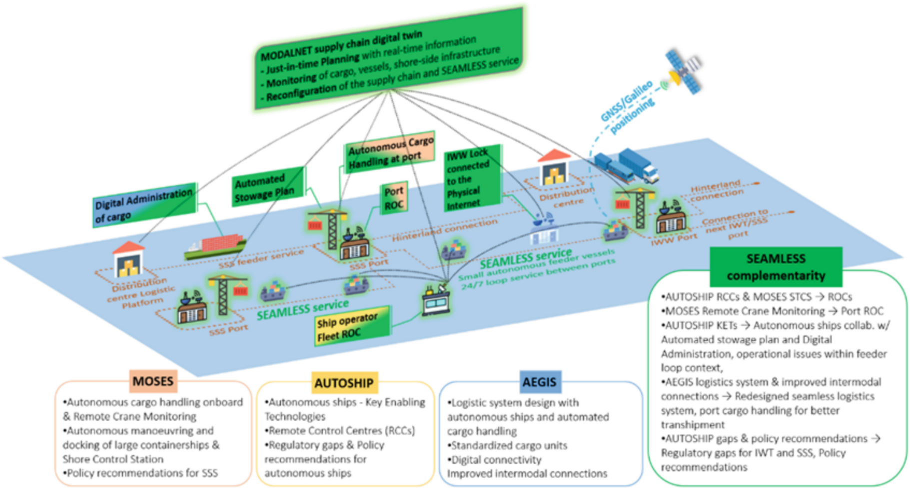

Fig. 1. SEAMLESS concept and technology building blocks for seamless and automated logistics. Image produced by Angeliki Stouraiti in Inkscape, an open source software

autonomous vessels involved in the SEAMLESS service, 2) an autonomous, innovative crane system for cargo handling at port supported by an automated stowage planning system, and 3) a system for handling automated port calls. The autonomous mooring module consists of a robotic arm that works with conventional mooring lines that maximizes the system's compatibility with legacy port infrastructure (e.g., bollards). The autonomous cargo handling module will consist of an innovative crane system designed to reduce cargo swing and rotation while exploiting the available real-time data from the autonomous mooring module regarding the vessel's relative position to the quay. The Voyage and Container Optimization Platform (VCOP) will provide the autonomous cargo handling system with the (un)loading sequence information in advance of the port call, while also interfacing with ModalNET (Building Block 3) to receive updated sequences and work orders. The Autonomous Vessels' Smart Port Manager (AVSPM) will enable automated port calls for autonomous vessels that will include negotiating port calls, monitoring safety and security and managing emergencies, and route planning optimisation.

2.2 Building Block 2: Modular Vessel and Operations Concepts

This building block addresses the design and operation phases for autonomous vessels and consists of the following modules: 1) rapid prototyping approach, 2) risk-based safety assessment, 3) a Guidance, Navigation and Control (GNC) scheme, and 4) the ROC concept. The SEAMLESS rapid prototyping approach will develop methods for quickly and easily evaluating green vessel concepts for commercial viability in specific operational contexts (incl. safety, environmental performance, and cost issues) in the early stages of design. In the context of risk-based safety assessment, SEAMLESS will develop an integrated risk assessment tool based on the principles of Operational

Envelopes [7] to construct standardised assurance cases for autonomous vessels that will enable risk-based approval with lower effort and cost. The GNC scheme will ensure safe interactions of autonomous marine and inland vessels with conventional, manned vessels by implementing COLREG-aware collision avoidance that will be supported by a monitoring module for detecting, diagnosing, and managing faults, as well as for identifying falsified sensor data (e.g. due to AIS spoofing) and will contribute towards fault-tolerant control. The SEAMLESS ROC concept will build on the technologies developed in the EC-funded, H2020 project AUTOSHIP towards the "low-attention ROC" concept, where a single operator supervises multiple vessel operations, while "high-attention" operations are maintained as a fail-safe strategy.

2.3 Building Block 3: Integrated Supply Chain Support (ModalNET)

The ModalNET logistics network "digital twin" will depend on the following modules: 1) a collaborative framework of logistics platforms, 2) digitalized administration procedures based on the requirements of relevant European regulations, and 3) voyage planning, navigational, and operational support. The functionalities of ModalNET, for example when a shipper or logistics will be planning and initiating any freight transport from a point of origin to a point of destination, include identifying the optimal combination of transports, calculating the most suitable schedule, the associated costs and predicting route performance, organizing the transport chain by generating all the booking and shipment orders and other documentation for the different modes of transport. In addition, ModalNET will monitor the fleet of small autonomous vessels involved in the seamless service throughout the transport lifecycle and evaluate how fleet the fulfils the transport needs (e.g., in case new vessel is required to meet increasing demand). The main digital assets that will be included in the ModalNET "digital twin" will be branch offices, shipments, transport units, transports, and stored items (linked with gate in and gate out operations). These will be complemented with other digital assets such as documents, services, procedures, transport means, location facilities, logistics charges and master data.

3 The SEAMLESS Methodology

For the SEAMLESS automated waterborne freight feeder loop service, the missing building blocks will be developed by following a four-phase approach: 1) Baseline/Positioning, 2) Innovation, 3) Verification, and 4) Impact Assessment. In the first phase, the system requirements for the SEAMLESS building blocks will be determined along with the baselines with which the performance of the SEAMLESS solutions will be compared and the redesigned logistics system. The Innovation phase will include determining the technical specifications and system design of the building blocks. In the Verification phase, the developed solutions will be verified and validated in full scale demonstrations in the context of the demonstration use cases and by means of simulation in the context of the transferability use cases. The Impact assessment phase will ensure the long-term sustainability and exploitation potential of the building blocks by: 1) assessing the individual and combined performance within the context of the

SEAMLESS use cases, 2) assessing the impact across the European supply chain, and 3) developing viable business models and business plans. The results will be used to document the positive effects of the new systems and to provide a roadmap for technical and policy initiatives.

The SEAMLESS Use Cases consist of the following (see Fig. 1): 1) two full-scale demonstrations that will combine the critical elements of the physical and digital assets developed in the project with existing assets in real-world conditions for SSS and IWT, and 2) five transferability use cases that cover a wide range of transport applications and geographical regions with different requirements throughout Europe.

The objective of the demonstration cases is to verify the Technological Readiness Level (TRL) achieved during the project and include a North European SSS case and a Central European IWT case. The SSS case involves a potential container feeder loop between the city of Bergen and Ågotnes in Norway demonstrated with a highly automated, fully electric RORO vessels that will be monitored by the SEAMLESS Remote Operations Centres (ROCs). The demonstration for the IWT case involves a highly automated, inland container barge and offering low to zero emission through an exchangeable battery-electric energy system.

The objective of the transferability cases is to assess the impact of the building blocks in various operational contexts and evaluate the replicability of the project results by implementing a structured methodological framework. For each use case, the performance of the SEAMLESS solutions will be benchmarked against a "reference case" that reflects existing transport solutions, including traffic flows, particulars of operating vessels, and market attributes. These cases include routes in the following regions: Western Mediterranean, Adriatic Sea, Eastern Mediterranean, the Black Sea, and the English Channel for SSS and Western and Central Europe for IWT.

4 The Expected Impact of SEAMLESS

The deployment of the SEAMLESS building blocks targets to promote maritime autonomous services on a Pan-European scale, by enabling streamlined and fast logistics via a fully automated waterborne freight feeder loop service that is integrated into the digital transport ecosystem and therefore promotes synchromodality. Operating this type of SEAMLESS service is expected to contribute to modal shift from land-based to waterborne transportation by 20% by increasing the competitiveness of the service against existing alternatives by the same percentage.

This will be achieved by effectively reducing the early movers' risks, in terms of safety, environmental performance, and required investment, of fully automated waterborne transport services. Towards this end, SEAMLESS will improve cost-effectiveness and safety of highly automated and autonomous port-side infrastructure in maritime and inland ports, simplify the deployment requirements for autonomous vessels, and develop sustainable business models for autonomous SSS and IWT. Indicatively, SEAMLESS targets a reduction of logistics services costs by 15% compared to similar existing services, while increasing the reliability of service by 40% and reducing the time for approval of autonomous vessels by 40% compared to the Yara Birkeland benchmark (i.e. 1 year for approval). In addition, SEAMLESS will reduce legal and regulatory uncertainty related to autonomous waterborne transport for both SSS and IWT by providing a roadmap to make deployment safer, cheaper, and with a positive social impact, as well as increasing public awareness concerning the implementation of autonomous transport technologies. Indicatively, SEAMLESS targets a shift of existing jobs to higher-skilled jobs by 30% to support autonomous SSS and IWT.

These achievements will not only enable the market uptake of the SEAMLESS solutions but will also improve the European competitive advantage within global markets with respect to connected and autonomous shipping, by fostering an increase in knowledge and availability of highly-skilled jobs across several member states and associated countries.

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References

1. Benamara, H., Hoffmann, J., Youssef, F.: Maritime transport: the sustainability imperative. In: Psaraftis, H. (ed.) Sustainable Shipping, pp. 1–31. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-04330-8_1
2. UNCTAD Meetings. http://unctad.org/en/Pages/Meetings/UNCTAD-Conferences.aspx
3. Sustainable Development Knowledge Platform Processes and UN System. https://sustainabledevelopment.un.org/rio20.html
4. EUR-Lex Document 52021PC0551. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0551
5. Li, X., Yuen, K.F.: Autonomous ships: a study of critical success factors. Marit. Econ. Logist. **24**, 228–254 (2022)
6. Ziajka-Poznańska, E., Montewka, J.: Costs and benefits of autonomous shipping—a literature review. Appl. Sci. **11**(10), 4553 (2021)
7. Rødseth, Ø.J., Lien Wennersberg, L.A., Nordahl, H.: Towards approval of autonomous ship systems by their operational envelope. J. Mar. Sci. Technol. **27**, 67–76 (2022)

Establishing Living Labs for City Logistics: Scoping and Initial Outcomes

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Abstract. Living Labs (LLs) are collaborative spaces where stakeholders are offered the opportunity to address relevant challenges. In the context of city logistics, LLs promote knowledge exchange, innovation, and learning among stakeholders, while also focusing on understanding how different UFT solutions are perceived by stakeholders, and how these perceptions influence solution adoption. In this direction, the aim of this study is twofold; first to provide a framework for establishing city logistics LLs, and second, to validate this framework via showcasing the challenges and barriers of LLs of different size, purpose and scope, to elicit requirements and foster the actual implementation of the envisaged solutions and their scale up. The research contributes to the advancement of sustainable urban logistics practices to enhance the efficiency, sustainability, and resilience of Urban Freight Transport (UFT) systems.

Keywords: Urban Freight Transport · Co-creation · Stakeholder Engagement · Knowledge Exchange

1 Introduction

Living Labs (LLs) are collaborative environments where various groups of stakeholders come together to co-create and co-design solutions addressing complex urban challenges [1]. In the context of city logistics, establishing LLs provides a platform for stakeholders to collaborate and test innovative solutions that improve the efficiency, sustainability, and resilience of Urban Freight Transport (UFT) systems. They facilitate the exchange of knowledge, ideas, and resources, enabling stakeholders to learn from each other successfully without being hampered by conflicting interests and agendas [2].

