lunch boxes at the JRC campus, in Ispra, Italy, based on a service design approach that embraces three dimensions of engagement in participatory design for sustainable change; scoping, developing and scaling (Smith & Iversen, 2018). Analytically, the objective is to (i) discuss the process of establishing and operating a LL where diverse participants can collaboratively explore potential futures and co-design services that align with their evolving goals and aspirations ("scoping phase"), (ii) co-map the planning of the service through user journeys and service blueprints ("developing phase"), and (iii) co-develop cooperative business models so that the service generate value and stays competitive, while also managing resources, and exploiting future growth opportunities ("scaling phase").

The rest of the paper is structured as follows: Section 2 reports past studies dealing with the use of droids in the delivery systems. Section 3 gives the background with respect to the study area and the scenario description, while it also outlines study's service design methodological steps. Section 4 describes the facilitation of the urban LL in Ispra and the results from the performed co-creation activities. Section5 presents the user journeys and the blueprint of the co-designed service. Section 6 details the business model, with a focus on revenue streams and cost structure. Finally, Section 7 concludes the paper and provides suggestions for future research.

2. Literature review

Before the COVID-19 pandemic, the concept of robots delivering parcels to customers might have seemed futuristic (Chen et al., 2021). However, with automation technology becoming increasingly pervasive and integrated into society, it is now easy to envision delivery robots eventually emerging as the dominant technology for last-mile delivery (Marciani, 2023) in the following years. From an economic point of view, droids can navigate flexibly, avoiding traffic congestion or accidents, allowing them to maintain more consistent and higher average speeds, which significantly reduces delivery times and adds reliability. From an environmental point of view, delivery robots produce a minimal footprint in terms of GHG and pollutant emissions, as they are powered by electric engines with rechargeable batteries (McKinsey, 2017).

Today, there are many pilots of droid-based delivery systems already in operation, with new ones launching almost every day (Ostermeier et al., 2021). From a business perspective, Hoffmann and Prause (2018) argued that delivery robots have substantial potential to create value for companies. Focusing on food delivery service particularly, Starship Technologies, a San Francisco-based company, operates a delivery robot service in North London. Earlier in 2020, the company expanded this service to six additional cities, including the launch of a grocery delivery service in Washington, D.C. (Starship Technologies, 2022). The business model of the service focuses on the cost advantage of last-mile delivery, with costs estimated to be less than €1 per unit/delivery, which - depending on local wage levels - can be up to 15 times lower than current costs (Starship Technologies, 2018). For customers, the added convenience comes from robot delivery offering a standard 15-to-20-min delivery window, a much more precise timeframe compared to traditional delivery, which typically provides only a general date (calendar day) in advance. In another example, Grubhub, a prominent food ordering and delivery platform, and Kiwibot, a leading company in last-mile robotic delivery, partnered in 2023 to offer robot delivery services on more than 250 college campuses throughout the United States, starting from the University of North Dakota (Kiwibot, 2022). Students were able to order meals from on-campus dining locations, via the Grubhub app, with Kiwibots delivering food even in extreme weather conditions, when other services were not operating. Of course, other than food delivery service pilots, many other droids' pilots can be spoted, ie. Amazon Scout, Postmates and FedEx's SameDay Bot in the US, DHL's PostBOT in Germany, and more.

As Srinivas et al. (2022) indicate in their review of recent developments and future directions on robot-driven deliveries, there are two critical aspects for the succesfull scale up of the pilots; (i) the system's flexibility in handling unforeseen circumstances, such as low battery charges or technical faults, and (ii) regulatory issues. As per the latter, in 2017, San Francisco officials have voted to restrict where delivery robots can go in the city mainly due to concerns about the safety of pedestrians, particularly elderly people and children (City logistics, 2017). Gehrke et al. (2023) examined sidewalk Autonomous Delivery Robots (ADRs) and quantified safety interactions with pedestrians and bicyclists using video-recorded interactions and Post-Encroachment Time (PET) analysis. Their study revealed that most severe conflicts occur at intersections and narrow pathways, highlighting the need for improved infrastructure design and sidewalk ADR regulations. Jennings and Figliozzi (2020) acknowledged that droids will compete for space on sidewalks with pedestrians and this will inevitable raise regulatory obstacles, and they distincted droids into Sidewalk ADRs and Road ADRs. In their study they performed an analysis of the characteristics and regulation of Road ADRs in the US and a study of the relative travel, time, and cost efficiencies that Road ADRs can bring about when compared to traditional van deliveries. The results indicated that Road ADRs can offer significant cost savings in many scenarios, though this comes at the cost of notably higher vehicle miles per customer served. Unlike Sidewalk ADRs, Road ADRs are likely to contribute substantially to increased vehicle miles per customer, concluding that while Road ADRs outperform conventional vans in competitiveness, their limitations - short range and limited storage capacity – remain significant barriers. A Road ADR pilot was run by Valeo, an automotive supplier specialized in developing electric, autonomous and connected vehicle technologies, in partnership with Meituan Dianping, China's leading e-commerce platform for services, operating popular food delivery services in many Chinese cities (Valeo, 2020).

The biggest advantage of droids is that they are able to drive autonomously, and a single operator can manage a whole fleet of robots (Poeting et al., 2019). On the contrary, a significant barrier is the readiness of the traffic environment for autonomous delivery robots. Arntz et al. (2023) named it as "roboreadiness", consisting of two components: the robot's performance within the traffic environment and its level of social acceptance. Kapser et al. (2021) and Abrams et al. (2021) examined the acceptance of droids as a means for contactless home deliveries. Both studies were performed in 2020, when restricting measures were imposed, due to Covid-19. Using online questionnaires and similar analysis methods, they both resulted that trust in technology, price sensitivity, innovativeness, performance expectancy, hedonic motivation - among other aspects - determine behavioural intention, discussing also respective policy implications. For example, Kapser et al. (2021) stressesed that if shipment costs are too high due to the use of expensive automation technology, there will be little acceptance in the population and advantages of droids as a contactless delivery option will be missed out. Public acceptance was also researched in later years – after COVID-19 pandemic - by Koh and Yuen (2025) who examined urban planning policies and how they shape ADR adoption using Structural Equation Modeling (SEM). They found that residents' perceptions of ADRs align with the Health Belief Model and Task-Technology Fit Model, suggesting that policies promoting safety and efficiency can enhance ADR adoption. Similarly, Yuen et al. (2022) used the Technology Acceptance Model and Theory of Planned Behavior to explore consumer behavior toward ADRs, concluding that COVID-19 acted as a significant accelerator for ADR acceptance, especially in dense urban settings.

Moreover, innovative evaluation methodologies for assessing droid deployments, through case studies' demonstration, are also under the research spotlight (Garus et al., 2022; Plank et al., 2022; Zeng et al., 2022). Analytically, Zeng et al. (2022) developed a multi-criteria decision-making framework integrating self-confidence aggregation and social trust networks to evaluate ADR feasibility. In a similar approach, Plank et al. (2022) developed a prototype evaluation methodology based on Open Street Map data to assess ADR deployments in different German cities. The results indicated varying performance outcomes depending on urban density and robot class selection. Specifically, small ADRs exhibited superior accessibility in pedestrian-dense urban cores but suffered from increased detour times due to restricted movement on sidewalks. In contrast, larger ADRs operating on roadways benefited from faster speeds and reduced detours but faced significant accessibility constraints in high-traffic areas. The study also found that sidewalk ADRs performed poorly across most cities, as infrastructure limitations and longer travel paths outweighed their accessibility advantages. Moreover, Garus et al. (2022) integrated multi-criteria decision-making analysis and scenario analysis to reflect stakeholder perspectives in last-mile delivery. Their findings indicate that low-capital investments in delivery droids could lead to operational cost savings and improved environmental performance but may raise social sustainability concerns related to safety and equity. Expanding on this, Garus et al. (2024) conducted a comparative analysis between ADRs, bicycles, and light commercial vehicles (LCVs) using GIS-based modeling and routing optimization. Their results indicate that ADRs are best suited for pedestrian-centric areas, bicycles for dense urban cores, and LCVs for suburban/rural last-mile operations, providing a data-driven foundation for optimizing vehicle allocation strategies.

While relevant business and operations research can be found sporadically, existing studies on last-mile delivery tend to focus on individual aspects, such as regulatory frameworks (Hoffmann & Prause, 2018), business models (Starship Technologies, 2022), or public acceptance (Kapser et al., 2021), without integrating the full cycle of service design. Table 1 summarizes relevant existing research, categorizing it into scoping, developing, and scaling phases, and includes a row for this study's unique coverage of all three phases.

As can be seen from the last row of Table 1, this research addresses the gap of covering all three phases, by proposing a service design framework that enables multi-stakeholder engagement and a phased approach to co-design, test, and scale a multimodal last-mile delivery service. To the authors' best knowledge, the only example of participatory desing is an initiative between Johanneberg Science Park and Chalmers University of Technology in Sweden (DriveSweden, 2023). In this initiative, HUGO, a small autonomous delivery robot, was deployed to deliver packages while also gathering insights on the societal acceptance, infrastructure readiness, and operational feasibility of autonomous solutions. Through real-world campus trials and focus groups, public perceptions and safety interactions were assessed, particularly in shared urban mobility contexts. The initiative involved multiple stakeholders, including researchers, product developers, property owners, and city authorities. This research extends beyond the HUGO initiative incorporating.

- Multimodal integration: Unlike HUGO, which primarily focused on standalone autonomous droid deliveries, this study integrates cargo bikes and droids into a joint delivery system, optimizing the efficiency of multimodal last-mile logistics.
- Decision-support framework: This study develops a structured methodology for stakeholder engagement and co-creation, ensuring that public authorities, businesses, and users actively shape service design. HUGO focused on user perception and qualitative assessments, while this study provides a decision-support framework to facilitate scaling and long-term service sustainability.
- Performance metrics: This study incorporates a data-driven approach to analyze the efficiency of the system, whereas HUGO focused more on qualitative user experience and route optimization.

3. BACKGROUND and METHODOLOGY

3.1. JRC campus in Ispra

The JRC in Ispra ranks as the third-largest European Commission site, following Brussels and Luxembourg. Originally established in 1960 as a nuclear research facility, it has evolved into one of Europe's premier research campuses, boasting numerous laboratories and unique research infrastructures. The site hosts a daily population of approximately 2200 Commission staff across over 100 buildings, with 36 km of internal roads and all necessary logistical services to operate a small town, including energy generation and water provision. Encompassing a fenced area of 167 ha, the JRC facility provides a safe, secure, yet real environment, where Italian laws related to safety, transportation, and highway codes are applied under its own responsibility (European Commission, 2024).

3.2. Methodology

The methodology of service design is structured into three

Table 1
Summary of existing research on droids categorized by scoping, developing, and scaling phases.

Study	Phase[a]	Focus Area	Methodology	Key Findings
McKinsey (2017)	Scoping	The role of automation in urban last-mile delivery	Market report & industry analysis	Identifies emerging trends in commercial urban transport, including electric vehicles (EVs), droids, and autonomous ground vehicles (AGVs) as potential solutions for reducing congestion, emissions, and operational costs. Highlights the impact of urban consolidation centers (UCCs) and parcel lockers in improving logistics efficiency.
Kapser et al. (2021)		Public acceptance	Survey Analysis	Identifies factors impacting user acceptance
Srinivas et al. (2022)		Systematic review of autonomous delivery robots (ADRs)	Literature Review, Taxonomy of ADR Research	Provides a comprehensive review of ADR-based delivery operations, analyzing factors like routing, fleet & infrastructure planning, efficiency, user acceptance, and social intelligence
Yuen et al. (2022)		Acceptance of ADRs in urban cities	Technology Acceptance Model (TAM) & Theory of Planned Behavior (TPB)	Identifies behavioral factors influencing ADR adoption, highlighting COVID-19 as a key adoption accelerator
Koh and Yuen (2025)		Consumer adoption of ADRs in urban planning	Structural Equation Modeling (SEM)	Analyzes urban planning policies and factors affecting ADR adoption, applying Health Belief Model and Task-Technology Fit Model
Alverhed et al. (2024)		Review of droids	Literature Review	Outlines focus areas like infrastructure and regulation
Hoffmann and Prause (2018)	Developing	Regulation	Case Study	Highlights regulatory challenges in autonomous delivery
Jennings and Figliozzi (2020)		Performance comparison of RADRs and conventional vans	Analytical modeling (Continuous Approximation Method)	Evaluates costs, travel time, and vehicle miles per delivery of Road Autonomous Delivery Robots (RADRs) vs. conventional vans. Finds RADRs can save costs but increase total vehicle miles traveled in urban settings.
Chen et al. (2021)		Optimization of droid-assisted last-mile delivery	Vehicle Routing Problem (VRP) modeling & matheuristic algorithm	Proposes a Vehicle Routing Problem with Time Windows and Delivery Robots (VRPTWDR), demonstrating potential operational savings with self-driving robots
Garus et al. (2022)		Sustainability assessment	Multi-criteria decision analysis	Evaluates environmental and operational impacts
Plank et al. (2022)		Geographic feasibility of autonomous delivery robots	GIS-based accessibility analysis using Open Street Map (OSM) data	Develops a prototype evaluation methodology for ADR deployment in German cities, assessing the accessibility of different droid configurations and identifying key urban infrastructure constraints for droid operations.
Zeng et al. (2022)		Decision-making framework for evaluating unmanned ground delivery vehicles (UGDVs)	Multi-criteria decision-making (MCDM) approach under Pythagorean fuzzy environment	Proposes a social network-based MCDM model for evaluating UGDVs, integrating expert trust aggregation and self-confidence weighting for robust decision-making. Demonstrates practical application with a case study.
Heimfarth et al. (2022)		Truck and droid hybrid delivery optimization	General Variable Neighborhood Search (GVNS) algorithm	Proposes a Mixed Truck and Robot Routing Problem (MTR-RP) to optimize cost and reduce vehicle miles traveled
Lemardele et al. (2023)		Life-cycle analysis of ADRs	Life Cycle Assessment (LCA) & Continuous Approximation (CA) methodology	Finds ADRs' biggest environmental burden is fleet production and renewal, recommending optimization of lifecycle sustainability
Gehrke et al. (2023)		Safety interactions of sidewalk autonomous delivery robots (SADRs)	Field study with video-recorded interactions and post-encroachment time (PET) analysis	Observes and quantifies conflicts between SADRs, pedestrians, and bicyclists, using surrogate safety measures (PET). Finds that most severe conflicts occur at intersections and narrow pathways, highlighting the need for better infrastructure and SADR safety regulation
Garus et al. (2024)		Comparative analysis of ADRs, bicycles, and LCVs in last-mile delivery	GIS-based modeling, Google OR-Tools, vehicle routing problem solver	Shows ADRs are most efficient in pedestrian-focused areas, bicycles in dense urban centers, and LCVs in suburban/rural settings
Starship Technologies (2022)	Scaling	Business models	Pilot Study	Shows cost savings in droids' delivery
DriveSweden, 2023 HUGO Initiative (Johanneberg Science Park & Chalmers University of Technology, Sweden)	All Phases[2]	Multi-stakeholder co-creation and social acceptance of autonomous droid deliveries	Participatory trials with focus groups and real-world deployment tests	Examines societal acceptance, infrastructure readiness, and operational feasibility of autonomous droids. Conducted fully automated pick-and-deliver tests
	Scoping phase: Conducted an assessment of last-mile delivery challenges, focusing on cost, environmental impact, and infrastructure feasibility for autonomous solutions. Explored the integration of autonomous droids with urban mobility systems, including shared pathways with pedestrians and cyclists. Development phase: Analyzed routing efficiency, and package handling under different conditions. Conducted focus groups to assess societal acceptance and interaction with users. Scaling phase: Transitioned from small-scale trials to broader urban demonstrations, focusing on refining business models and regulatory adaptation. Explored new use cases for commercial applications, including integrated passenger-freight systems. Investigated multi-robot cooperation and the potential for scaling operations in complex urban environments.			
(This research)	All phases	Multimodal last-mile delivery with droids and bikes	LL with participatory co-design	Integrates all three phases to co-design, test, and scale a comprehensive urban logistics solution

[a] Note: The categorization of studies into Scoping, Developing, and Scaling phases follows the broader service design methodology of this study (see section "BACKGROUND AND METHODOLOGY" below). While these phases apply directly to delivery services' design, they have also been used for structuring research contributions in this field.

interconnected phases: scoping, developing and scaling (Smith & Iversen, 2018). These phases provided a systematic approach to conceptualizing, developing, and implementing services while ensuring iterative engagement with stakeholders. Fig. 1 presents a structured visualization of how these phases interlink within the service design approach, facilitating a smooth transition from problem exploration to service implementation and scaling.

The scoping is the foundational step where relevant stakeholders are engaged in co-design activities to collaboratively explore the research field, identify challenges, and define (research) questions. This phase is crucial in shaping participation, ensuring that a diversity of perspectives was included in the early stages of service development. The primary goal is to establish a LL as a dynamic space where uncertainty and complexity are embraced, fostering dialogue, shared understanding, and innovation-driven collaboration (Ebbesson et al., 2024).

In this study, the scoping phase involved a series of co-creation activities (i.e. meet-ups and workshops) that identified key challenges in last-mile delivery at the JRC Ispra campus. The activities shaped the requirements for the integrated droid-cargo bike system, defining user expectations and operational constraints. Stakeholder insights gathered at this stage laid the groundwork for the subsequent development of user journeys and service blueprints (see subsection "Scenario Description as an Output of the Scoping Phase" for workshop insights).

The developing phase moves beyond conceptual exploration to focus on practical service development, integrating both tangible and intangible elements. Rather than simply creating technological artifacts, this phase prioritizes digital practices and interaction frameworks, ensuring that services evolve in response to specific contextual needs (Marsden et al., 2008). However, a key challenge in this phase is that many stakeholders may not fully grasp the potential of digital tools, requiring an approach that facilitates experimentation and engagement rather than prescribing rigid procedures (Iversen & Dindler, 2014).

In this study, the developing phase involved the iterative design of user journeys and service blueprints, ensuring that service planning was directly informed by real user needs and ecosystem challenges. Insights from the scoping phase shaped the mapping of logistics flows, allowing for continuous refinement of the blueprint design based on stakeholder feedback. Fig. 8 illustrates this iterative process, demonstrating how adjustments were made to align the service structure with user expectations and operational realities.

Finally, the scaling phase extends service development beyond prototyping, ensuring that solutions are economically viable, scalable, and sustainable. This phase emphasizes co-creating business ecosystems through the development of a sustainable business model canvas, the identification of revenue streams, and the establishment of cooperation agreements and arbitration frameworks. Scaling is not limited to tangible service implementation; it also includes the creation of collaborative networks and governance structures that drive long-term adoption (Katsela & Pålsson, 2021).

In this study, the scaling phase involved the co-development of cooperative business models in collaboration with logistics providers and policymakers. This ensured that the droid-cargo bike service extended beyond its initial testing phase. The business model canvas (see Fig. 13) was designed to outline viable revenue structures, cost models, and stakeholder roles, ensuring long-term financial and operational sustainability. By aligning regulatory adaptation with service implementation, this phase facilitates the transition from a localized pilot to a scalable, replicable urban freight solution.

4. Urban living lab in Ispra

LLs are collaborative environments where various groups of stakeholders come together to co-create and co-design solutions that address complex urban challenges (Pink et al., 2022). In the context of city logistics, establishing LLs provides a platform for stakeholders to collaborate and test innovative solutions aimed at improving the efficiency, sustainability, and resilience of UFT systems (Ebbesson et al., 2024). They also act as trading zones where stakeholders can exchange knowledge, ideas, and resources, enabling them to learn from each other without being hindered by conflicting interests and agendas (van Waes, & NikolaevaRaven, 2021).

Fig. 2 shows the different stakeholders involved in Ispra LL, categorizing the groups based on their level of involvement. The outer layer - Informed - includes contact people. The middle layer -Involved - consists mainly of the service enablers (ie. riders, canteen workers, new final users, etc.). The innermost layer, labeled "Core team", comprises the logistics service providers and fleet operators (YAPE and MEASY), data analysts, and Ispra JRC campus site services. Specifically, YAPE is an Italian-based provider of AI-powered self-driving droids designed for pedestrian environments, capable of navigating sidewalks and urban pathways. MEASY is an Italian company operating in the field of vehicular robotics logistics specializing in cargo bike-based last-mile delivery solutions. In context of this study, YAPE and MEASY play the role of the logistics service provider and fleet operator combined, as YAPE droids are used to transport meals within a designated operational area and MEASY provides the cargo bike, which transports meals from the central canteen to an intermediary point, where YAPE droids take over (see subsection "Service Blueprint").

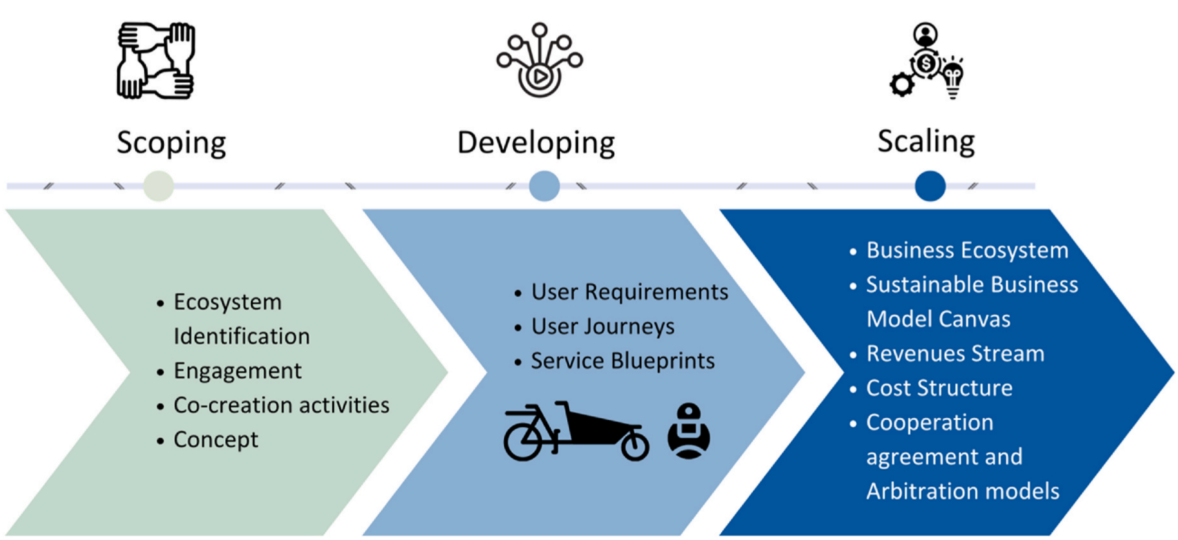

Fig. 1. Service design methodology.