Recent literature on Living Labs (LLs) for last-mile delivery innovations indicates that LLs are a pluralistic approach centered around bringing together diverse sets of stakeholders in new formations to co-create products and services in complex settings [1]. While most LLs focus on fostering interactions between end-users and private actors for technology development through a triple helix perspective, the emerging concept of urban LLs specifically emphasizes urban and civic innovation through quadruple helix co-creation. This approach facilitates spatially embodied collaboration between private entities and civil society [2, 3]. As a result, urban LLs have become a means to approach

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smart mobility or smart city futures, where multiple actors need to align to solve complex challenges [3].

The innovation of the current framework discussed in this article lies in recognizing that, while urban LLs provide a promising arena for co-creation, there is room for expanding the methodology further. Key areas for improvement include how to engage and align stakeholders throughout the innovation process [4], how to create environments where stakeholders can co-create and learn from each other successfully without conflicting interests and agendas, and how to leverage outcomes from Living Labs on a larger scale [2, 5]. Additionally, there is a need for further research on methods for citizen engagement in urban LLs to better understand how these labs could and should interact with citizens [6, 7].

In this direction, the aim of this study is twofold; first to provide an innovative framework for establishing city logistics LLs, and second, to validate this framework via showcasing the challenges and barriers of LLs of different size, purpose and scope, to elicit requirements to foster the actual implementation of the envisaged solutions and their scale up. To achieve the first objective, key stakeholders involved in the city logistics sector were identified, along with their respective roles. Then a conceptual framework for the establishment of LLs is developed. The envisaged framework outlines a process for developing a shared vision and establishing governance and management structures to promote stakeholder engagement and effective collaboration. The framework is applied to five case studies –Athens/Greece, Barcelona/Spain, Flanders/Belgium, Ispra/Italy, Oxfordshire/UK– currently deployed in the frame of the European Horizon project GREEN-LOG [8]. As per the second objective, through iterative engagement with stakeholders in the period January-June 2023, challenges and barriers for all five LL were identified.

2 Developing a Co-creative Living Lab Framework - Charting the Scoping Phase

LL co-creation has to be tailored to the local social and cultural context and organised through inclusive and iterative processes that involve engaging diverse stakeholders, fostering open dialogue, facilitating knowledge exchange, and providing opportunities for collaborative decision-making and experimentation. While many LLs primarily emphasize on enhancing interaction between end-users and private entities to drive technology development within a triple helix framework, the GREEN-LOG LL model distinguishes itself by placing a particular emphasis on urban and civic innovation. This is achieved through a quadruple helix co-creation approach that encourages collaborative efforts within physical spaces between private entities and civil society [3].

The adopted framework approach of this study is inspired by the methodology of Smith & Iversen [9]. It begins with Scoping activities, serving as a preliminary Phase Zero phase in participatory design projects; it is then followed by subsequent phases involving Developing and Scaling dimensions. Focusing on the Scoping dimension, it involves predefined stakeholders in co-design activities and timelines to initiate the development of protagonist communities within the LL. A protagonist community refers to a group of individuals or stakeholders who actively take a leading role in initiating and driving positive change within their community. Moreover, user definition and participation configuration are also integral parts of the phase.

The Scoping phase is characterized by two distinct subphases; the introduction of the LLs, and the alignment of goals and visions. As per the former, LLs are often requested to provide two key contacts (in the frame of city logistics, these could be a city representative and a logistics service provider) to conduct initial interviews. These interviews aim to map existing activities, experiences from previous projects, expectations, collaboration visions and future activities.

3 Results of Scoping Phase

The first step of Scoping phase in the GREEN-LOG project required the identification and clustering of stakeholders whose perspectives are crucial for developing effective policies/solutions. Based on an extended literature review [10], four main clusters main clusters emerged. The corresponding stakeholder categories to these clusters can be seen in Table 1.

Table 1. GREEN-LOG stakeholder clustering.

Cluster	Stakeholder Category
Cluster A	Local government agencies, Environmental groups, Community groups/Citizens, Emergency responders
Cluster B	Researchers and academics, Financial institutions, Insurance companies
Cluster C	Businesses/Shippers, Logistics companies, Technology companies, EV manufacturers and charging infrastructure providers
Cluster D	End users/Customers

Moreover, customized "Meet-Ups" were arranged for all five LLs. These involved, inter alia, determining potential local stakeholders; developing goals' and barriers' alignment; planning potential user journeys and more.

3.1 Determining Local Stakeholders and Organizational Structure

The various LLs underwent a facilitated process to create an organizational structure that defines the roles of local stakeholders within the project. This structure delineates core team members (fully dedicated to the project), involved team members (regular contributors), and informed team members (stay updated and provide input as needed) (Fig. 1).

3.2 Goals and Barriers

The LLs within the GREEN-LOG project engaged in collaborative discussions to articulate their respective goals/visions and barriers. The discussions took place on a

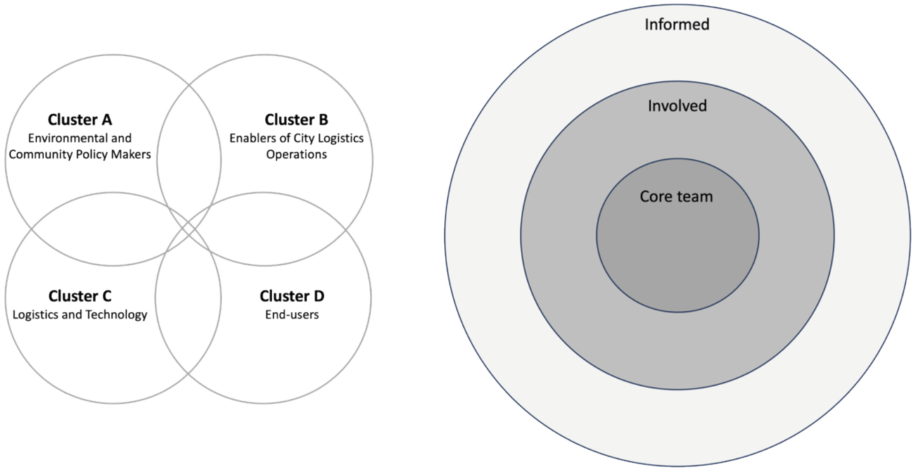

Fig. 1. LL structure to organise local stakeholders by clusters and levels of engagement.

Table 2. LL goals identified by core teams in GREEN-LOG's Living Labs.

LL	What does it want to achieve?
ATH	1. Improve citizens quality of life 2. Raise awareness on green innovative solutions 3. Promote Athens as a green tech implementation hub 4. Digitize last mile solutions
BAR	1. Public Transport participation in last mile delivery solutions 2. Greener and more efficient last mile logistics 3. More sustainable city logistics (less driven kilometres and vehicle movements, visible changes in the city)
FLA	1. Connecting supply and demand for both sender and receiver, with a technological solution that is data driven 2. Sender's and receiver's role being effectively included in the last-mile logistics Awareness of societal costs of last/first mile deliveries
ISP	1. Sustainable delivery process 2. Mixing different vehicle technologies to exploit their unique comparative advantages 3. Prototype this service and transfer it to a city-like case 4. Facilitate the promotion of innovation 5. Enable growth and economy at JRC site
OXF	1. Real world demonstration and data collection of the possibilities and benefits of using micro consolidation including simulation of CAVs 2. Understand the feasibility, potential, and societal response to micro consolidation 3. Long-term space to continue collaborative innovation and testing green logistics solutions among a wider group of stakeholders

shared digital platform using MIRO software, and the outcomes are summarized below (Table 2).

LLs identified also key barriers that challenge the realization of their objectives. These barriers span a range of logistical, regulatory, and operational challenges as follows (Table 3).

Table 3. LL barriers identified by core teams in GREEN-LOG's Living Labs.

LL	Main Barriers
ATH	1. Lack of infrastructure and regulation on micro mobility 2. In order to expand and replicate the solution, concern should be given to the implementation process of the micro consolidation centres
BAR	1. Lack of economic viability 2. Lack of alignment between stakeholders both internally and externally 3. Slow and difficult decision-making processes for public entities 4. Operators loosing clients/money during trial-phase 5. Lack of understanding of the LL trial-error approach 6. Conflicts of interests related to multiple stakeholders
FLA	1. Finding common ground for all 3 cities: overcome the differences in cities 2. Resistance to the involvement of end-receivers/shop-owners/traditional LSPs/political representatives 3. Time to bring in all stakeholders in all cities
OXF	1. Procurement issues and processes: delays, and value for money 2. Problems finding suitable site with good cycle access 3. Too slow development of technology 4. Difficulties in buy-in couriers and national parcel carriers outside of consortium 5. Social, legal and political barriers 6. Problems with involving the right partners
ISP	1. System continuity 2. Paths identification physical barriers (sidewalks, steps) 3. Final users' involvement 4. Delivery robot traveling without interfering with other road users 5. Administrative coordination between stakeholders 6. Technical integration of the solution 7. How to offer a continuative service and manage corner cases (guarantee the delivery if technical faults arise, location of logistics hubs, etc.)

3.3 Tentative User Journeys

Each of the LLs was also guided through the Scoping phase to cultivate a user-centric approach to developing delivery solutions. This involved identifying potential users and mapping their interactions with the solution through a process known as "User Journeys." A User Journey serves as a design tool that illustrates the complete sequence of interactions and experiences a user undergoes when engaging with a product or service, starting from their initial awareness and engagement, and concluding with the desired outcome or conversion. User Journeys are invaluable for gaining insight into user perspectives, pinpointing pain points and opportunities, and guiding the design and optimization of products or services [11].

In the GREEN-LOG project, this particular activity was primarily centered around 'proto personas.' Proto personas are preliminary and generalized representations of potential users, often based on assumptions or limited research. They serve as a foundation for guiding early-stage design decisions. As a result of this activity, tentative User Journeys were created. These User Journeys played a crucial role in planning upcoming user-involved co-creation activities and defining user requirements. Moreover, these provisional User Journeys also served as effective communication tools during co-creation activities. They helped solidify the local delivery solutions, paving the way for future engagements with LL stakeholders. Figure 2 shows the tentative User Journeys of Ispra LL which is focused on the development of a delivery platform that integrates a booking system with delivery robots.