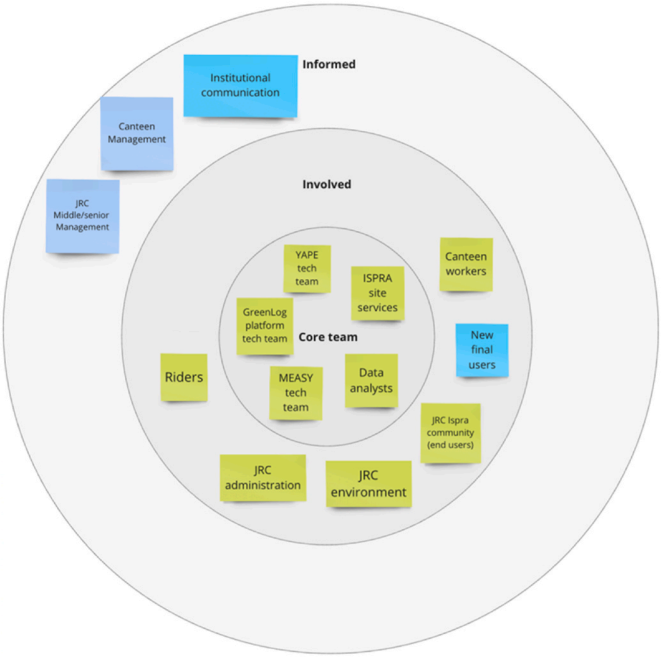

Fig. 2. Ecosystem's stakeholders Communication in Ispra LL

Stakeholder engagement began in January 2023, and since then, multiple activities have been conducted. Table 2 provides an overview of the co-creation activities conducted over the 18-month scoping phase period (GREEN-LOG, 2023), detailing the purpose, research and documentation methods, stakeholder representation (linked to Fig. 2), and documentation methods used in each activity.

Other than the four digital meetings (Meet-ups) and other bilateral meetings among the stakeholder groups, a co-creation workshop titled "Co-Creating Next-Generation Last-Mile Solutions" held on September 29th, 2023, in the JRC premises of Ispra, Italy. The workshop aimed to (i) clearly define the problem needing resolution and (ii) finalize and validate the envisioned service concept, while also identifying potential hidden opportunities. In total, ten onsite and eighteen online participants, attended the workshop. The ten JRC participants included representatives responsible for canteen management, site management, logistics sector and JRC employees.

Key discussions focused on the problem statement, specifically addressing the needs of service users (**analyzed in the next section**) and JRC employees as customers. Topics included enhancing food hygiene, streamlining payment processes, challenges of traveling to the canteen—particularly on busy, rainy, cold, or hot days—finding parking near the canteen entrance, and reducing long wait times in canteen queues. Workshop discussions also highlighted the potential for using advanced technological solutions to meet the targets of the JRC site, emphasizing the importance of reducing carbon emissions, and creating efficient, user-friendly services for ordering and tracking deliveries.

4.1. Scenario description as an output of the scoping phase

The scoping phase resulted in the following delivery service scenario: The operation begins each day at the canteen, where a cargo bike, loaded with freshly prepared lunch boxes, sets off towards an intermediary, partly refrigerated, point (Fig. 3). There, the task of delivering meals is transferred to trio of droids, which spread out to serve meals within a predetermined delivery zone, accommodating 1000 employees. It is worth noting that the demand is variable, as more than half of this population typically works remotely, and some prefer to bring their own meals.

The delivery service at its current fleet size aims to deliver initially 40-80 orders daily. This goal is supported by the operational capabilities of the droids, which can complete a delivery in 10–15 min, and the cargo bike, which can transport between 10 and 20 lunch boxes in one go. A SWOT analysis for the envisioned service is given in Fig. 4.

Strengths: The service's core strength lies in its sustainable and green delivery process, utilizing electric bikes and droids to significantly reduce CO_2 emissions and pollution, supporting urban sustainability goals. By employing mixed vehicle technologies, the service adapts flexibly to different conditions such as weather and traffic, ensuring reliable operations. It also enhances user convenience by saving time, reducing the need for walking, especially during busy or inclement weather days. Predictive, data-driven models enable real-time optimization of deliveries, improving operational efficiency and user satisfaction. Overall, the service enhances the quality of life by providing flexible, efficient lunch delivery options, particularly for users who wish to avoid long canteen lines or have tight schedules.

Weaknesses: One major weakness involves concerns surrounding data privacy and security, especially regarding the handling of user information. The service also faces challenges in addressing complex user preferences; while some may embrace the convenience of droids' delivery, others may prefer walking to the cafeteria or selecting their food in person. Integration of multiple systems, such as Measy and Yape, adds another layer of complexity, making seamless operation across platforms challenging, particularly at scale. Additionally, some users may be hesitant to adopt the technology due to a lack of digital literacy or discomfort interacting with automated systems, presenting barriers to widespread acceptance.

Opportunities: There are numerous opportunities for the service to support the local economy by driving additional orders for local food providers, especially those who experience lower foot traffic. The service also acts as a platform for innovation in human-robot interaction, providing valuable insights that could be applied to future models and broader applications. By promoting eco-friendly last-mile deliveries, the service reduces traffic congestion and CO_2 emissions, offering sustainability gains. Public awareness campaigns can further highlight the environmental benefits, encouraging broader adoption of the service and sustainable practices. Moreover, the service's flexibility, such as delivering during adverse weather conditions or high-demand periods, enhances user convenience and adaptability, allowing it to cater to various user needs.

Threats: The service faces several threats, including infrastructure limitations, such as the availability of charging stations or pathways for droids, which may hinder scalability considering all JRC campus. Regulatory and policy challenges related to autonomous delivery systems and green technology could also pose significant hurdles, slowing the implementation process. Skepticism and resistance to change are additional threats, as some users may fear job displacement by droids or prefer traditional food access methods, like walking to the canteen. Furthermore, the rise of remote work could reduce demand for on-site food delivery services, potentially affecting service uptake and overall profitability.

5. User requirements, user journeys and service blueprint

5.1. User requirements

In requirements engineering, requirements elicitation refers to the process of discovering system requirements from users - customers and other stakeholders - to uncover all necessary requirements (Browne & Rogich, 2001). This process is essential before requirements can be analyzed and specified, though it can be challenging due to potential issues in fully capturing all necessary information from stakeholders (Lee et al., 2022).

The co-creation workshop held in Ispra identified several critical factors for the successful implementation of the service. A list of user requirements, as these arouse from the minutes of the workshop, were

Table 2
Overview of the main co-creation activities.

#	Activity	Purpose	Resear. Method	Documentation Method	Stakeholder Representation	No. of participants	Duration
1	Introduction	- Create teams, - Record experiences and expectations	- Discussion - Lunch seminar - Initial interviews	Attendance list, Notes	Core team, Involved, Informed	9	1 h
2	Meet-Up 1	- Identify expectations, challenges, goals and success factors - Identifying existing and needed stakeholders	- Structured discussion (use of Miro tool[a])	Miro boards, Notes	Core team, Involved, Informed	7	1 h
3	Meet-Up 2	- Identify core team and collaborative structure with involved and informed stakeholders - Identify possible users of the LMD service, and map coming activities	- Structured discussion (use of Miro tool)	Miro boards, Notes	Core team, Involved, Informed	8	1 h
4	Meet-Up 3	- Present top four things to achieve, geographical orientation, user journey ideas, top three challenges, top three success factors	- Structured discussion (use of Miro tool) - Presentations	Miro boards, Notes, Presentations	Core team, Involved, Informed	6	1 h
5	Co-creation workshop	- Conceptualise/Validate the envisioned service - Explore hidden opportunities and further synergies	- Workshop (physical attendance) - Presentations - Polls - Free discussion	Attendance list, Recorded session (video), Polls, Notes	All 14 stakeholder groups represented (Fig. 2)	28 (10 onsite, 18 online)	4 h
6	Meet-Up 4	- Iterating LL requirements from user perspectives to integrate more in-depth knowledge and prepare for implementation	- Structured discussion (use of Miro tool) - Presentations	Miro boards, Notes, Presentations	Core team, Involved, Informed	9	1 h

[a] https://miro.com/. Miro is a collaborative online whiteboard platform used for visual brainstorming, organizing ideas, and real-time stakeholder interaction during workshops.

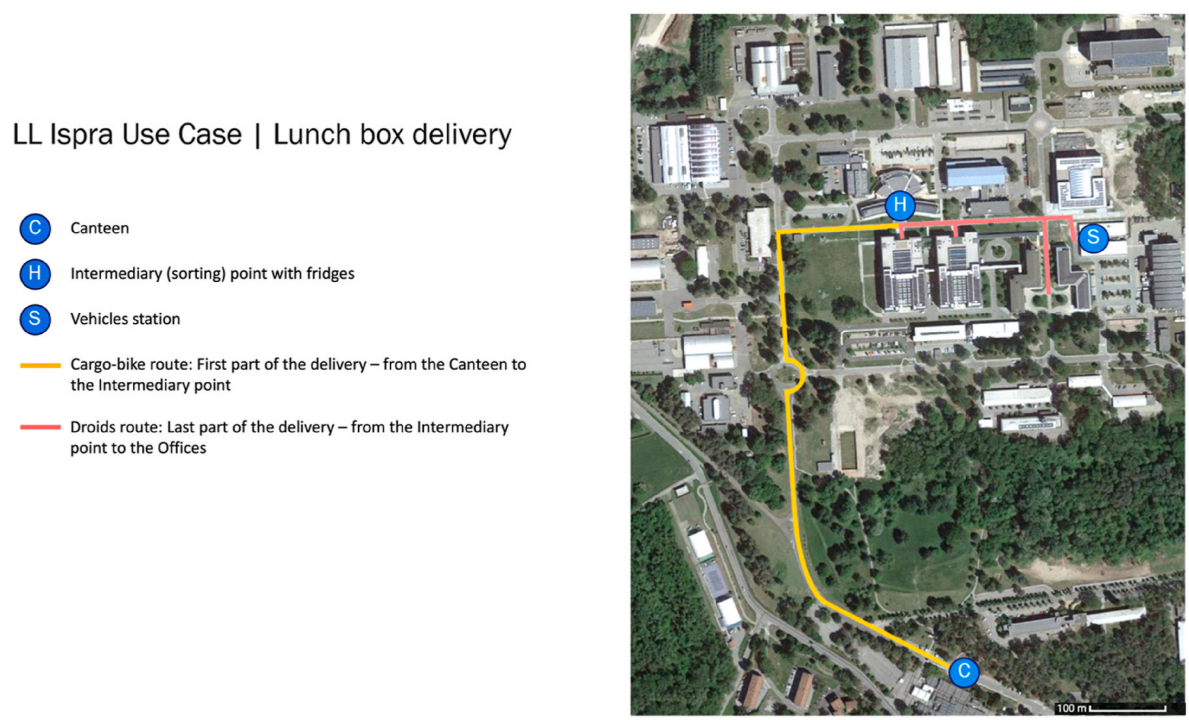

Fig. 3. Location and schematic representation of the delivery service.

clustered into respective key areas for service improvement (see Table 3).

5.2. User journeys

Having elicited the user requirments, next step was to formulate the sequences of the service and develop the service blueprint. To achieve that, the primary users were identified and their respective user journeys were developed to describe the process a user goes through when interacting with the service, so that critical areas for improvement are identified. Figs. 5–7 focus on customers (JRC employees), canteen operator, and logistics service provider (Measy cargo bike operator, Yape droids operator, Platform developer) respectively, while pain points, opportunities, and areas for enhancement were identified to

Fig. 4. SWOT Analysis based on Ispra's Living Lab Core Team Co-creation Activities.

improve the user experience.

As illustrated in Fig. 5, customers place their orders through JRC's internal system, namely pre notation system through which the customer (JRC employee) will declare their chosen lunch and preferred delivery times. On the day of delivery, the latter are notified via email when their order is about to arrive.

Fig. 6 shows the canteen operator journey. The canteen operators start by preparing all the meals that the customers have booked through the marketplace platform. Once the meals are ready, they pack them into lunch boxes. Next, the canteen operator logs into the pre-notation system to manage the day's orders. With all orders reviewed, the canteen operator organizes the packed lunch boxes and hands them over to the cargo bike rider, ready for delivery.

Furthermore, Fig. 7 shows how the canteen operators and logistics service provider work together to ensure a smooth operation. Once the packed orders are loaded onto the Measy cargo bike, they are transported to the exchange point. Then, the Yape droids take over, each assigned to specific deliveries based on a routing algorithm that considers proximity, route length, battery status, and user preferences.

5.3. Service Blueprint

Based on the user journeys and the underlying processes, a detailed service blueprint was generated. As shown in Fig. 8, the process begins with the user placing an order through the JRC prenotation platform. JRC compiles the daily orders list, which is accessible to the canteen. The canteen then receives the order list, prepares the lunch boxes, and hands them to a cargo-bike rider. The cargo-bike rider transports the lunch boxes to the intermediary (sorting) point and loads them onto the Yape droids. The fleet platform assigns deliveries to each droid for the final leg of the journey. The platform receives updates on the delivery status, which are shared in a common data space. Finally, the fleet platform informs the user via email once the order has arrived, ensuring a smooth and timely delivery experience within the JRC campus. It is noted that supportive modules such as the "Day-to-day optimization" module and the "Event-triggered optimization" module provide essential enhancements to this process. The "Day-to-day optimization" module uses artificial intelligence algorithms to predict logistics demand in the medium term, acting as an anticipatory shipping module that supports scheduling and modeling tasks. The "Event-triggered optimization" module, on the other hand, dynamically adjusts delivery operations in response to unexpected events, such as weather changes or fluctuations

Table 3
List of user requirements.

No	Area	Requirement
1	User-Friendly Digital Interface	- Ensure the ordering platform is efficient and easy to use - Provide clear usage instructions and explanations for the ordering platform
2	Diverse and Flexible Food Options	- Offer a variety of lunch options - Ensure the service integrates naturally into customers' daily routines, making it a convenient alternative to visiting the canteen
3	Seamless and Timely Delivery	- Guarantee on-time, seamless delivery solutions that fit into users' busy schedules, particularly during bad weather or high-demand periods
4	Privacy	- Address privacy concerns related to downloading work-related apps on personal devices
5	Clear Communication and Green Branding	- Develop a strong communication strategy to highlight the service's benefits, particularly its sustainability aspects - Build a green brand identity that resonates with the JRC community
6	Support for Work-Life Balance	- Ensure the service supports other activities, such as meetings, by offering flexible delivery times
7	Operational Efficiency and Stakeholder Buy-In	- Ensure the service is easy to adopt for users and stakeholders (canteen workers, management) - Streamline canteen operations to avoid additional workload or disruptions - Address concerns over the use of public funds and manage perceptions of robotic delivery systems

in order volumes, ensuring the system remains flexible and resilient in real-time.

6. Cooperative business models

The third and final phase ("scaling") focuses on value creation with an emphasis on ensuring the financial sustainability of the proposed service, if economy of scale is achieved (Ville, Gonzalez-Feliu, & Dablanc, 2012). In their study, Katsela and Pålsson (2021) highlight several successful implementations of business models in city logistics while analyzing critical factors, ie. number of stakeholders involved, internalizing externalities, subsidies, etc. One common conclusion is that a viable business model must attract sufficient customers to achieve economies of scale. Specifically, it is crucial to understand the service's cost and revenue structures to identify the "break-even volume" required for financial sustainability.

6.1. Pilot results

The piloting of the delivery service took place between November 11–15, 2024 and January 20, 2025 assessing the feasibility of the joint delivery system in a real-world environment. During this period, the service successfully delivered 20 food packages in total to four different buildings. The pilot data indicated that droids traveled a total of 5.67 km and 2.16 km, respectively, completing deliveries through a combination of autonomous navigation, remote control, and local manual control (Fig. 9).

In "Autonomous Mode", droids navigated and completed deliveries independently, utilizing onboard sensors to follow predefined routes without human intervention. In the "Remote Control Mode", the operator (rider) monitored and directed the droid's movements from a remote location, typically intervening when the droid encountered unexpected obstacles, unclear pathways, or areas where full autonomy was not yet reliable. In "Local Control Mode", the operator (rider) was physically present and manually operated or assisted the droid in response to unpredictable conditions, such as crowded areas or insufficient mapping data. Fig. 9 indicates, on January 20, 2025, remote control was not necessary, as sufficient mapping data were already available.

Furthermore, the analysis of journey time distribution revealed that the majority of time for the deliveries that took place on November 11–15, 2024 was spent on navigation (72.45 %), while sender wait time (9.78 %) and receiver wait time (17.77 %) accounted for the remaining duration. Fig. 10 indicates, on January 20, 2025, the sender waiting time was reduced, suggesting enhanced delivery performance (Fig. 10).

Finally, user feedback from the pilot was largely positive (Fig. 11). Ninety percent of participants rated the service as either "satisfying" or "very satisfying," while only ten percent reported dissatisfaction. This indicates that the delivery system was well received, with users recognizing its potential for convenience and efficiency. When asked about the long-term implementation of the service, 40 % were totally in favor, 50 % were in favor, and 10 % were opposed, with no participants expressing opposition.

6.2. Revenue streams and cost Structure

The cost and revenue structure of the delivery service includes both fixed and variable elements (Table 4), providing a detailed financial breakdown of investment, operational costs, and revenue streams. The

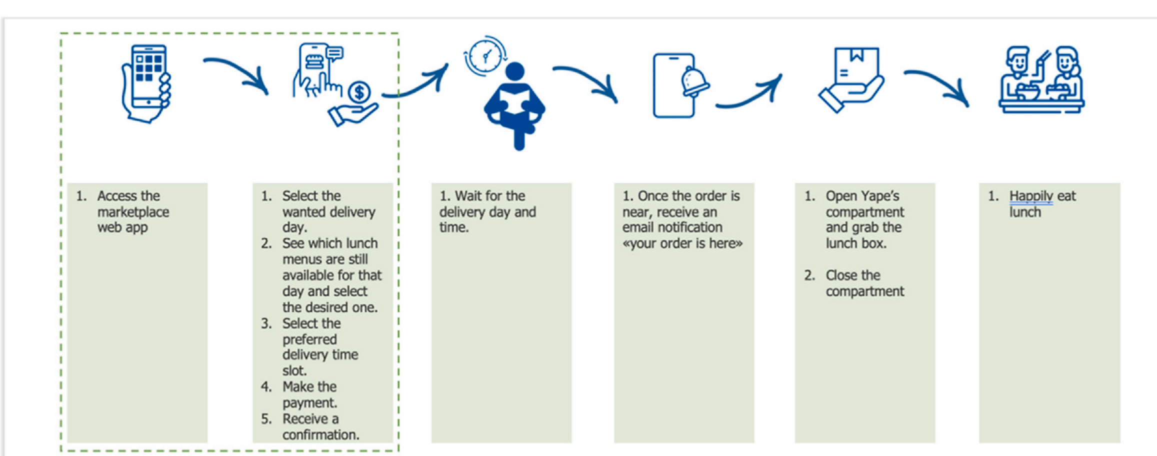

Fig. 5. Customer journey.
Note: Marketplace stands for the pre-notation system, which could possibly in the future include other additional vendors.

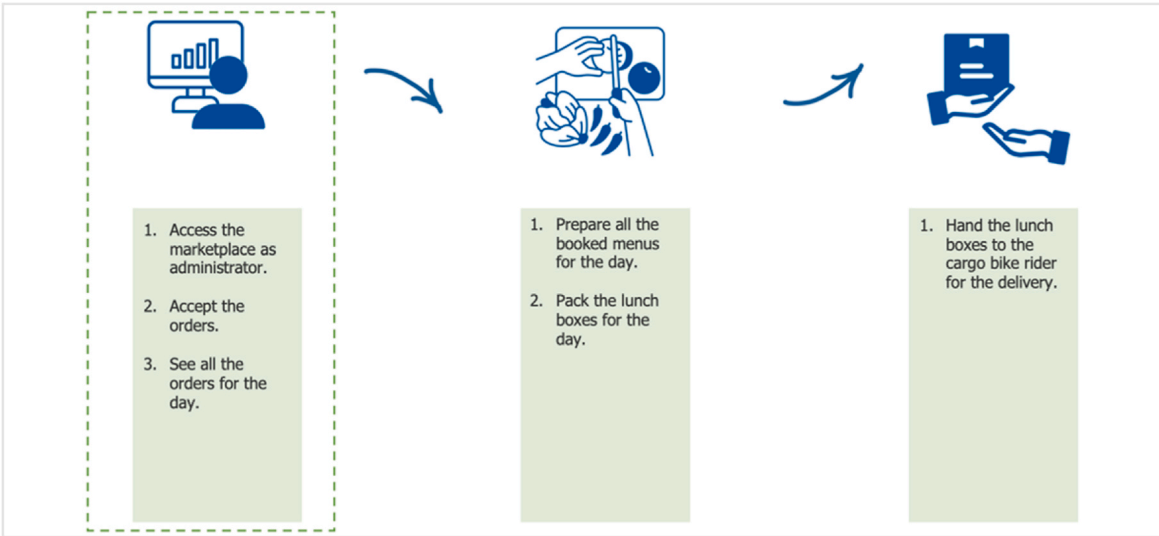

Fig. 6. Canteen operator journey.

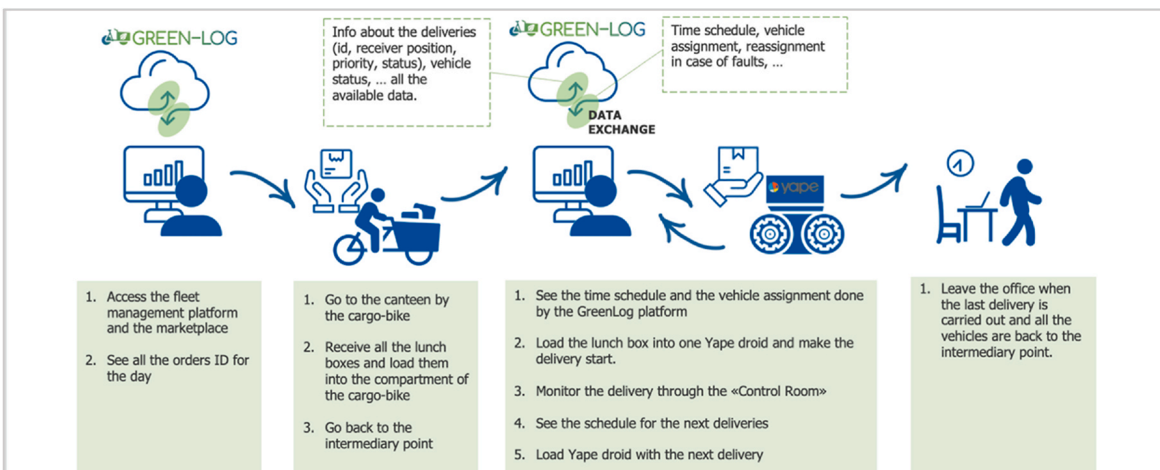

Fig. 7. Logistics service provider journey.

input for these estimations was provided by Yape (droid company), Measy (cargo-bike company) and JRC facility representatives (6 persons) in December 2024, after piloting the service for the first time in November 2024, allowing stakeholders to refine cost and revenue estimates based on initial real-world observations.

The following financial projection of the service is analyzed over a 10-year period, taking into account different daily delivery volumes: 20, 40, 60, and 80 deliveries per day (Fig. 12). The financial projections indicate that only the 20 deliveries/day scenario is profitable, reaching a cumulative profit of €83,375 by Year 10. In contrast, 40, 60 and 80 deliveries/day result in growing deficits of €22,250, €127,875 and €233,500, respectively. The key reason for these financial losses lies in the high procurement cost of droids and cargo bikes, alongside the strict delivery time window, which limits scalability. The key assumptions taken for drafting the financial projections are the following:

- The service must complete all deliveries within 2–3 h (lunch period)
  - o 20 deliveries/day require 1 employee,[1] 1 cargo bike, and 3 droids.
  - o 40 deliveries/day require 2 employees, 2 cargo bikes, and 3 droids, significantly raising fixed costs.
  - o 60 deliveries/day would require 3 employees, 3 cargo bikes, and 9 droids.
  - o 80 deliveries/day would require 4 employees, 4 cargo bikes, and 12 droids.
- A single set consisting of 1 cargo bike and 3 droids receives €30,000 per year in sponsorship (Item 13 in Table 4)
  - o A double set (2 cargo bikes, 6 droids) receives €45,000 per year (1.5 times the base case).
  - o A triple set (3 cargo bikes, 9 droids) would receive €60,000 per year (2 times the base case).
  - o A quadruple set (4 cargo bikes, 12 droids) would receive €75,000 per year (2.5 times the base case).