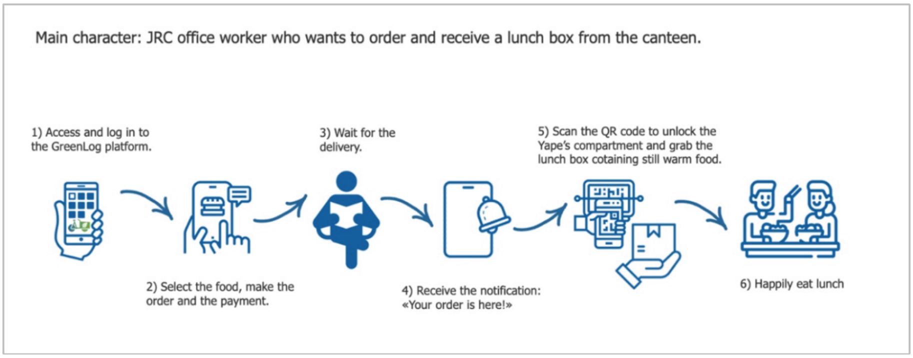

Fig. 2. LL Ispra's tentative User Journey presents how an office worker orders a lunch box from the canteen delivered by a delivery robot service.

4 Concluding Discussion

During the Scoping phase presented in this study, co-exploration was facilitated, relevant participants were identified and dialogues leading to common understandings among stakeholders and researchers were encouraged. Other key conclusions was the strong consensus on the importance of sustainable logistics solutions among stakeholders and the revealed varying perspectives and priorities of different stakeholders.

Moving forward, the next critical step is to transition the LLs into the Developing phase. In this phase, collaborative work will be undertaken with stakeholders to engage iteratively with the technological solutions, addressing various levels of abstraction. To initiate this phase, the creation of both generic and context-specific activities and frameworks, aligned with the active involvement of citizens and local stakeholders, will be pursued. Through these measures, the aim is to encourage experimentation and co-development of their own implementation practices, fostering innovation and sustainable solutions within the GREEN-LOG project.

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References

1. Bergvall-Kåreborn, B., Eriksson, C.I., Ståhlbröst, A., Svensson, J.: A milieu for innovation: defining living labs. In: ISPIM Innovation Symposium, 06 December 2009–09 December 2009 (2009)
2. Baccarne, B., Logghe, S., Schuurman, D., De Marez, L.: Governing quintuple helix innovation: urban living labs and socio-ecological entrepreneurship. Technol. Innov. Manag. Rev. **6**(3), 22–30 (2016). https://doi.org/10.22215/timreview/972
3. Puerari, E., De Koning, J.I., Von Wirth, T., Karré, P.M., Mulder, I.J., Loorbach, D.A.: Co-creation dynamics in urban living labs. Sustainability **10**(6), 1893 (2018)
4. Kalinauskaite, I., Brankaert, R., Lu, Y., Bekker, T., Brombacher, A., Vos, S.: Facing societal challenges in living labs: towards a conceptual framework to facilitate transdisciplinary collaborations. Sustainability **13**, 614 (2021). https://doi.org/10.3390/su13020614
5. van Waes, A., Nikolaeva, A., Raven, R.: Challenges and dilemmas in strategic urban experimentation an analysis of four cycling innovation living labs. Technol. Forecast. Soc. Change **172**, 121004 (2021). ISSN 0040-1625. https://doi.org/10.1016/j.techfore.2021.121004
6. Compagnucci, L., Spigarelli, F., Coelho, J., Duarte, C.: Living labs and user engagement for innovation and sustainability. J. Clean. Prod. **289**, 125721 (2021). ISSN 0959-6526. https://doi.org/10.1016/j.jclepro.2020.125721
7. Menny, M., Palgan, Y.V., McCormick, K.: Urban living labs and the role of users in co-creation. GAIA Ecol. Perspect. Sci. Soc. **27**(Suppl. 1), 68–77(10) (2018). https://doi.org/10.14512/gaia.27.S1.14
8. GREEN-LOG EU project. https://greenlog-project.eu/. Accessed 08 Oct 2023
9. Smith, R.C., Iversen, O.S.: Participatory design for sustainable social change. Des. Stud. (2018). https://doi.org/10.1016/j.destud.2018.05.005
10. GREEN-LOG project: Knowledge Base of Last-mile Solutions and GREEN-LOG requirements specification. Deliverable 1.1 (2023)
11. Eriksson, M., Niitamo, V.P., Kulkki, S.: State-of-the-art in utilizing Living Labs approach to user-centric ICT innovation-a European approach. Lulea: Center for Distance-spanning Technology. Lulea University of Technology Sweden, Lulea (2005)

Adapting MTVRPTW for Small Business: A Simplified Approach to Optimizing Food Delivery Logistics

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Abstract. This paper presents a case study of a food delivery startup, and uses Operations Research (OR) techniques to address the complex logistics challenges faced by the company. The objective is to develop an automated and optimal solution for a startup located in Montpellier, France that faces many problems with delivery operations, taking into account factors such as resource allocation and environmental impact. The study focuses on the vehicle routing problem (VRP) with Multiple Trips and Time Window (MTVRPTW), and employs a heuristic algorithm to generate a complete delivery plan based on customer orders and the company's existing infrastructure. The goal is to provide the startup with a sustainable and efficient logistics solution that can help them to reduce costs and improve their overall operations.

Keywords: food delivery startup · logistics optimization · vehicle routing problem

1 Introduction

The rise of e-commerce and on-demand delivery services has led to a significant increase in the volume of goods being transported around cities and towns [1]. This has put pressure on businesses to optimize their logistics operations in order to reduce costs and improve efficiency [2]. One key aspect of logistics management is the vehicle routing problem (VRP), which concerns the optimal selection of routes for a fleet of vehicles to service a set of customers [3]. The VRP is particularly challenging for startups, which often have limited resources and a need to quickly scale their operations in response to changing market conditions [4].

Solving the VRP requires taking into account a wide range of factors, such as the number and location of customers, the capacity and constraints of the vehicles, and the time windows for deliveries [5]. Additionally, there is the increasing concern for sustainability, to minimize the environmental impact of transportation, especially in urban areas [6]. For example, the CO_2 emissions generated by delivery vehicles can contribute to air pollution and climate change [7]. As such, it is important for startups to consider

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the environmental impact of their logistics operations when developing solutions for the VRP [8].

The Multi-Trip Vehicle Routing Problem with Time Windows (MTVRPTW) is one of the variations of the classic VRPTW that arises in many real-world applications where a set of customers need to be visited by a fleet of vehicles and those vehicles can return to the depot to start a new route. In the MTVRPTW, each vehicle can make multiple trips to serve the customers within a certain time window, and the objective is to minimize the total cost while satisfying all the constraints.

Despite the challenges, the MTVRPTW has been successfully applied to various real-world applications, including waste collection, logistics, and transportation. For example, the MTVRPTW has been used to optimize the routing and scheduling of waste collection vehicles in urban areas [9], the scheduling of nurse visits to elderly patients [10], and the optimization of delivery routes for online grocery retailers [2]. In these applications, the MTVRPTW has been shown to provide significant benefits in terms of cost savings, improved efficiency, and reduced environmental impact.

2 Methodology

2.1 Problem Statement

The studied company is located in France and is specialized in delivering baskets of vegetables and fruits on a weekly basis. Deliveries are mostly made to intermediate delivery points, called “relay points”, which presents a significant logistical challenge for the startup. These locations are mostly located in city centers where congestion and emissions are already high.

Additionally, due to French rules on city congestion, there are many areas that can only be delivered by bike, as they are designated as low-emission zones (LEZ). These zones, created by the Loi d’Orientation des Mobilités (LOM) in 2019, limit or prohibit the circulation of the most polluting vehicles in order to improve air quality. This restriction to bike deliveries, which have limited capacity and require multiple roundtrips, highlights the need for a vehicle routing problem (VRP) approach that can optimize the delivery routes and resources.

2.2 Data Collection/Current Situation

The study involved mapping all company data processing procedures, starting from the moment a customer purchases a basket, including data extraction, transformation, and loading processes. In the case study, relay points were categorized into groups based on their time windows and assigned to specific work teams or shifts, each associated with a particular vehicle type, accounting for MTVRPTW constraints.

Upon comprehending the driver’s route, shift compositions, and corresponding groups of relay points, we explored commercial software to optimize delivery sequencing using the VRPTW concept. However, this software couldn’t support the complex multiple trip concept, and it’s essential to note that few user-friendly commercial solutions are available for MTVRPTW.

We utilized the predefined shifts (relay point groups with respective addresses) as inputs for the commercial software, which generated an optimal visiting sequence. To compare results, we conducted similar tests using our VRP algorithm, considering minimal distance parameters. We then compared the total distances traveled using our software's chosen route and the commercial software's recommended route. Our algorithm was evaluated under the same load and time constraints, aiming to minimize travel time across 30 previously utilized routes.

2.3 Analysis

To improve the company operations, we developed an algorithm to automate the process of gathering and organizing order data, integrating it with relay point details, including addresses. This algorithm served as a data pipeline, feeding information into our route optimization system. It takes inputs like total orders with addresses, available vehicles, and their capacities. Additionally, we utilize a file containing all deliveries for the week to create a distance matrix.

The distance matrix is a vital tool, listing distances, travel times, or costs between different locations. It plays a crucial role in logistics, helping us determine the shortest or fastest routes between various points. Leveraging the Google Distance Matrix API, we precomputed this matrix, enabling our route optimization algorithm to calculate precise road distances between all origin and destination addresses. This matrix serves as essential input for our optimizer, facilitating efficient route planning. This process was repeated for over 10 relay points, ensuring comprehensive coverage of our delivery network.

2.4 Software Optimizer and Heuristics

For our small business logistics solution, we opted for Google's route optimizer in OR-Tools, utilizing Python. This tool takes the distance matrix between all relay points, their time windows, vehicle details, and capacities, as outlined in Table 1, as its input. It efficiently computes the fastest routes between relay points, optimizing point grouping to yield the most efficient results. Table 1 shows the initial results.

Our chosen software optimizer uses our reference of time windows and score to ensure that each vehicle's route complies with the customers' time window for visits. However, when the time window is narrow, meaning that there is only a short window of time available for the vehicle to visit the customer, it becomes challenging for the algorithm to find a viable solution.

This scenario presents edge cases where the algorithm cannot balance two conflicting objectives: minimizing the total distance traveled by the vehicles and ensuring that each customer is visited within their time window. To solve this, we propose to increase the number of vehicles to find a viable solution.

The VRPTW solver in OR-Tools uses a combination of heuristics and exact algorithms to find solutions. The algorithm is based on the ideas of Clarke and Wright, and uses a combination of savings and sweep algorithms to construct initial solutions. The Sweeping Algorithm constructs initial solutions by starting at the depot and adding stops in a circular sweep around the depot. The algorithm assigns each customer to the nearest route based on the distance from the depot. Let the set of relay points be denoted as RP, and let the coordinates of the deposit be denoted as (0,0). The Sweeping Algorithm assigns each customer to the nearest route based on the distance from the depot. This can be expressed as follows:

The algorithm starts setting the angle of the sweep be denoted as:

$$\theta = 0^\circ \tag{1}$$

Then it sorts the relay points by angle from the depot: RP = {rp1, rp2, …, rpn}, sorted by:

$$arctan(yi, xi) \tag{2}$$

We let the set of routes be denoted as R = {R1}, where R1 is the route containing the depot.