The financial breakdown across different scenarios reveals that fixed costs and revenues play a much larger role in overall profitability than variable costs. The bottom graphs demonstrate that while variable revenues contribute to total earnings, they do not significantly offset the high fixed costs associated with fleet procurement, infrastructure, and labor. Thus, the financial viability remains highly dependent on sponsorships and grants.

[1] A single cargo bike transports up to 20 meals per trip.

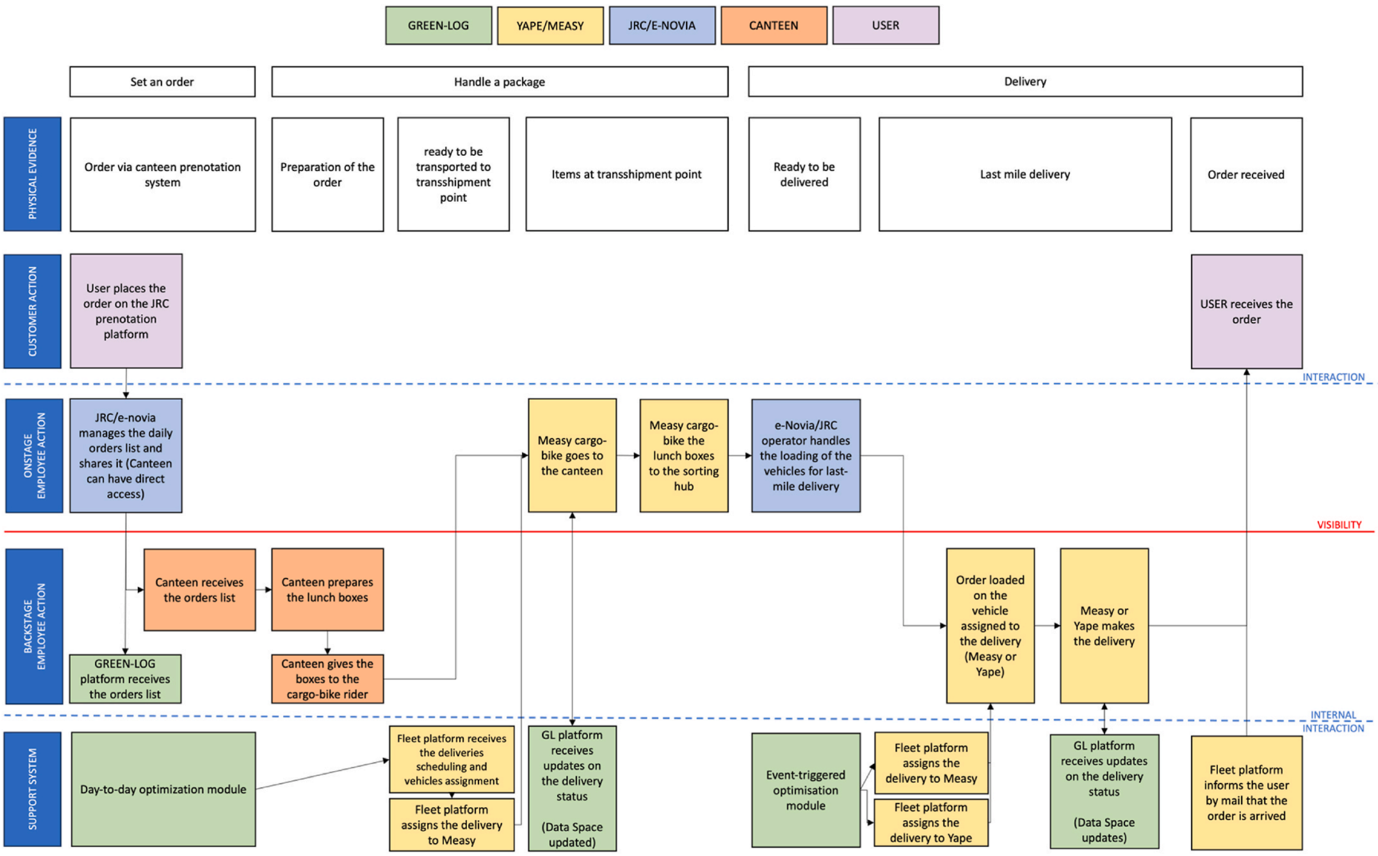

Fig. 8. Service blueprint.

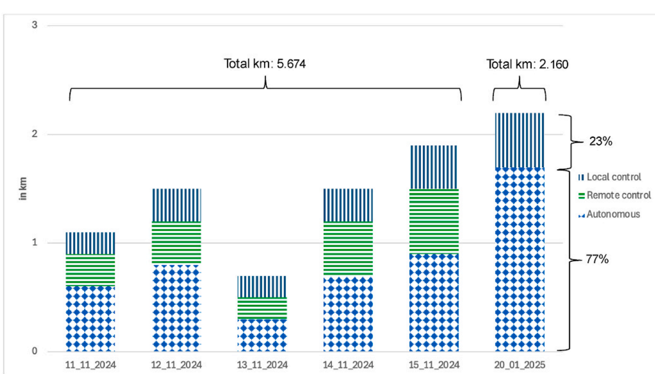

Fig. 9. Droids' distance Traveled.

It should be noted that, the estimated 5.42-h working day used in the financial model (see Table 4) reflects a calculated operational workload based on delivery volumes and cycle time. This estimate assumes uninterrupted execution of delivery tasks and excludes idle time or breaks. It does not represent an actual employment contract. In real-world implementations, labor planning would need to align with local employment laws and typical contractual structures, such as 6-h part-time or full-time shifts, and incorporate contingencies for delays or downtime.

Moreover, while the financial projections assume software development as a one-time cost - reflecting the in-house prototyping during the pilot - this approach differs from standard industry practice. In commercial implementations, fleet management systems are typically delivered as Software-as-a-Service (SaaS) subscriptions, often bundled with the robot hardware and support. These systems cover routing, diagnostics, and user interfaces, and their cost structure would impact both capital and operational expenses. Future deployments of the service would therefore need to adopt a modular or subscription-based software model, which may offer more scalable and predictable cost planning.

6.3. Sustainable business model canvas analysis

This research adopts and adapts the Business Model Canvas framework (Osterwalder & Pigneur, 2010) to explore the business value of the service. Central to value creation is an emphasis not only on financial gains but also on sustainability, which plays a pivotal role. Therefore, the proposed business model aim at creating value for all the partners by combining different kinds of value, ie. societal and environmental impact value.

By its definition, the business model canvas can be explained by nine building blocks, i.e. customer segments, value propositions, channels, customer relationships, revenue streams, key resources, key activities, key partnerships, and cost structure. In this research, two additional building blocks are examined to capture the sustainability footprint (externalities) of the proposed solutions; Eco-Social Benefits and Eco-Social Costs. Eco-Social Costs describes all the costs incurred for operating the business on an environmental and societal level, while Eco-Social Benefits describes, respectively, all the benefits. Fig. 13 provides an illustration of the business model canvas highlighting how all components collectively contribute to the overall success of the delivery service.

6.4. Cooperation aspect

Efficient cooperation is a precondition for scaling up and building capacity. Ferrero et al. (2018) point out that many initiatives tend to

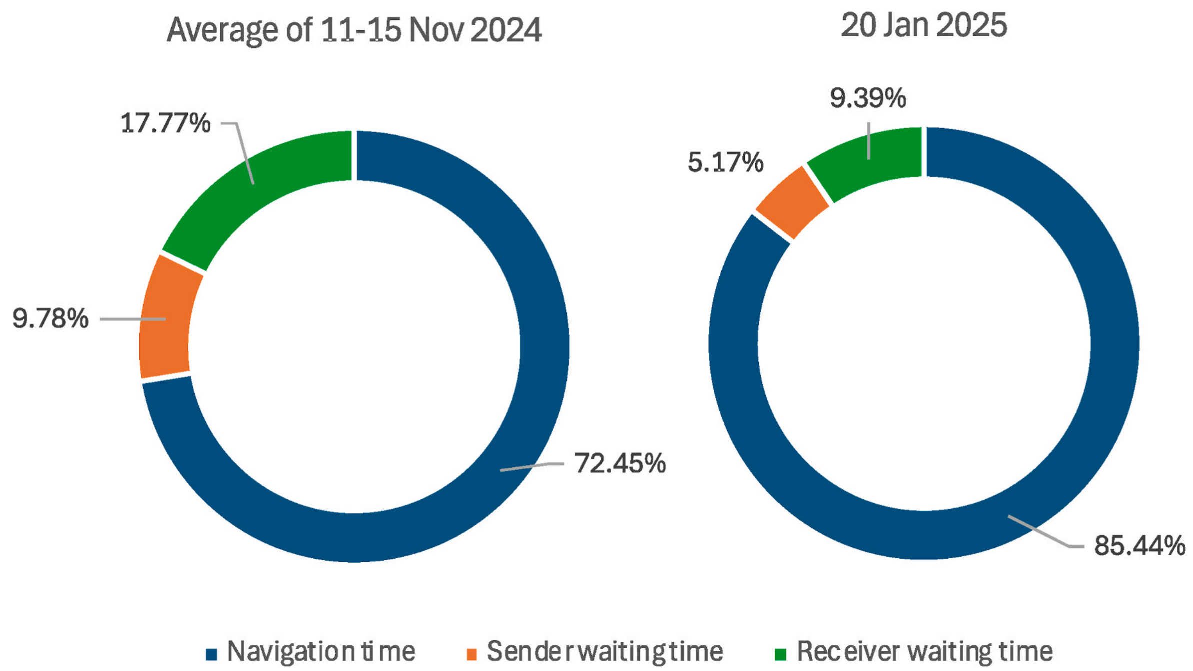

Fig. 10. Droids' Journey time distribution.

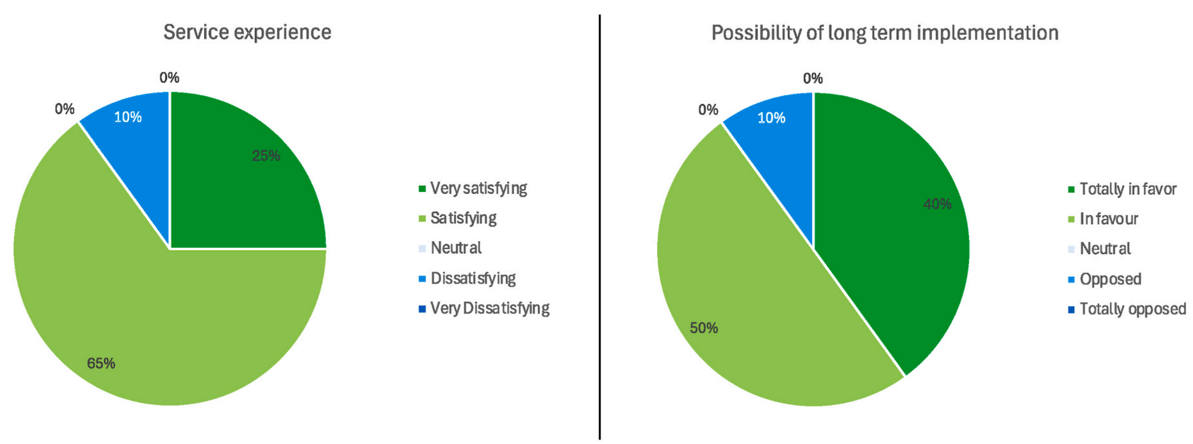

Fig. 11. Service experience and possibility of long term implementation.

overemphasize technology, such as platforms and optimization tools, while neglecting the critical link between business and operational models. This oversight complicates the alignment of stakeholders' diverse objectives (Lagorio et al., 2017) and results in diminished support and commitment, ultimately hindering collaboration. A better understanding of what drives stakeholder collaboration is crucial, as it can foster the development of policy measures that balance the interests and goals of both private and public stakeholders in city logistics (Le Pira et al., 2017).