We add the first relay point to the route R1 = {0, rp1}.

For each remaining relay point i from 2 to n, the solver follows the steps:

a. Let Rj be the route with the closest last stop to ci
b. If adding rpi to Rj would not violate any constraints, add ci to Rj
c. Otherwise, create a new route Rk for ci: Rk = {0, ci}

Then the algorithm returns the set of routes: R = {R1, R2, ..., Rk} respecting those rules.

Finally, the distance between the depot and each customer can be calculated using the Euclidean distance formula:

$$distance = \sqrt{(x2 - x1) + (y2 - y1)^2)} \tag{3}$$

Once initial solutions are constructed, the algorithm uses a combination of local search and metaheuristics to further improve the solutions.

2.5 Scoring Algorithm

In order to create multi trips and allow the vehicle to return to the deposit respecting the time windows of the relay points and also the data of vehicles working times, a system of routes scoring is needed to be attached to the VRPTW Solver as a filter, so the complete solution can work.

The main objective of the Scoring Algorithm is to prioritize the relay points considering their time window restrictions and to divide them into the multipaths vehicles, we created a scoring system, which is the first soft restriction.

This scoring system effectively optimizes delivery routes, considering factors like vehicle capacity and time windows. In our example, with two vehicles each having a capacity of 10 baskets, we ensure that the total number of baskets doesn't exceed the combined capacity of both vehicles.

The optimizer handles relay points 1 to 4 initially, as relay 5 can't fit into the first shift due to capacity constraints. It later returns for relay 5. After supplying this relay data to the optimizer, we obtain the optimized routes and the return time to the depot for each vehicle.

3 Results

Based on the conducted experiments, the results indicated that the proposed reference model was able to achieve up to 95% improvement in terms of computational time (see Fig. 1) and 6% of average improvement in terms of the total distance traveled by the vehicles, compared to the baseline model of the commercial software.

Making a comparison of route traveled distances between the two softwares, the graph below shows the results of each software for each route. The diagonal line represents the situation in which the result of the two softwares is identical in terms of distance. Points above this line are the routes where our software has obtained a better result than the commercial software, and points below the line represent the other case. In 60% of the analyzed points, our algorithm results found better solutions for the tested routes (see Fig. 2).

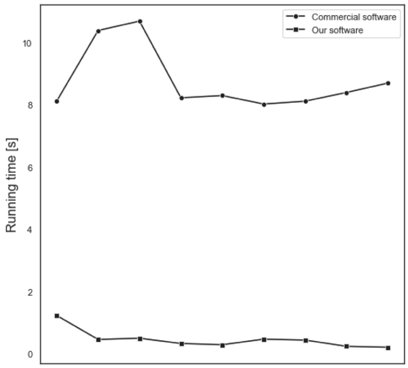

Fig. 1. Software Running Time

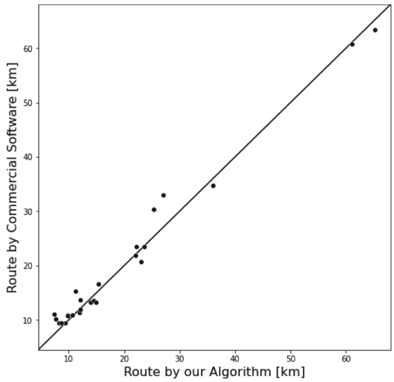

Fig. 2. Route total distance

4 Discussions and Conclusion

The study discusses the successful application of Operations Research techniques in tackling complex logistical issues faced by food delivery startups. It highlights the use of a heuristic algorithm to devise efficient delivery plans based on customer orders and the company's infrastructure, considering factors like resource allocation, environmental sustainability, and vehicle type limitations. Although the algorithm was effective, it faced limitations with existing Vehicle Routing Problem (VRP) tools, leading to the reliance on a scoring system for route sorting. Future enhancements could involve incorporating clustering algorithms and real-time data to further refine the solution.

References

1. Shen, Q., Cheng, T.C.E., Wang, D.: An overview of the literature on urban goods delivery. Transp. Res. Part E Logist. Transp. Rev. **89**, 1–15 (2016)

2. Kao, C., Hsu, C., Wang, Y.: A comprehensive review of vehicle routing problem: classical and recent developments. Eur. J. Oper. Res. **267**(1), 1–17 (2018)
3. Toth, P., Vigo, D.: The vehicle routing problem. Soc. Ind. Appl. Math. (2002)
4. Gendreau, M., Laporte, G.: A guide to vehicle routing problems. Eur. J. Oper. Res. **129**(1), 1–26 (2000)
5. Solomon, M.M.: Algorithms for the vehicle routing and scheduling problem with time window constraints. Oper. Res. **35**(2), 254–265 (1987)
6. Wagner, H.M., Bons, A., Koster, A., van der Vorst, J.G.A.J.: Sustainable Logistics and Supply Chain Management: Principles and Practices for Sustainable Operations and Management. Wiley, Hoboken (2015)
7. Banister, D.: Sustainable transport: prospects for the future. J. Transp. Econ. Policy **42**(1), 1–26 (2008)
8. Fujii, H., Nakano, R., Tamaki, Y.: A review of vehicle routing problems with environmental considerations. J. Oper. Res. Soc. **63**(7), 1175–1186 (2012)
9. Lin, C.-T., Chen, T.-S., Chen, Y.-L.: Multi-trip vehicle routing problem with time windows for waste collection. Waste Manag. **67**, 230–239 (2017). https://doi.org/10.1016/j.wasman.2017.05.025
10. Jin, S., Guo, S., Wei, Y., Wu, J., Liu, Y.: Solving the multi-trip vehicle routing problem with time windows for home health care service. Expert Syst. Appl. **168**, 114229 (2021). https://doi.org/10.1016/j.eswa.2020.114229
11. Clarke, G., Wright, J.W.: Scheduling of vehicles from a central depot to a number of delivery points. Oper. Res. **12**(4), 568–581 (1964)

Data-Driven Decision-Making in Fashion Logistics: A Systemic Approach in the Greek Clothing Industry

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Abstract. In the wake of the pandemic, the fashion sector faces unparalleled challenges, marked by sustainability issues, supply chain disruptions, the diversification of customer communication channels, and an urgent demand for technological adaptation and rapid deliveries. As this landscape evolves, the essence of data-driven decision-making becomes paramount, particularly for retailers. It is an essential shift in response to evolving consumer demands and broader societal pushes for zero emissions in transportation. Central to this discussion is Logistics 4.0, which underscores the need for transitioning from conventional methods to intelligent, evidence-backed decision-making processes. Using a Greek clothing company as a case study, this paper delves into the myriad of external factors, ranging from political to environmental influences, and internal business processes that shape logistic choices. Through in-depth interviews with executives and a comprehensive survey, the research team gauged the current state of logistics management in the Greek clothing industry, with a special focus on the noticeable absence of Business Intelligence techniques in some firms. Conclusively, a novel BI Decision-Making tool will be introduced, birthed from the BI&OX project, designed to support and streamline inventory, production, and transportation planning. This tool is pivotal for decision-makers, enabling them to test various scenarios and craft strategies that cater to company-specific needs, with applications from demand forecasting to intricate supplier evaluations.

Keywords: data-driven · supply chain · fashion retail

1 Introduction

The Greek fashion sector navigates a complex web of external elements that profoundly shape its logistics and supply chain strategies. These elements cover political, legal, economic, social, technological, and environmental domains. For businesses in the Greek fashion domain, understanding these elements is crucial to maintaining competitiveness and enhancing operations. This study seeks to examine the primary external influences

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impacting logistics within this industry, utilizing a questionnaire-based survey method. The findings aim to provide valuable insights, assisting companies in enhancing their logistics and supply chain responsiveness to constantly changing external conditions. The methodology for this topic is organized as follows: It begins with an extensive literature review, highlighting the challenges faced by the Retail Fashion Sector. This is followed by a comprehensive review of insights from a study under the BI&OX project banner, emphasizing the challenges the Greek Fashion Sector faced during the pandemic. The research then delves into the external environment with the survey to identify challenges and opportunities for Greek fashion enterprises. The study concludes by emphasizing crucial aspects of the Supply Chain, highlighting the importance of flexible management techniques suitable for the dynamics of the fashion retail environment. With a thorough understanding of their external environment, Greek fashion firms can identify emerging opportunities and challenges, leading to informed decisions and effective supply chain strategies.

2 Literature Review

The fashion retail industry, in its dynamic nature, faces complex challenges that influence its supply chain and logistics. Fundamental concerns revolve around identifying trustworthy suppliers, ensuring punctual deliveries, navigating reduced lead times, and addressing broader issues such as labour disputes and subpar supplier communications (Fashinza 2023). Overlaying these are external challenges. Events like pandemics, economic shifts (McKinsey & Company 2021), climatic disruptions, and geopolitical tensions (Seara et al. 2022) compound the inherent variability and transience that define the sector (Wang et al. 2012). This fluid landscape, accentuated by the volatility stemming from fickle consumer behaviours, underscores the necessity of continuous evaluations of brand strategies and operational intricacies (Bindi et al. 2021; Newman & Foxall 2003; Ponis 2007). It's imperative to address nuances like the "Bullwhip effect", where slight demand variations amplify supply chain uncertainties (Lee et al. 1997; Christopher 2004). In response to the industry's complexities, innovative approaches have been championed, notably the adoption of technology like data analytics platforms that enhance supply chain collaboration and provide better visibility. This technological emphasis became particularly salient during the recent pandemic, which disrupted European fashion but simultaneously spotlighted the need for digital and sustainable transitions (McKinsey & Company 2022). This endeavour, aimed at heightening responsiveness to customer trends and swiftly shifting demands, seeks to boost the efficiency of the entire supply chain, from suppliers to end customers (Vona 2003). Building on this, the study evaluates the impact of these determinants on the logistics and strategies of Greek fashion companies.

3 Methodology and Key Findings

HIT/CERTH developed an in-depth methodology to assess the Greek fashion retail industry, which underwent substantial shifts from 1995 to 2022 due to both external and internal influences. As demonstrated in Fig. 1 this analytical approach involved:

1. Distilling insights from a Sectoral Study.
2. Administering a dedicated online questionnaire and workshops with business' representatives to understand real-world challenges and supply chain methodologies.
3. Employing a PEST analysis specific to the Greek Fashion Retail Sector, also using online surveys.

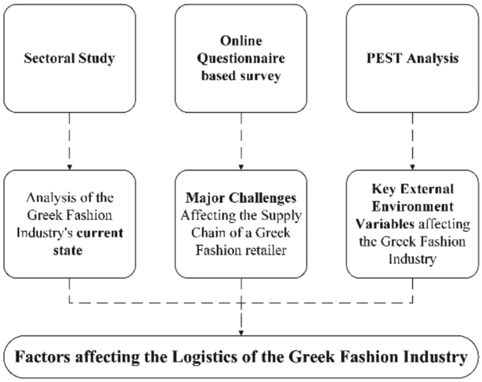

Fig. 1. Methodology

These surveys were collaboratively crafted by HIT/CERTH, Emetris S.A., and with instrumental input from SEPEE (The Association of Knitting and Ready-to-Wear Clothing Companies of Greece), grounded in an exhaustive literature exploration. They were disseminated digitally via the Google Forms platform targeting businesses within the Greek retail fashion retail landscape, operating both locally and internationally. Over a span of two months, feedback was gathered from representatives of 18 of the 25 firms identified by SEPEE as most pertinent to this investigation.

3.1 Key Sectoral Study Findings

The Association of Knitting and Ready-to-Wear Clothing Companies of Greece (SEPEE) conducted an analysis assessing the fashion retail industry's shifts in Greece over an extended period. This study revealed the industry's fluctuating state, especially during the COVID-19 pandemic. In 2020, following tourism and other sectors, the fashion-textile industry faced significant losses, including a 30% drop in turnover. Men's fashion retail suffered the most, while underwear and sports categories declined the least. Despite previous growth in exports, 2020 saw a decrease to €1.55 billion from €1.91 billion in 2019. While 83% of fashion exports targeted EU countries, the overall imports for the fashion-textile sector dropped by 19.7% in 2020. However, 2021 marked a recovery, with increased exports by 33.8% and a boost in domestic retail sales by 43.4%, signalling a rebound towards pre-pandemic levels. In the future, factors such as political support, ongoing pandemic effects, the energy crisis, and emerging industry trends like fast fashion and just-in-time inventory management will be pivotal for the Greek fashion-textile industry (SEPEE 2022).

3.2 PEST Analysis Results

The Greek fashion retail sector is shaped by political, economic, social, and technological (PEST) influences. This section presents findings from a sectoral study and survey, emphasizing external factors affecting Greek fashion retailers. The “external environment” encompasses broader forces impacting a sector, not just individual companies (Papadakis 2016). This broad analysis, called PEST Analysis, provides insight into overarching systems like political, economic, social, and technological landscapes that a business operates within but doesn’t control (Economy-pedia.com 2022). After identifying the critical elements of each PEST category through literature, businesses rated their significance on a scale ranging from ‘Very Unimportant’ to ‘Very Important’. For clarity in assessment, these ratings were converted to scores: 1 for ‘Very Unimportant’ up to 5 for ‘Very Important’. These scores revealed the dominant factors within each PEST element. Table 1 shows the top-rated factors. Political considerations highlight government stability, taxation, and incentives. Economically, household purchasing power is paramount, with a secondary focus on energy costs and inflation. Social trends emphasize digital distribution channels influenced by social media and demographics. Technologically, e-commerce growth and IT advancements are pivotal, enabling data-driven decision-making.

Table 1. PEST Analysis highest scored factors per External Environment

PEST element	Factor	Score	%
Political External environment	Governmental Stability	4.1	82%
	Taxation	3.8	76%
	Special taxation incentives	3.4	69%
Economic External environment	Household purchasing power	4.6	91%
	Energy costs	4.3	87%
	Inflation rate/GDP	4.1	82%
Social External Environment	Shift to multiple distribution channels	3.8	77%
	Strong influence from social media Marketing (influencers’ impact)	3.7	73%
	Demographics	3.5	70%
Technological External Environment	The emergence of the Internet and e-Commerce	4.1	81%
	Evolution Information Technology	3.9	78%
	Investments in infrastructure and R&D activities	3.8	76%

3.3 Major Challenges and Factors Affecting the Supply Chain

This chapter details the results of a survey of Industry experts and business representatives on challenges Greek fashion retailers face in supply chain operations, especially in inventory management and supplier relationships. Survey findings underscored the predominant challenge in inventory management: the intricate task of demand forecasting. A vast majority of businesses grapple with either an overabundance or a severe lack of inventory, both of which have profound implications. Furthermore, escalating operational costs related to storage compound these challenges, adding financial strains. While these challenges are paramount, the survey also explored the strategies that these retailers employ to navigate these issues. Most retailers rely on routine inventory checks and centralized warehouses for efficient distribution. Key data metrics like inventory turnover and item-specific costs are closely monitored. As these businesses gear up for a new season, past sales figures prominently influence their collection decisions. Interestingly, while trends are paramount for a significant proportion of businesses, other metrics like leftover inventory and production costs also weigh in. Unfulfilled orders hold considerable importance for half of the participants, with other indicators like return rates and past forecasting accuracy considered less crucial. When shifting the focus to Supply Chain Management, supplier selection emerges as a vital component for these retailers. Quality and cost of service dominate their decision-making process. Yet, it's also evident that factors like reliability and delivery speed are indispensable in this selection. While responsiveness and flexibility rank high, other aspects like the supplier's geographical location and environmental impact seem to take a backseat in priority. Overall, these findings provide an intricate understanding of the multifaceted challenges and strategies within the Greek fashion retail sector, laying the groundwork for targeted strategic interventions.

4 Conclusions

To sum up between 1995 and 2022 various internal and external factors have had an impact, on the fashion sector in Greece causing changes in its growth and operations. Despite facing challenges and undergoing adjustments this industry remains crucial to the Greek economy particularly in terms of exports. It also continues to embrace advancements. The future success of this sector relies on adopting technology implementing practices focusing on exports and effectively managing resources. Within this context the BI&OX Project by HIT/CERTH provides a decision support tool for professionals in the industry. It incorporates findings from this study to facilitate data driven decision making. The services offered by this project along, with their high-level architecture are depicted in Fig. 2.

The tool includes four main functions/services that each one can give input to the next one but can also operate independently. Each step takes into consideration the challenges the Greek Fashion Retailers face to give the optimal result. Finally, it assists the retailers with providing visibility in regard to the cost of their optimal order, based on the demand forecasting results, the optimal inventory results, how these are translated to textile needs and the supplier rankings.

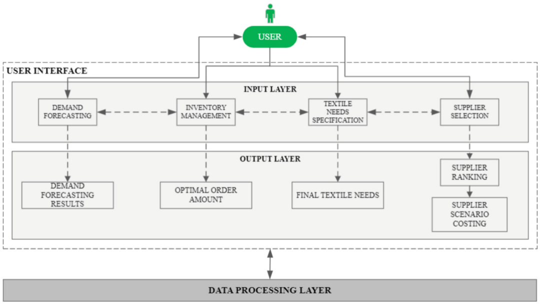

Fig. 2. Data-driven decision-making tool functions

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References

Bindi, B., Bandinelli, R., Fani, V., Pero, M.E.: Supply chain strategy in the luxury fashion industry: impacts on performance indicators (2021)

Christopher, M.: Building the resilient supply chain. Int. J. Logist. Manag. (2004)

Economy-pedia.com: Economy-pedia.com (2022). https://el.economy-pedia.com/11039584-pest-analysis

Fashinza: Supply chain challenges in the apparel industry and how you can fix them (2023). https://fashinza.com/supply-chain/challenges/supply-chain-challenges-in-apparel-industry-and-how-you-can-fix-them/

Lee, L.H., Padmanabhan, V., Whang, S.: The bullwhip effect in supply chains. Sloan Manag. Rev. (1997)

McKinsey & Company: The State of Fashion 2022 [PDF] (2021). https://www.mckinsey.com/~/media/mckinsey/industries/retail/our%20insights/state%20of%20fashion/2022/the-state-of-fashion-2022.pdf

McKinsey & Company: The State of Fashion 2023: Holding onto growth as global clouds gather, 29 November 2022. https://www.mckinsey.com/industries/retail/our-insights/state-of-fashion

Newman, A.J., Foxall, G.R.: In-store customer behaviour in the fashion sector: some emerging methodological and theoretical directions (2003)

Sampson, L.: Fashion Supply Chain: Everything You Need to Know (2023). www.oracle.com, https://www.oracle.com/retail/fashion/fashion-supply-chain/

Seara, J., et al.: The Future of Fashion Sourcing. BCG Global (2022). https://www.bcg.com/publications/2022/the-future-of-fashion-sourcing

Vona, R.: Marketing e produzione nel pronto-moda: il “modello” Zara. In: Proceedings of the International Conference Marketing trends in Europe (2003)

Wang, X., Chan, H.K., Yee, R.W., Diaz-Rainey, I.: A two-stage fuzzy-AHP model for risk assessment of implementing green initiatives in the fashion supply chain (2012)

Papadakis, V.: Business Strategy: Greek and International Experience, 7th edn. (2016)
Ponis, S.: The bullwhip effect. PLANT Manag. (2007)
SEPEE (Association of Knitting and Ready-to-Wear Clothing Companies of Greece): Sector Study on Clothing and Textile Manufacturing in Greece, Thessaloniki (2022)

Decarbonising Last Mile Logistics

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Abstract. Logistics is at the core of modern society and essential to transport food and goods in the heart of cities, where most Europeans live. However, recent statistics show that only half of truckloads moved at maximised capacity in 2021 [1], and the rapid increase in the last mile deliveries - 78% by 2030 [2] - affects the economics of logistics and its externalities on the urban tissue, including high traffic, noise and air pollution. It is worth noting that last mile logistics represent 30% of the total CO2 emissions of logistics transportation. Amongst the EU Green Deal objectives, several aim to tackle this: 55% reduction of emissions from cars and 50% from vans by 2030 [3]. On a local level, there is also an increasing push for zero-emission zones in inner cities, as 26 of the world's largest cities signed up to the Green and Healthy streets pledge [4]. To foster and accelerate this transition towards economically, environmentally, and socially sustainable city logistics, systemic changes in last mile delivery ecosystems are needed. The analysis of previous collaborative urban logistics experiences shows that future urban logistics consolidation frameworks must be built on six fundamental pillars to guarantee the success and sustainability of their generalisation: collaboration, sustainable business models and added-value services, urban integration and space management optimisation, regulation, digital infrastructure, and innovation transferability enablers.

Keywords: Last-mile logistics · decarbonisation · collaboration · digitalisation · intelligent transport systems · Physical Internet · Logistics-as-a-Service · Digital Twins · Blockchain · Micro-consolidation

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1 Introduction

The rapid growth of e-commerce poses sustainability challenges, with a 25 million-tonne CO2 increase and 21% rise in traffic congestion in the last mile. This contradicts European Green Deal, Paris Agreement, and Green City Accord goals for zero-emission urban logistics by 2030. Urban logistics faces challenges like a lack of focus, coordination, and data. European Union (EU)-funded projects aim to address these by testing solutions, emphasizing the need for strategic urban logistics focus, better coordination among stakeholders, and improved data and information for operational efficiency and long-term planning, aligning with overarching sustainability objectives.