In the envisioned cooperative business model in Ispra, shared decision-making and a sense of collective ownership are central. Cooperation agreements detailing collaboration terms and partners' rights are already in place, while a Med-Arb (Mediation-Arbitration) model has been adopted to resolve potential disputes through mediation (Pappas, 2015).

7. Concluding discussion

This study presents the design and implementation of an innovative last-mile food delivery solution at the EU JRC campus in Ispra, Italy, using a service design approach consisting of three phases; scoping, developing and scaling.

Pilot results come from two distinct test rounds: a) Nov 11–15, 2024 and, b) Jan 20, 2025. Results showed that during the first test round the droids traveled a total distance of 5.674 km, completing deliveries through a combination of autonomous (49 %[2]), remote (29 %), and local control (22 %) modes. Notably, during the second test round, were 2.160 km were covered, remote control was 0 %, indicating improved mapping data and enhanced navigation capabilities based on the learnings from the initial test round. Operational improvements were observed also in "Sender waiting time" which was decreased from 9.18 % to 5.17 %, promising greater efficiency in delivery operations and a smoother user experience. As per the latter, user feedback was overwhelmingly positive, with 90 % of participants rating the service as satisfactory or very satisfactory.

Beyond its operational strengths, the service also contributes to

[2] Average of 5 days: kilometers traveled autonomously over total kilometers traveled.

Table 4
Service's Cost structure and Revenue streams.

#	Category	Item	Estimation (in €)	Comment
Cost Structure				
1	Initial Investment Costs (Fixed)	Droid Procurement	69,000.00	Estimated average cost for 3 droids
2		Cargo Bike Procurement	5000.00	Estimated cost for 1 cargo bike
3		Intermediary Refrigerated Point	4000.00	Estimated cost for a refrigerated unit storing approx. 100 meal packages
4		Software Development	65,000.00 (Total est. cost)	Order management system: 10,000 € Delivery management system: 15,000 € Status update & tracking system: 8000 € Visualization & analytics dashboard: 10,000 € Demand rediction & planning: 7000 € DataSpace & system integration: 15,000 €
5	Operational Costs (Fixed)	Labor Costs (Wages for loading/ unloading)	20,312.50	No. of packages delivered/day by 1 rider: 20 packages Average delivery time per package with droid: 12.5 min Total time for deliveries (excluding loading/unloading): 250 min (4.17 h) Time for loading, unloading, and Riding to intermediary point: 85 min (1.25 h) Total daily work hours (including all tasks): 5.42 h Rider's hourly wage: 15 €/hour Daily labor cost: 81.25 €/day Annual labor cost (250 working days): 20312.50 €
6		Labor Costs (Overtime)	3000.00	Annual cost (Approximation)
7		Energy Costs (Fueling batteries for droids)	450.00	Annual cost per droid unit: 150 €
8		Maintenance and Repairs (droid and cargo bike)	2650.00	Annual cost per droid unit: 750 € Annual cost per cargo bike unit: 400 €
9		Refrigeration Costs (for intermediary point)	200.00	Annual cost
10		Licensing and Permits | Fixed cost	1500.00	Annual cost
11	Operational Costs (Variable)	Contigency costs	0.30	Per delivery (Approximation), ie. failed deliveries, delays, malfunctions
12		Food Packaging	0.05	Per delivery, ie. stickers, printing material
Revenue Streams				
13	Revenues (Fixed)	Corporate Sponsorship (branding on droids/bikes)	30,000.00	Annual revenues for a set of 1 cargo bike and 3 droids: 30,000.00€ Annual revenues for 2 sets: 30,000.00€ * 1.5 Annual revenues for 3 sets: 30,000.00€ * 2 Annual revenues for 4 sets: 30,000.00€ * 2.5
14		EU bodies funding green mobility solutions	125,000.00	Once
15		Grants supporting 3 droids/1 cargo bike	50,000.00	Once
16	Revenues (Variable)	Revenues	1.00	Per delivery (Approximation)

sustainability in three key ways. First, many employees currently drive to the canteen, as walking takes over 10 min, particularly in extreme weather conditions such as cold, heat, wind, rain, or snow. By providing a delivery alternative, the service helps reduce unnecessary car trips and their associated emissions. Second, sustainability extends beyond environmental and economic aspects to encompass social equity. Previously, the absence of a delivery service meant that employees with mobility challenges had to depend on colleagues for assistance. By introducing a reliable meal delivery option, the service ensures equitable access for all employees, fostering a more inclusive and supportive workplace. Third, while CO_2 reduction was not directly measured, the use of electric cargo bikes and droids supports the claim that the service contributes to green last-mile deliveries.

Weakness of the service is the vague picture with regards to customer preferences. Some users may still favor walking to the canteen for social or personal reasons (Horton & Forsberg, 2020), thus understanding these preferences is key for scalability. Another weakness is that although the service received no strong opposition, 10 % of participants expressed dissatisfaction, which could indicate skepticism about robotic delivery replacing traditional methods, echoing concerns of resistance to change and job replacement (Polydoropoulou et al., 2023). Furthermore, the need for remote and local control in the initial test round and local control in the second test round indicates integration challenges and the necessity of refining autonomous navigation.

Moreover, a detailed analysis of cost and revenue structures alongside financial projections was presented. The financial projections highlighted the need for improvements and alternative pricing models to enhance financial viability. Based on the presented calculations, the service remains highly dependent on sponsorships and grants, a common characteristic in the city logistics domain (Nascimento et al., 2023).

Achieving financial viability begins with integrating advanced technology, such as AI-based path planning and enriched mapping data, continuously refined through repetitive delivery trips. This will increase the proportion of fully autonomous navigation per trip and reduce the current 12.5-min average delivery time per droid, which is presently impacted by delays from remote and local control interventions. Consequently, this optimization will enable a higher number of deliveries within the strict lunch window. Additionally, establishing a credible delivery system will further maximize deliveries within the available timeframe. A reliable system encourages recipients to be present on time, minimizing sender waiting times and eliminating unnecessary delays. Furthermore, as automation technology advances and market adoption grows, procurement costs for droids and cargo bikes are expected to decline. This will lower the initial investment burden and enhance the overall return on investment, making the service more

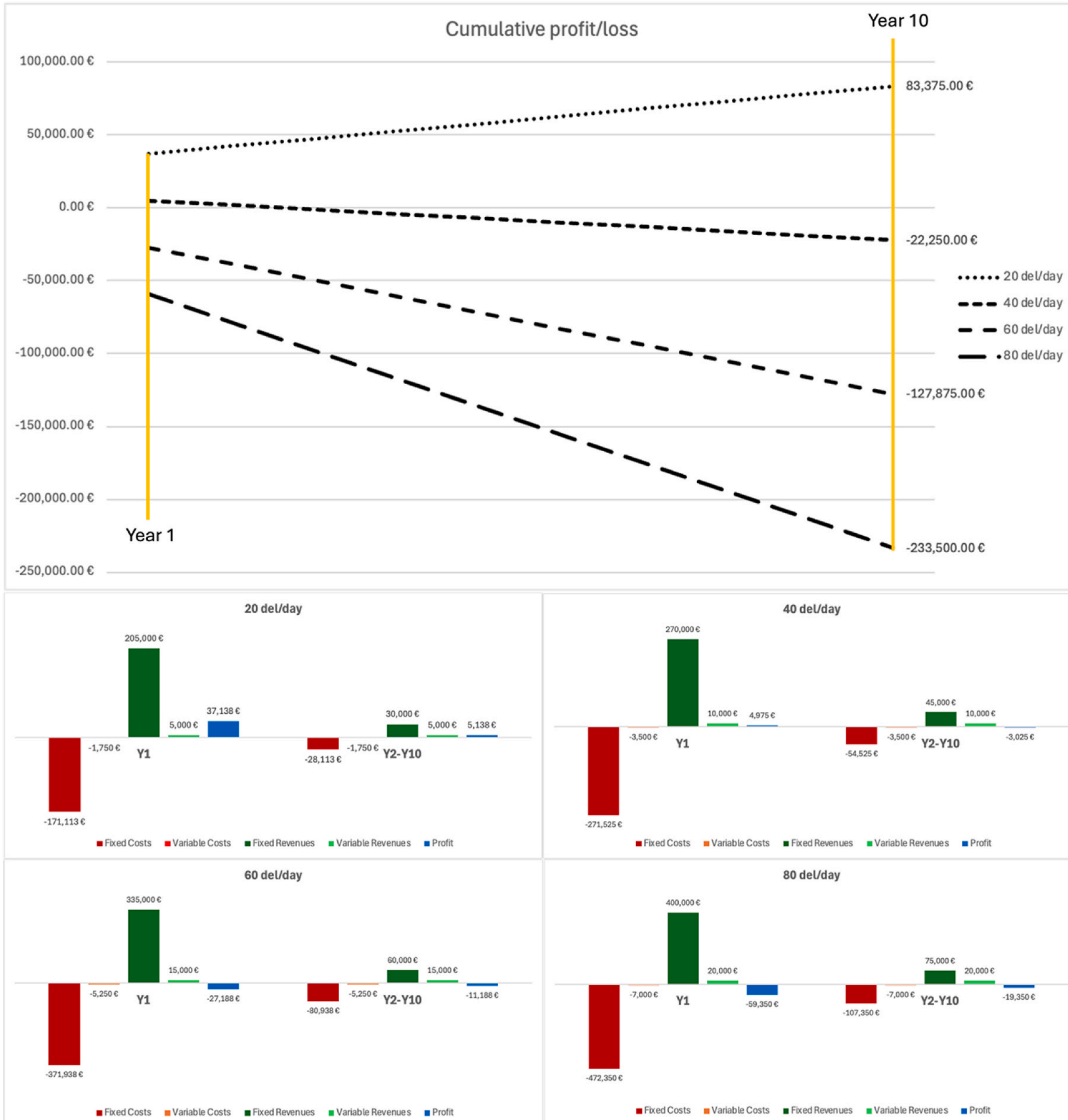

Fig. 12. Cumulative profit/loss and cost-revenue breakdown over 10 Years.

financially sustainable. Moreover, introducing alternative pricing models - such as premium-priced express deliveries - could increase profit margins. Customers willing to pay a higher fee for faster service would generate greater revenue compared to the current €1 per delivery model. Finally, contingency costs (€0.30 per delivery) are expected to decrease over time due to increased operational efficiency, improved battery life, and software optimizations, further contributing to long-term financial sustainability.

7.1. Limitations

This study has limitations. First, the research primarily focuses on a campus, which may limit the generalization of the findings to other urban contexts where the interaction with users differ. Second, the implementation of autonomous droids and cargo bikes is still in its early stages, and long-term operational data is lacking. This makes it challenging to fully assess the scalability and sustainability of these solutions over time. Third, the study relies heavily on stakeholder engagement and co-creation activities, which, although beneficial, may introduce biases based on the participants' perspectives and the specific socio-economic environment. Finally, regulatory and policy hurdles, as well as infrastructure limitations, present significant barriers that require comprehensive strategies and collaborations beyond the scope of this initial research.

7.2. Future research

Future research should focus on scaling these solutions to the JRC campus and adapting the prototypes for broader urban environments. The pilot was initially limited to four buildings, underscoring the need to expand service coverage to assess its effectiveness in diverse campus settings. In an urban context, successful implementation will require addressing the unique logistical challenges while continuously refining the business models to ensure they remain sustainable and effective.