2 State of Play- Key Areas

2.1 Collaboration

The existing literature reviews highlight various forms of collaboration, each presenting distinct potentials and barriers. Vertical collaboration involves coordination across modes and service operators throughout the value chain, while horizontal collaboration focuses on multiple providers working within the same transport chain section, sharing orders and infrastructure [5]. The motivation behind such collaborations includes demonstrated effectiveness in reducing last-mile logistics costs and environmental impact, and improvements in service quality by minimizing lead times [6]. Despite these benefits, financial sustainability remains uncertain, contingent on the type of goods being delivered. Trust issues, along with competitive dynamics in the logistics sector, pose challenges, particularly in terms of data sharing. Access to data is vital to enhance knowledge, develop digital tools, and tailor hypotheses and optimization scenarios to showcase the economic advantages of collaboration. Public authorities play a crucial role in fostering a conducive environment for collaboration and solution implementation, with powerful legal frameworks to promote sustainable practices and innovative models within their local strategies. This synergy ensures a transformative ecosystem, making projects like those discussed in this paper highly promising.

2.2 Sustainable Business Models and Added-Value Services

Regarding collaboration and asset sharing, the evolving challenges in city logistics also demand innovative business models. Overcoming traditional asset management boundaries, these models create added value services. A notable example is the joint establishment and management of Urban Consolidation Centers (UCCs), where logistics players (potential competitors) implement horizontal collaboration to enhance performance and resource utilization. Recognizing each entity's contribution and role within the urban freight ecosystem and assessing each entity's contribution to value creation, paralleled by an estimation of the distribution of related benefits and costs is of utmost importance. Exploring sharing, specialization, and allocation strategies can lead to sustainable Collaborative Business Models (CBMs) in city logistics, fostering economic viability and cooperation among providers. Integrating value-added delivery models (such as urban logistics hubs, micro-consolidation centers, etc.), together with autonomous vehicles, innovative cargo-bikes, and zero-emission transport modes optimizes urban logistics for sustainability and efficient resource allocation.

2.3 Regulation

On another note, the acceptability of low emissions zones (LEZs) may face economic and social challenges, but their demonstrated positive environmental impact, including a notable reduction in NO2 concentrations [7], provides a compelling rationale. LEZs can serve as an incentive for carriers to invest in sustainable vehicles, such as cargo bikes, prompting a fleet upgrade to continue operations in restricted-access areas [8]. Concurrently, restricting conventional delivery trucks through policies like time limits, congestion charges, noise pollution restrictions, and pedestrian zones can bolster support for alternative transport modes like cargo bikes. In addition to adapting local regulations, endorsing cycle logistics as a viable and competitive alternative in last-mile transport is crucial. Complementary support from public frameworks includes strategies such as facilitating real estate access in dense areas, incorporating urban logistics into broader planning schemes, utilizing cycle logistics in public procurement, offering financial incentives, and creating platforms for knowledge exchange among cycle logistics stakeholders. Numerous ongoing projects exemplify best practices and success factors in regulations and public policy frameworks, aiming to provide accessible, replicable, and operational guidelines for a sustainable transition across economic, environmental, and social dimensions.

2.4 Urban Integration and Space Management Optimization

Modular approaches in urban logistics involve dissecting the intricate logistics ecosystem into smaller, interoperable modules adaptable to urban needs. These modules, including electric vehicles, micro-containers, micro-fulfilment centers, and smart traffic management systems, offer flexibility for customized integration in city planning. The three primary solution categories are 1) delivery fleet modal shifts, 2) consolidation and emerging urban storage infrastructure, and 3) innovative delivery frameworks, encompassing the entire last-mile process. European Union-funded projects like URBANE (39 partners with 12 Living Labs and 6 pilots - 6 feasibility studies), DECARBOMILE (31 partners, with 4 Living Labs and 4 Satellite Cities, implementing 11 use cases), and GREEN-LOG (30 partners with 5 LLs, 10 cities implementing various use cases - at least one per city) bring together diverse partners to tackle urban logistics challenges. Through living labs and pilot studies, these initiatives aim to address congestion, emissions, and delivery costs in real-life scenarios, contributing to the evolution of sustainable urban logistics (Table 1).

2.5 Digital Infrastructure

Digital transformation has revolutionized logistics and last-mile delivery, playing a pivotal role in the transition path towards safe, efficient, and sustainable last mile transport. In

Table 1. Intervention mapping (At the time the paper is written, these are the planned interventions. As we are in preparation phase of the pilots, changes may occur.)

INTERVENTIONS	URBANE	DECABOMILE	GREEN-LOG
Alternative delivery fleet mode			
Electric Delivery Vehicles	Valladolid, Helsinki, Bologna, Karlruhe	Hamburg, Istanbul, Logrono, Nantes	Athens, Gent, Leuven, Mechelen, Oxfordshire
Drones, droids			Ispra
Autonomous vehicles, connected Autonomous vehicles, cargo-bikes and robots	Helsinki, Karlsruhe	Sarajevo	Ispra, Athens, Gent, Leuven, Mechelen, Oxfordshire
Public Transport modes for delivery fleet re-balancing (e.g. trams, trains)	Karlsruhe		Barcelona
Consolidation & emerging urban storage infrastructure			
Innovative standard micro-container for aggregation and multimodal use		Nantes, Logrono, Hamburg	
Urban consolidation centers (UCC), micro consolidation centers, mobile depot, micro logistics hub	Helsinki, Bologna, Thessaloniki, Barcelona	Nantes, Hamburg, Logrono, Istanbul, Getafe, Ghent, Tallinn	Athens, Barcelona, Oxfordshire
Connected parcel lockers for both pickup and delivery	Helsinki, Bologna, Thessaloniki	Hamburg, Logrono, Istanbul, Nantes, Getafe	Athens, Barcelona
Innovative Delivery Framework			
Delivery parking zones	Valladolid	Nantes	Athens, Barcelona, Oxfordshire
Real time assets monitoring and tracking		Istanbul, Logrono, Hamburg, Nantes	Ispra, Barcelona
Vehicle routing and crowd shipping deliveries	Bologna, Thessaloniki, Helsinki	Istanbul, Logrono, Hamburg	Oxfordshire, Ispra

(*continued*)

Table 1. (*continued*)

Innovative Delivery Framework			
New urban access regulation to LEZ & respecting loading/ unloading zones	Valladolid	Tallinn, Sarajevo	
Dynamic re-routing	Bologna, Valladolid	Hamburg, Logrono, Istanbul	Oxfordshire, Ispra
Fleet and route optimisation	Valladolid, Karlsruhe, Thessaloniki, Barcelona	Logrono Nantes, Istanbul	Oxfordshire, Ispra

this crucial phase of the supply chain, digital tools, technologies, and concepts that realize Physical Internet vision [9] through interconnected dataspaces, optimization tools, Logistics-as-a-Service (LaaS) platforms [10], the inclusion of green autonomous vehicles, Digital Twins (DT) and blockchain are the key elements to reduce traffic congestion, emissions, and energy consumption achieving efficiency and sustainability. Indicative tools for optimizing logistics include: i) LaaS marketplaces with dynamic pricing for flexible logistics services; ii) Artificial Intelligence-enabled augmented intelligence platforms for demand modeling and location planning; iii) Dynamic routing with real-time tracking and monitoring, supported by machine learning and demand prediction, to optimize deliveries and reduce congestion; iv) DT leveraging real-time data through interactive user interfaces, incorporating modern digital mapping and geographic information systems. These tools collectively enhance efficiency, reduce empty loads, and address congestion challenges in the logistics ecosystem. All these digital tools accompanied by their underlying supporting technologies and scientific knowledge can augment the planning of modern supply chains at all levels: strategic, tactical, and operational levels.

3 Innovation Transferability Enablers

EU Member States (MS) are actively working towards promoting the seamless adoption of innovative last-mile solutions across multiple European cities through the use of "Innovation Transferability Enablers" (ITE). These tools aim to facilitate the implementation of successful interventions in optimizing last-mile networks. The previous sections outlined a diverse range of interventions, spanning both physical and digital infrastructure, regulatory measures, and policy implementations. These interventions span a broad spectrum, ranging from the application of crowd shipping services [11] to fleet smart management systems [12], as well as other types of Intelligent Transport Systems enabled by enhanced connectivity [3]. Even scientific tools like mathematical programming scheduling models [13] for optimal transshipment or unloading of vessels [14] and trucks [15] constitute interventions that can offer decision support towards effective transportation and logistics networks planning. The key emphasis is on ensuring that these interventions go beyond ad-hoc solutions, requiring creators to prioritize scalability, adaptability, and robustness to meet the varied requirements of EU cities and MS. Open-access digital platforms, known as transferability enablers, allow for the exploitation and replication of successful last-mile logistics innovations in European cities. These platforms support upscaling, re-deployment, and the identification of sustainable solutions, allowing follower cities to implement cost-effective, green logistics networks with defined Key Performance Indicators (KPIs) and efficient sustainable solutions.

4 Conclusions

Digital tools are crucial for enhancing collaboration between Public and Private sectors in European last-mile logistics. The ITEs support stakeholders, local authorities, and logistics providers in exploring collaborative schemes to benefit the city and boost private sector competitiveness. Public authorities can encourage collaboration, promote shared logistics infrastructure, and impose legislative frameworks or KPIs for improved urban community outcomes. Thus, the integration of digital tools is crucial for realizing emission-free innovative and collaborative logistics initiatives.

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References

1. Inefficiency is breaking supply chains. Flock Freight (2022)
2. https://www3.weforum.org/docs/WEF_Future_of_the_last_mile_ecosystem.pdf
3. European Commission: A European Green Deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en. Accessed 06 Sept 2023
4. C40 Cities Climate Leadership Group (2018)
5. Cleophas, C., et al.: Collaborative urban transportation: recent advances in theory and practice. Eur. J. Oper. Res. **273**(3), 801–816 (2019)
6. De Souza, R., et al.: Marginalizing last mile logistics cost through 4th party milk run (2019)
7. Beckers, J., Cardenas, I., Le Pira, M., Zhang, J.: Exploring logistics-as-a-Service to integrate the consumer into urban freight. Res. Transp. Econ. **101**, 101354 (2023)
8. 2019_09_Briefing_LEZ-ZEZ_final.pdf. transportenvironment.org
9. librairie.ademe.fr/cadic/8143/panorama-cyclologistique-france-2023-rapport.pdf
10. Crick, J.M., Crick, D.: Developing and validating a multi-dimensional measure of coopetition. J. Bus. Ind. Mark. **34**(4), 665–689 (2019). https://doi.org/10.1108/JBIM-07-2018-0217
11. de Man, A.-P., Luvison, D.: Collaborative business models: aligning and operationalizing alliances. Bus. Horiz. **62**(4), 473–482 (2019). ISSN 0007-6813. https://doi.org/10.1016/j.bushor.2019.02.004
12. LNCS. http://www.springer.com/lncs. Accessed 21 Nov 2016

13. European Commission: “Fit for 55”: delivering the EU’s 2030 Climate Target on the way to climate neutrality (2021). https://ec.europa.eu/info/sites/default/files/chapeau_communication.pdf. Accessed 17 June 2022
14. Cebeci, M.S., Tapia, R.J., Kroesen, M., de Bok, M., Tavasszy, L.: The effect of trust on the choice for crowdshipping services. Transp. Res. Part A Policy Pract. **170**, 103622 (2023). https://doi.org/10.1016/j.tra.2023.103622
15. Moghaddass, R., Mohammed, O.A., Skordilis, E., Asfour, S.: Smart control of fleets of electric vehicles in smart and connected communities. IEEE Trans Smart Grid, 1 (2019). https://doi.org/10.1109/TSG.2019.2913587

Integrating Parcel Delivery Services into Public Transport Operations Through a Common ICT Platform

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Abstract. Transport organizations and local authorities are facing growing challenges due to increasing traffic within city centers caused by delivery traffic. New sustainable mobility concepts for urban logistics are therefore needed that are able to make use of the existing infrastructure in a more efficient way by decreasing the overall traffic volume. The project logIKTram focuses on shifting delivery traffic from road to rail on medium and short distances by integrating cargo tram operations into a common ICT platform, specifically on extending the public transport planning and control systems (ITCS) and the design of interfaces between public transport and logistics systems. The ICT platform follows a data broker architecture (MQTT) enabling data provision to all relevant systems including the logistics, the public transport and the tracking as well as the booking system. Existing systems in place, such as the on-board computer (OBU) of the tram, the ITCS of the public transport operator, the load carrier system of the logistics provider, as well as the booking and tracking system of the freight operator will be modified and connected via interfaces with the ICT platform allowing seamless integration of all systems.

Keywords: cargo tram · urban logistics · public transport · ICT platform

1 Introduction

Cities are facing growing challenges due to the increase in traffic within city centers. A major contributor is the growing high volume of delivery traffic in inner cities that has led to congestion and parking issues, increased emissions, notably CO2, NOx and fine particular matter, as well as noise pollution and safety issues [1]. This increase in delivery traffic in cities reflects a large increase in online shopping behavior and was recently amplified during the COVID-19 pandemic, exposing weaknesses of a transport system running at maximum capacity and lacking political regulations and guidelines [2]. As of today, many current solutions that aim at switching to electric drives within the same modal split only help reducing local emissions. However, they do not improve the overall traffic load on the road nor parking issues [3].

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Therefore, there is a need for new sustainable mobility concepts for urban logistics that make more efficient use of existing infrastructure by decreasing the overall traffic volume. Furthermore, new cross-company cooperative bundling concepts and intermodal solutions, based on existing transport corridors and infrastructure for freight transport, which defuse land conflict and, through selective additions, create a new sustainable transport system for a urban and regional selection of companies and households.

The research project logIKTram [4] focuses on shifting delivery traffic from road to rail on medium and short distances by connecting distribution centers in the urban hinterland with logistic hubs in the inner city. The cargo tram concept in this research uses the existing two-system tram and rail infrastructure of Karlsruhe, Germany, to provide electro mobility solutions for commercial inner city logistics. The cargo tram concept developed in this research thereby represents a novel vehicle concept that was not previously adapted in other applications. While freight trams have been successfully applied before, such as the cargo tram in Dresden that was exclusively used for factory logistics and the cargo tram in Zurich used for bulky waste logistics, they were operated on separate dedicated vehicles [5]. The cargo tram concept in the logIKTram project, on the other hand, is intended for combined transport of both passengers and goods in an urban and regional context, across the B2B and B2C sectors. The consolidation of goods in cross-docking (goods handling) have so far only taken road transport into account, characterized by different shipment sizes and vehicle containers. This requires a combination of an ICT-supported consolidation platform that encompasses transport planning, automatic transport handling and an integration into the public transport operations system for offering economic viable services.

The focus of this article lies on the required technical infrastructure and on the conceptualization of an integrated information and communications technology (ICT) platform for the combined transportation of goods and passengers.

2 Cargo Trams and regioKArgo

2.1 A Brief History of Cargo Trams

The concept of cargo trams is an old concept that dates back until the 1860s. One of the earliest application of cargo trams could be found in Arad, Romania where operations where based on horse carriages [6]. Following this example, cargo trams in the early years were widely used for postal, delivery, and heavy-duty construction operations, with prominent examples found for example in Frankfurt, Germany (postal tram) or in Vienna, Austria (heavy duty transport). With the introduction of individual motorized transport, cargo trams operations declined rapidly. However, some operations existed well into the 90s, such as in Timișoara, Romania (until 1993) or in Gotha, Germany (until 1988). In the early 2000s, cargo trams saw a revival in Dresden, Germany, where a dedicated cargo tram was used for industrial supply of goods to the Volkswagen car manufacture plant in the city, or in Zurich, Switzerland, where a cargo tram has been used for waste disposal since 2003 [7]. More recent projects can be found in Saint-Étienne, France, Frankfurt, Germany and Berlin, Germany where cargo trams are used as a testbed for delivery services in the frame of research projects. However, most of these applications focus on inner city logistics and do not take the urban hinterland into account.

2.2 The regioKArgo Concept

The regioKArgo [8] concept aims at providing a holistic approach towards sustainable delivery services, by making use of the existing regional tram-train network in the Karlsruhe, Germany region. A special case of tram-train service in Karlsruhe is the "Karlsruher Model" [9], a tram-train concept making it possible for seamlessly operating a tram on the city tram and on the heavy rail network in the region combining 750V DC and 15kV AC operation into one dual mode vehicle. Due to these combined operations, the tram-train network of Karlsruhe is one of the largest tram-train networks consisting of over 500 km total track length. This makes it possible to connect the urban hinterland directly with the city center and making it favorable for cargo tram operations, as major delivery centers are generally located outside of the city. Figure 1 displays the concept behind regioKArgo and the research project logIKTram, where the tram-train will be used to connect large delivery centers located at the outskirt of the city with local distribution hubs in the city center, running the delivery service on both the heavy rail network and the tram network. Once the goods reach the delivery hubs in the citer centers, last-mile sustainable solutions such as cargo bikes will be used for final distribution to the customers.

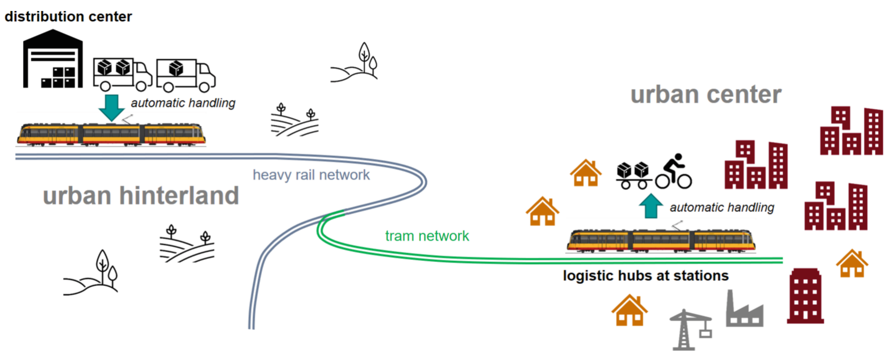

Fig. 1. The regioKArgo and logIKTram concept for integrating parcel deliveries into tram-train operations connecting delivery centers with local city hubs in the inner city

3 Development of an Integrated ICT Platform

One of the main objectives of logIKTram is the development of an integrated ICT platform combining systems from logistics and public transport. This common ICT platform will also be able to interact with the cargo tram by direct communication with relevant tram systems, such as the onboard computer (OBU), the braking assistant (relevant for precise loading and unloading) as well as with the handling carriage for tracking the delivery services. Figure 2 depicts the scope of the ICT platform and its interaction with the physical cargo tram concept. The platform covers the whole process of the cargo tram-based transportation services, including the booking and transport planning, the handling and journey planning, the monitoring of the operations (public transport and delivery service), as well as the accounting and eco-balancing of the service. The interaction of the ICT-platform with the cargo tram systems includes the bundling process, the loading and coupling process, the operation of the tram and finally the uncoupling and unloading process.

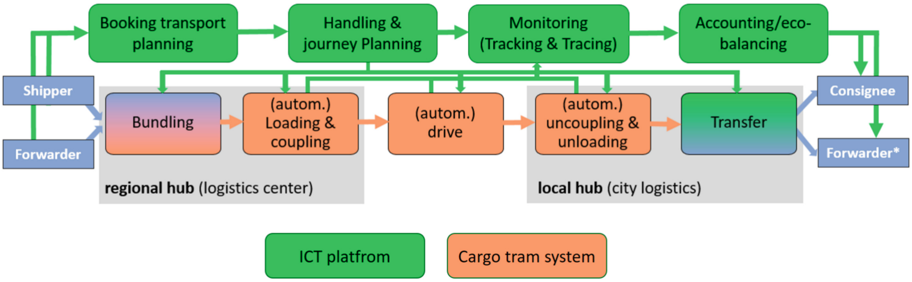

Fig. 2. Components of the integrated ICT-platform interacting with the cargo tram system.

In order to facilitate the integration of a widespread range of systems, one of the main objectives is the use of existing standards whenever possible. At the core of the ICT-platform stands a Message Queue Telemetry Transport (MQTT) broker, which functions as a central data exchange component. All components of the platform can publish data on the broker and – at the same time – subscribe to data via defined topics. VerneMQ [10], which is distributed as open source software (Apache 2.0 license), is used as MQTT broker in logIKTram, hence, it supports the ICT-platforms whole lifecycle from research to commercial service. The broker structure enables all actors to access data by using standard exchange formats:

- Communication standards defined by VDV (Association of German Transport Companies) and the General Transit Feed Specification (GTFS) on the public transport side
- Electronic Data Interchange for Administration, Commerce and Transport (EDIFACT), Global Standards (GS1) to connect logistics systems with the public transport systems.

The logistics requirements, which require planning security of 24–48 h, were implemented with the help of schedule data in the VDV and GTFS standards. This enables planning security of several days as well as short-term and current changes to upcoming planning measures that may require re-planning of the logistics service. Additionally, they integrate delays as well as GPS data in the logistics process in order to provide real time information for freight forwarders, public transport as well as last mile operators. The integrated ICT-platform includes elements from logistics (logistics back- and frontend), public transport operations (ITCS, onboard components, planning), tracking (back- and frontend, apps), simulation, and the cargo tram system (see Fig. 3).