Another key research direction involves gaining a deeper understanding of complex user preferences. As noted, employees who prefer

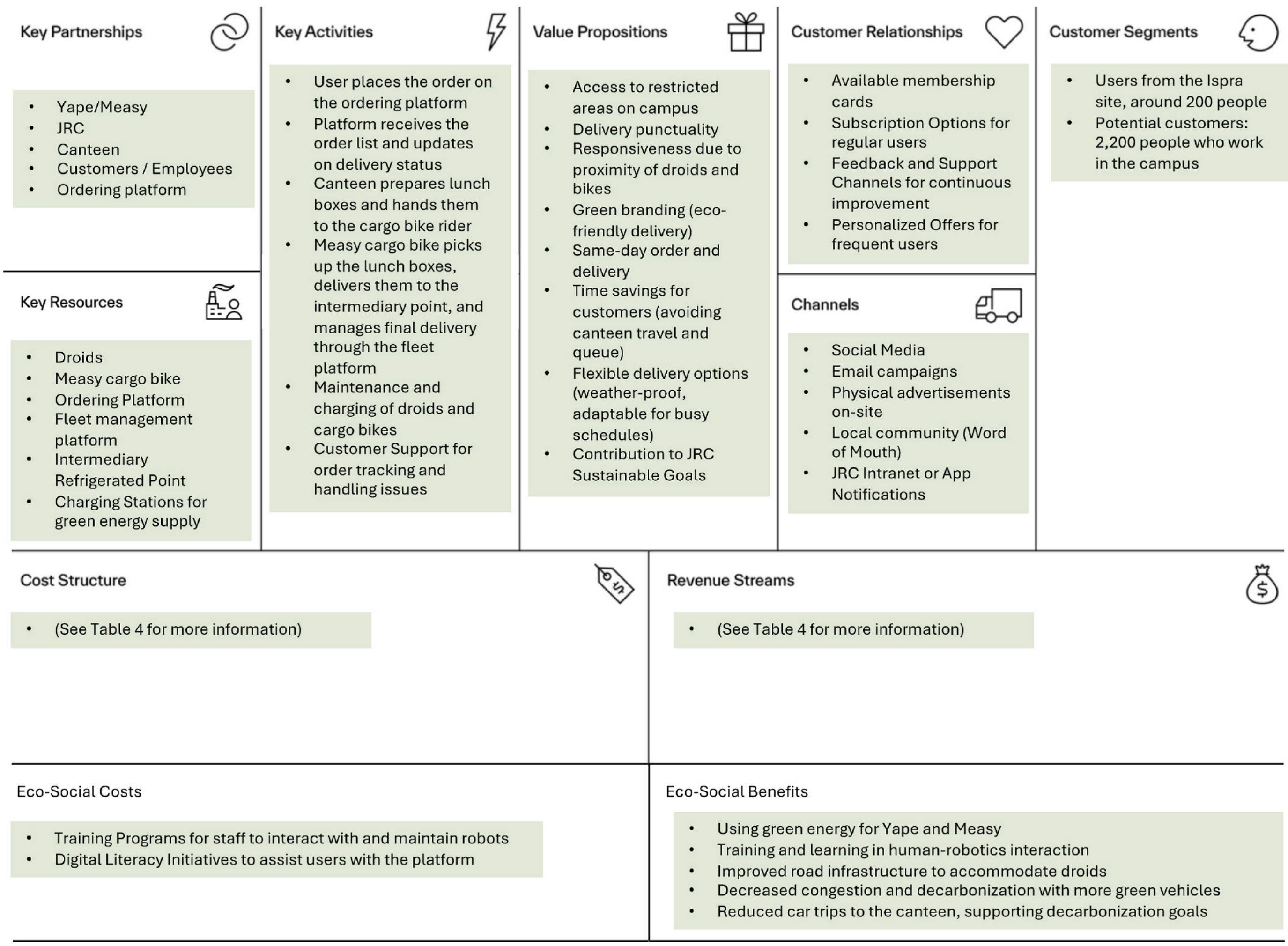

Fig. 13. Sustainable business model canvas.

walking to the canteen for social interaction or exercise are less likely to adopt the service. These individuals either work near the canteen and find delivery unnecessary or are captive walkers - those who choose to walk despite having access to alternative transport modes, such as cars or bicycles. While this behavior may seem intuitive, further research could provide valuable insights into their decision-making process and identify potential incentives that might encourage occasional service use.

CRediT authorship contribution statement

Ioannis Karakikes: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Athena Tsirimpa:** Writing – review & editing, Software, Resources, Methodology, Investigation, Funding acquisition. **Federico Moro:** Validation, Software, Resources, Conceptualization. **Vaike Fors:** Visualization, Methodology, Investigation. **Amalia Polydoropoulou:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to proofread some parts of the document. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

- Scoping Phase: Encompasses early-stage exploration of technological, regulatory, and societal factors influencing autonomous delivery solutions. This includes studies that examine public perceptions, governance challenges, feasibility assessments, and emerging trends, laying the foundation for co-design and stakeholder engagement.
- Developing Phase: Covers practical implementation efforts, including studies that propose optimization models, technological refinements, operational frameworks, and feasibility testing. In the service design context, this phase focuses on iterative development, prototyping, and the adaptation of digital tools and logistics solutions.
- Scaling Phase: Relates to business ecosystem development, policy integration, and long-term adoption strategies. Research in this phase explores economic viability, regulatory adaptation, governance models, and operational scaling. In service design, this corresponds to the co-creation of sustainable business models, collaborative networks, and strategies for wider deployment.

Data availability

The data that has been used is confidential.

References

Abrams, A., Dautzenberg, P., Jakobowsky, C., Ladwig, S., & Rosenthal-von der Pütten, A. (2021). A theoretical and empirical reflection on technology acceptance models for autonomous delivery robots. In *Proceedings of the 2021 ACM/IEEE international conference on human-robot interaction (HRI '21)* (pp. 272–280). New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3434073.3444662.

Alfandari, L., Ljubić, I., & da Silva, M. (2022). A tailored Benders decomposition approach for last-mile delivery with autonomous robots. *European Journal of Operational Research, 299*(2), 510–525. https://doi.org/10.1016/j.ejor.2021.06.048. ISSN 0377-2217.

Allen, J., Piecyk, M., Piotrowska, M., McLeod, F., Cherrett, T., Ghali, K., Nguyen, T., Bektas, T., Bates, O., Friday, A., Wise, S., & Austwick, M. (2018). Understanding the impact of e-commerce on last-mile light goods vehicle activity in urban areas: The case of London. *Transportation Research Part D: Transport and Environment, 61*(Part B), 325–338. https://doi.org/10.1016/j.trd.2017.07.020. ISSN 1361-9209.

Alverhed, E., Hellgren, S., Isaksson, H., et al. (2024). Autonomous last-mile delivery robots: A literature review. *Eur. Transp. Res. Rev., 16*, 4. https://doi.org/10.1186/s12544-023-00629-7

Arntz, E. M., Van Duin, J. H., Van Binsbergen, A. J., Tavasszy, L. A., & Klein, T. (2023). Assessment of readiness of a traffic environment for autonomous delivery robots. *Frontiers in Future Transportation, 4*. https://doi.org/10.3389/ffutr.2023.1102302

Beckers, J., Weekx, S., Beutels, P., & Verhetsel, A. (2021). COVID-19 and retail: The catalyst for e-commerce in Belgium? *Journal of Retailing and Consumer Services, 62*, Article 102645. https://doi.org/10.1016/j.jretconser.2021.102645. ISSN 0969-6989.

Browne, G. J., & Rogich, M. B. (2001). An empirical investigation of user requirements elicitation: Comparing the effectiveness of prompting techniques. *Journal of Management Information Systems, 17*(4), 223–249. https://doi.org/10.1080/07421222.2001.11045665

Chen, C., Demir, E., Huang, Y., & Qiu, R. (2021). The adoption of self-driving delivery robots in last mile logistics. *Transportation Research Part E: Logistics and Transportation Review, 146*, Article 102214. https://doi.org/10.1016/j.tre.2020.102214. ISSN 1366-5545.

City logistics. (2017). San Francisco to restrict goods delivery robots. http://www.citylogistics.info/policies/san-francisco-to-restrict-goods-delivery-robots/. (Accessed 1 October 2024).

DriveSweden. (2023). Synergetic autonomous transport. Final report https://www.drivesweden.net/sites/default/files/2023-08/slutrapport_sat.pdf. (Accessed 28 February 2025).

Ebbesson, E., Lund, J., & Smith, R. C. (2024). Dynamics of sustained co-design in urban living labs. *CoDesign, 1–18*. https://doi.org/10.1080/15710882.2024.2303115

European Commission. (2021). "Fit for 55": Delivering the EU's 2030 climate target on the way to climate neutrality. https://ec.europa.eu/info/sites/default/files/chapeau_communication.pdf. (Accessed 20 July 2024).

European Commission. (2024). Soon in Ispra. https://commission.europa.eu/document/download/c8fa2fea-193f-4203-b84c-9a52a691bad0_en. (Accessed 22 July 2024).

Ferrero, F., Perboli, G., Rosano, M., & Vesco, A. (2018). Car-sharing services: An annotated review. *Sustainable Cities and Society, 37*, 501–518. https://doi.org/10.1016/j.scs.2017.09.020. ISSN 2210-6707.

Galambos, K. J., Palomino-Hernández, A. B., Hemmelmayr, V. C., & Turan, B. (2024). Sustainability initiatives in urban freight transportation in Europe. *Transportation Research Interdisciplinary Perspectives, 23*, Article 101013. https://doi.org/10.1016/j.trip.2023.101013. ISSN 2590-1982.

Garus, A., Alonso, B., Alonso Raposo, M., Grosso, M., Krause, J., Mourtzouchou, A., & Ciuffo, B. (2022). Last-mile delivery by automated droids. Sustainability assessment on a real-world case study. *Sustainable Cities and Society, 79*, Article 103728. https://doi.org/10.1016/j.scs.2022.103728. ISSN 2210-6707.

Garus, A., Christidis, P., Mourtzouchou, A., Duboz, L., & Ciuffo, B. (2024). Unravelling the last-mile conundrum: A comparative study of autonomous delivery robots, delivery bicycles, and light commercial vehicles in 14 varied European landscapes. *Sustainable Cities and Society, 108*, 105490. https://doi.org/10.1016/j.scs.2024.105490. ISSN 2210-6707.

Gatta, V., Marcucci, E., & Le Pira, M. (2023). E-Commerce and urban logistics: Trends, challenges, and opportunities, chapters. In E. Marcucci, V. Gatta, & M. Le Pira (Eds.), *Handbook on city logistics and urban freight* (pp. 422–443). Edward Elgar Publishing (chapter 21).

Gehrke, S., Phair, C., Russo, B., & Smaglik, E. (2023). Observed sidewalk autonomous delivery robot interactions with pedestrians and bicyclists. *Transportation Research Interdisciplinary Perspectives, 18*, 100789. https://doi.org/10.1016/j.trip.2023.100789. ISSN 2590-1982.

GREEN-LOG project. (2023). Knowledge base of last-mile solutions and GREEN-LOG requirements specification. *Deliverable, 1.1*.

Heimfarth, A., Ostermeier, M., & Hübner, A. (2022). A mixed truck and robot delivery approach for the daily supply of customers. *European Journal of Operational Research, 303*(1), 401–421. https://doi.org/10.1016/j.ejor.2022.02.028. ISSN 0377-2217.

Hoffmann, T., & Prause, G. (2018). On the regulatory framework for last-mile delivery robots. *Machines, 6*(3), 33. https://doi.org/10.3390/machines6030033

Horton, P., & Forsberg, C. (2020). Safe spaces? A social-ecological perspective on student perceptions of safety in the environment of the school canteen. *Educational Research, 62*(1). https://doi.org/10.1080/00131881.2020.1715235

Hutter, M., Gehring, C., Lauber, A., Gunther, F., Bellicoso, C. D., Tsounis, V., Fankhauser, P., Diethelm, R., Bachmann, S., Bloesch, M., Kolvenbach, H., Bjelonic, M., Isler, L., & Meyer, K. (2017). ANYmal - toward legged robots for harsh environments. *Advanced RoboticsOpen AccessVolume, 31*(17), 918–931. https://doi.org/10.1080/01691864.2017.1378591

Iversen, O. S., & Dindler, C. (2014). Sustaining participatory design initiatives. *CoDesign, 10*(3–4), 153–170.

Janjevic, M., & Ndiaye, A. B. (2014). Development and application of a transferability framework for micro-consolidation schemes in urban freight transport. *Procedia - Social and Behavioral Sciences, 125*, 284–296. https://doi.org/10.1016/j.sbspro.2014.01.1474. ISSN 1877-0428.

Jennings, D., & Figliozzi, M. (2020). Study of road autonomous delivery robots and their potential effects on freight efficiency and travel. *Transportation Research Record, 2674*(9), 1019–1029. PDF.

Kapser, s., Abdelrahman, M., & Bernecker, T. (2021). Autonomous delivery vehicles to fight the spread of Covid-19 – how do men and women differ in their acceptance? *Transportation Research Part A: Policy and Practice, 148*, 183–198. https://doi.org/10.1016/j.tra.2021.02.020. ISSN 0965-8564.

Katsela, K., & Pålsson, H. (2021). Viable business models for city logistics: Exploring the cost structure and the economy of scale in a Swedish initiative. *Research in Transportation Economics, 90*, Article 100857. https://doi.org/10.1016/j.retrec.2020.100857. ISSN 0739-8859.

Kiwibot. (2022). Grubhub and Kiwibot partner for robot delivery on college campuses. https://www.kiwibot.com/blog-posts/grubhub-and-kiwibot-partner-for-robot-delivery-on-college-campuses. (Accessed 1 October 2024).

Klose, L., Beckmann, A., Ihlenburg, S., Preindl, R., & Straube, F. (2022). Guidelines for transferring sustainable urban logistics concepts. In W. J. Kersten, C. Blecker, T. Ringle, & M. Christian (Eds.), *Changing tides: The new role of resilience and sustainability in logistics and supply chain management – innovative approaches for the shift to a new era. Proceedings of the hamburg international conference of logistics (HICL)* (Vol. 33, pp. 753–797). https://doi.org/10.15480/882.4701. ISBN 978-3-756541-95-9, epubli GmbH, Berlin.

Koh, L-Y., & Yuen, K-F. (2025). Individual-, task-, and technology-fit perspective of autonomous delivery robots confirmation and adoption in smart cities. *International Journal of Hospitality Management, 128*, 104182. https://doi.org/10.1016/j.ijhm.2025.104182. ISSN 0278-4319.

Lagorio, A., Pinto, R., & Golini, R. (2017). Urban logistics ecosystem: A system of system framework for stakeholders in urban freight transport projects. *IFAC-PapersOnLine, 50*(1), 7284–7289. https://doi.org/10.1016/j.ifacol.2017.08.1402. ISSN 2405-8963.

Law, W. T., Fan, K. W., Li, K. S., & Mo, T. (2023). Applied design and methodology of delivery robots based on human–robot interaction in smart cities. *EAI Endorsed Trans Smart Cities, 7*(2), e3.

Le Pira, M., Marcucci, E., Gatta, V., Inturri, G., Ignaccolo, M., & Pluchino, A. (2017). Integrating discrete choice models and agent-based models for ex-ante evaluation of stakeholder policy acceptability in urban freight transport. *Research in Transportation Economics, 64*, 13–25. https://doi.org/10.1016/j.retrec.2017.08.002. ISSN 0739-8859.

Lee, S. C., Nadri, C., Sanghavi, H., & Jeon, M. (2022). Eliciting user needs and design requirements for user experience in fully automated vehicles. *International Journal of Human-Computer Interaction, 38*(3), 227–239.

Lemardelé, C., Melo, S. P., Cerdas, F., Herrmann, C., & Estrada, M. (2023). Life-cycle analysis of last-mile parcel delivery using autonomous delivery robots. *Transportation Research Part D: Transport and Environment, 121*, 103842. https://doi.org/10.1016/j.trd.2023.103842. ISSN 1361-9209.

Marcianni, M. (2023). What is the role of Urban Logistics and Last Mile Delivery robots in the city of the future?. Available here: https://www.fitconsulting.it/en/the-role-of-urban-logistics-and-last-mile-delivery-robots-in-the-city-of-the-future/. (Accessed 30 September 2024).

Marcucci, E., Le Pira, M., Gatta, V., Inturri, G., Ignaccolo, M., & Pluchino, A. (2017). Simulating participatory urban freight transport policy-making: Accounting for heterogeneous stakeholders' preferences and interaction effects. *Transportation Research Part E: Logistics and Transportation Review, 103*, 69–86. https://doi.org/10.1016/j.tre.2017.04.006. ISSN 1366-5545.

Marsden, G., Maunder, A., & Parker, M. (2008). People are people, but technology is not technologyPhil. *Trans. R. Soc. A, 366*, 3795–3804. https://doi.org/10.1098/rsta.2008.0119

McKinsey. (2017). https://www.mckinsey.com/capabilities/sustainability-and-resource-productivity/our-insights/urban-commercial-transport-and-the-future-of-mobility?cid=other-eml-alt-mip-mck-oth-1709&hlkid=dc391fa1a8a34aa3b79ea96d72d550df&hctky=1965171&hdpid=2d1b7499-8124-4e17-b80c-61628ed55538. (Accessed 1 October 2024).

Nascimento, C., Gatta, V., & Marcucci, E. (2023). Green Crowdshipping: Critical factors from a business perspective. *Research in Transportation Business & Management, 51*, Article 101062. https://doi.org/10.1016/j.rtbm.2023.101062. ISSN 2210-5395.

Nathanail, E., Mitropoulos, L., Karakikes, I., & Adamos, G. (2018). Sustainability framework for assessing urban freight transportation measures. *Logistics & Sustainable Transport, 9*(2), 16–36. https://doi.org/10.2478/jlst-2018-0007

Ostermeier, M., Heimfarth, A., & Hübner, A. (2021). Cost-optimal truck-and-robot routing for last-mile delivery. *Networks*, 1–26. https://doi.org/10.1002/net.22030

Osterwalder, A., & Pigneur, Y. (2010). *Business model generation: A handbook for visionaries, game changers, and challengers*. New Jersey: Wiley.

Pappas, B. (2015). Med-arb and the legalization of alternative dispute resolution. *Harvard Negotiation Law Review, 20*(1). Available at: SSRN https://ssrn.com/abstract=4102353. (Accessed 30 June 2024).

Pink, S., Fors, V., Lanzeni, D., Duque, M., Sumartojo, S., & Strengers, Y. (2022). *Design ethnography: Research, responsibilities, and futures* (1st ed.). Routledge. https://doi.org/10.4324/9781003083665

Plank, M., Lemardelé, C., Assmann, T., & Zug, S. (2022). Ready for robots? Assessment of autonomous delivery robot operative accessibility in German cities. *Journal of Urban Mobility, 2*, Article 100036. https://doi.org/10.1016/j.urbmob.2022.100036

Poeting, M., Schaudt, S., & Clausen, U. (2019). *A Comprehensive Case Study in Last-Mile Delivery Concepts for Parcel Robots," 2019 Winter Simulation Conference (WSC)* (pp. 1779–1788). MD, USA: National Harbor. https://doi.org/10.1109/WSC40007.2019.9004811

Polydoropoulou, A., Thanopoulou, H., Karakikes, I., Pronello, C., & Tyrinopoulos, Y. (2023). Adapting to the future: Examining the impact of transport automation and digitalization on the labor force through the perspectives of stakeholders in all transport sectors. *Frontiers in Future Transportation, 4*. https://doi.org/10.3389/ffutr.2023.1173657

Polydoropoulou, A., Tsirimpa, A., Karakikes, I., Tsouros, I., & Pagoni, I. (2022). Mode choice modeling for sustainable last-mile delivery: The Greek perspective. *Sustainability, 14*, 8976. https://doi.org/10.3390/su14158976

Prencipe, L. P., Colovic, A., Binetti, M., & Ottomanelli, M. (2024). Zero-emission vehicle adoption towards sustainable e-grocery last-mile delivery. *Research in Transportation Economics, 104*, Article 101429. https://doi.org/10.1016/j.retrec.2024.101429. ISSN 0739-8859.

Simoni, M., Kutanoglu, E., & Claudel, C. (2020). Optimization and analysis of a robot-assisted last mile delivery system. *Transportation Research Part E: Logistics and Transportation Review, 142*, Article 102049. https://doi.org/10.1016/j.tre.2020.102049. ISSN 1366-5545.

Smith, R. C., & Iversen, O. S. (2018). Participatory design for sustainable social change. *Design Studies*. https://doi.org/10.1016/j.destud.2018.05.005. . (Accessed 1 June 2024)

Srinivas, S., Ramachandiran, S., & Rajendran, S. (2022). Autonomous robot-driven deliveries: A review of recent developments and future directions. *Transportation Research Part E: Logistics and Transportation Review, 165*, Article 102834. https://doi.org/10.1016/j.tre.2022.102834. ISSN 1366-5545.

Starship Technologies. (2018). Data protection? We need a feasible balance between business and privacy. Available online: https://www.european-business.com/starship-technologies/interviews/data-protection-we-need-a-feasible-balance-between-business-and-privacy/. (Accessed 19 May 2018).

Starship Technologies. (2022). Starship technologies FAQ. https://www.starship.xyz/contact/faq/. (Accessed 20 February 2024).

Statista. (2023). Retail e-commerce sales worldwide from 2014 to 2027. https://www.statista.com/statistics/379046/worldwide-retail-e-commerce-sales/#:~:text=In%202023%2C%20global%20retail%20e,estimated%205.8%20trillion%20U.S.%20dollars. (Accessed 19 July 2024).

Udoh, D. E., Ekpo, D. D., & Nkan, I. E. (2024). Design and development of a package delivery robot. *International Journal of Multidisciplinary Research and Analysis, 7*(Issue 06). https://doi.org/10.47191/ijmra/v7-i06-13

Valeo. (2020). https://www.valeo.com/en/ces-2020-in-a-world-first-valeo-is-unveiling-its-autonomous-electric-delivery-droid-developed-in-partnership-with-meituan-dianping-chinas-leading-e-commerce-platform-for-services/. (Accessed 1 October 2024).

van Waes, A., Nikolaeva, A., & Raven, R. (2021). Challenges and dilemmas in strategic urban experimentation. An analysis of four cycling innovation living labs. *Technological Forecasting and Social Change, 172*, Article 121004. https://doi.org/10.1016/j.techfore.2021.121004. ISSN 0040-1625 . (Accessed 1 June 2024).

Ville, S., Gonzalez-Feliu, J., & Dablanc, L. (2012). The limits of public policy intervention in urban logistics: Lessons from vicenza (Italy). *European Planning Studies, 21*(10), 1528–1541. https://doi.org/10.1080/09654313.2012.722954

World Economic Forum. (2024). How delivery companies can help cities reduce congestion and emissions. https://www.weforum.org/agenda/2024/01/deliveries-cities-reduce-congestion-emissions/. (Accessed 21 June 2024).

Yu, S., Puchinger, J., & Sun, S. (2022). Van-based robot hybrid pickup and delivery routing problem. *European Journal of Operational Research, 298*(3), 894–914. https://doi.org/10.1016/j.ejor.2021.06.009. ISSN 0377-2217.

Yuen, K-F., Koh, L-Y., Anwar, M., & Wang, X. (2022). Acceptance of autonomous delivery robots in urban cities. *Cities, 131*, 104056. https://doi.org/10.1016/j.cities.2022.104056. ISSN 0264-2751.

Zeng, S., Zhang, N., Zhang, C., Su, W., & Carlos, L.-A. (2022). Social network multiple-criteria decision-making approach for evaluating unmanned ground delivery vehicles under the Pythagorean fuzzy environment. *Technological Forecasting and Social Change, 175*, Article 121414. https://doi.org/10.1016/j.techfore.2021.121414. ISSN 0040-1625.