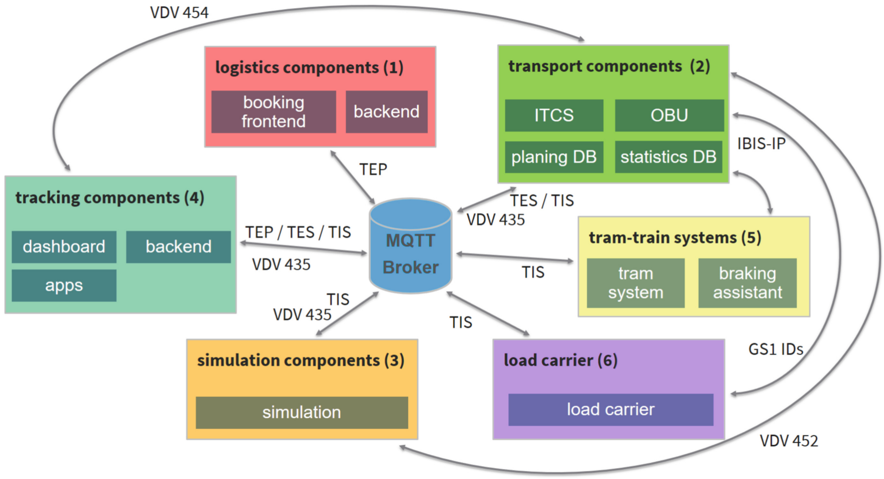

Fig. 3. The ICT platform architecture of the logIKTram cargo tram

The logistics components (1) consist of a booking frontend and backend, which allow the forwarder to access the logistic planning system and to process transport requests, while also allowing the cargo tram to access the transport offer. Alternatively, the forwarder is able to book delivery slots through the use of a frontend interface. The public transport components (2) consists of the intermodal transport control system (ITCS), the panning and statistics databases of the public transport operator, and the OBU system in the cargo tram. The public transport components provide public transport planning, dispatching and scheduling as well as real-time positioning and status updates to all components of the ITC-platform. Data provisioning is handled via the MQTT broker, with the exception of the planning data and the real-time status updates, which are directly transferred via APIs in the VDV and GTFS formats. Information from the logistics components about the deliveries and routing (Transport Execution Status (TES) and Transport Information Status (TIS)) is consumed by the public transport components via the MQTT broker. The Simulation components (3) act as a digital twin as well as an agent-based scenario simulation, allowing for running scenarios and simulating the cargo tram, together with the whole logIKTram ICT-platform system. The tracking components (4) consisting of front- and backend, are processing the Transport Execution Plan (TEP) form the logistics component as well as the real-time data from the public transport and the simulation components. The data is exchanged via the MQTT broker and via standardized VDV APIs for real-time status updates of the cargo tram. Besides the position of the tram, information about delays, vehicle, and scheduling is provided and distilled in a graphical user interface (GUI) for the customer to track the status and expected arrival time of the delivery. The interaction with the physical systems, including the tram systems (5) and the load carrier (6), is managed via the public transport components (OBU) using IBIS-IP protocols. The information exchanged include details about the stopping position, loading and unloading station, as well as shipping information that is transmitted from the logistics components via the MQTT broker and OBU of the cargo tram.

4 Conclusion and Discussion

Enabling delivery services into combined passenger and goods tram-train operations is a challenging task from both an operational and an information technology perspective. The work presented here focuses on the integration of multiple systems from multiple domains that are required to offer a holistic ICT platform for cargo tram operations. A major challenge next to the lack of standards between the different systems is the fundamental difference in planning and operation of logistic and public transport services. Information on the capacity and status of the cargo tram running on scheduled series is needed to serve the highly dynamic nature of delivery services. The broker architecture provided sufficient scalability and adaptability in order to interface the different components. After the successful testing of the ICT-platform in a virtual environment through by means of simulation (digital twin), a real world demonstration is planned in the frame of the regioKArargo initiative.

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References

1. Yannis, G., Golias, J., Antoniou, C.: Effects of urban delivery restrictions on traffic movements. Transp. Plan. Technol. **29**(4), 295–311 (2006)
2. Viu-Roig, M., Alvarez-Palau, E.J.: The impact of E-commerce-related last-mile logistics on cities: a systematic literature review. Sustainability **12**(16) (2020)
3. Beheshtian, A., et al.: Bringing the efficiency of electricity market mechanisms to multimodal mobility across congested transportation systems. Transp. Res. Part A Policy Pract. **131**, 58–69 (2020)
4. logIKTram project. https://logiktram.de/en/logiktram-the-freight-tram/. Accessed 10 Oct 2023
5. Freemark, Y.: Opportunities abound for transporting goods by tram-if properly coordinated. Transp. Politic (2011)
6. Günther, A., Tarkhov, S., Blank, C.: Straßenbahnatlas Rumänien 2004. Arbeitsgemeinschaft Blickpunkt Straßenbahn e. V. Berlin (2004)
7. City of Zurich, Cargo Tram. https://www.stadt-zuerich.ch/ted/de/index/departement/medien/medienmitteilungen/2013/august/130813a.html. Accessed 10 Oct 2023
8. regioKArgo. https://ae-network.de/regiokargo/. Accessed 09 Oct 2023
9. Brandl, G., Axhausen, W.K.: Karlsruhe 1975–1995: a case study of light rail transit development. Transp. Res. Rec. **1623**(1), 155–164 (1998)
10. VerneMQ. https://vernemq.com/. Accessed 02 Oct 2023

Customer and Retailer Expectations from City Logistics: Comparative Analysis of the Market in Thessaloniki, GR

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Abstract. City logistics operations are significantly affected by the rapid expansion of electronic commerce (e-commerce). The pressure of the demand is being transferred to the last-mile distribution, disproportionately increasing the workload of service providers, while affecting the overall cost and fulfillment times for the entire supply chain. In this study, the expectations and demands of consumers and online retailers concerning city logistics provision are captured. A questionnaire survey carried out, addressing independently the two target groups focusing on the market routines in Thessaloniki, Greece. The purpose is to record and analyze the market needs to identify niche areas that are under-served, and their service will maximize sustainability and the overall benefit for the local users and the society. In general, it was recorded that delivery speed, reliability and flexibility are essential for both user categories. Service providers should focus on under-served market segments to gain competitive advantages and benefit the overall city logistics system. Specific suggestions for researchers and practitioners are also provided.

Keywords: City logistics · e-commerce · customers

1 Introduction

City logistics operations are significantly affected by the rapid expansion of electronic commerce (e-commerce), which has experienced unprecedented growth in recent years. Online sales in 2019 reached levels that were, approximately, 3 times higher than the corresponding of 2014 [1]. Due to the COVID-19 pandemic, the percentage of online sales to the total sales increased even more between 2020–2022. Customer demand and the promise of operational cost reductions prompted retailers to increasingly use online channels for their sales; a strategic move that could grant them significant competitive advantages and contribute to their expansion [2]. Predictions for last-mile delivery in the forthcoming years surpass the figures of the pandemic, with a forecasted annual growth rate of 9.29% in USD billion projected until 2027 [3].

The pressure of the unforeseen growth, however, is being transferred to the last-mile distribution, disproportionately increasing the workload of service providers, while

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affecting the overall cost and fulfillment times for the entire supply chain [4]. This negatively impacts the overall shopping experience of the consumers and damages the credibility of retailers to execute their orders on time.

This study analyses the dynamics of the online retail market at the city of Thessaloniki, Greece, aiming to comprehend the expectations and demands of consumers and retailers concerning city logistic services. It comparatively analyzes user expectations and requirements to propose measures that maximize the overall system sustainability. A questionnaire survey is carried out addressing independently the two target groups. The two questionnaires were developed based on extant city logistics typologies, covering parameters like storage, transport, delivery, product and time. Results analysis identified points of conflict and areas of convergence between the two user types. As a general conclusion, it was recorded that delivery speed, reliability and flexibility are essential for both categories of users of a city logistics network.

In Sect. 2 city logistics characteristics are defined, in Sect. 3 the study methodology is presented, in Sect. 4 the city logistics and e-commerce landscape in Greece. Section 5 analyzes the survey results and Sect. 6 summarizes the main outcomes, proposing insights for practitioners and researchers.

2 Theoretical Background

City logistics consists of functions necessary to serve the demand for the distribution of goods in urban environments; starting from the moment an order enters the last mile until reaching the customer [5], crucially influencing the daily life of cities and citizens [6]. It entails activities spanning from order delivery to store replenishment, construction, and the reverse chain (waste, recycling, returns). These activities aim to serve specific market segments (e.g., prepared food, groceries, clothing, pharmaceuticals, homewares, pet supplies, electronics, books, office supplies) that require different transport types (e.g., courier, general cargo, temperature-controlled, waste).

Given the growing urban population, expected to reach 68% of the total world population by 2050, from 55% currently [7], cities will face serious consequences from logistics operations soon. City logistics contribute to greenhouse gas (GHG) emissions with 23% of the total transport and logistics GHG [8]. Due to its composition of various components (e.g., equipment, products, infrastructure, stakeholders, etc.), the business model used to transport goods within urban areas is shaping the quality of city logistics services. Establishing and maintaining effective city logistics operations is a formidable challenge, with the swift growth of e-commerce further amplifying it.

A city logistics system is described based on [5]: (1) the type of storage (e.g., urban distribution center, micro-consolidation), (2) the means of transport (e.g., bicycles, trucks, drones, etc.), and (3) the type of delivery (e.g., home delivery, self-service with or without supervision). [9] present 11 models that are classified according to: (1) type of goods (e.g., refrigerated, postal, waste), (2) type of change (i.e., means and supply chain configurations), and (3) means of transport (e.g., trucks, bicycles, buses, boats, trams). [10] recognizes three types of end-user service: (1) pickup from distribution point or store, (2) grouping for collection from designated point (e.g., post office, etc.) and (3) house delivery. [1] suggest that cargo size and delivery urgency dictate the utilized transport methods. Combining the above categorizations, last mile systems could differentiate according to the following properties: (1) *type of city logistics activity*; (2) *type of storage* (3) *means of transport*; (4) *type of delivery*; (5) *delivery time*; (6) *type of products*; (7) *package size*.

3 Methodology

A questionnaire survey has been employed for data collection addressing two types of city logistics services users: the end consumers and the online retailers. Questionnaire research is often used in research that studies business and operational functions, especially when the focus is the analysis of habits [11]. In conjunction with the questionnaire survey, an analysis of existing literature and good practices was carried out. This helped understanding the research context (i.e., the Greek market) and shape the structural framework of the questions. The questionnaires employed structured closed and open questions to include motionless answers as well as flexibility and richness [12]. The questionnaires aimed to (1) record what city logistics characteristics are considered important, (2) record the intentions of users. The study was carried out between 01.06.2022–31.07.2022 in the city of Thessaloniki, Greece, using Google Forms to develop and distribute the questionnaires. The Consumer Questionnaire collected 110 responses (50.9% male, 46.4% female, 86.4% of them in the 18–44 age group). The Business Questionnaire preceded a market analysis identifying 300 online retailers, mostly related to food services and thus excluded. The survey was sent to 100 companies (response rate 35%), predominantly small (77%) with physical/online presence (94%), mainly active in clothing (34.29%), household (20%), and office supplies (20%).

4 City Logistics and E-Commerce: The Situation in Greece

The total e-commerce value in Greece for 2021 was estimated at €14b (2019 and 2020, €9b and €11.5b, respectively) [13]. A consistent upward trajectory is evident, bolstered notably by the COVID-19 pandemic. The trend shows stabilization tendencies, with e-commerce purchases accounting for over 10% of the overall expenditure. The pandemic's lasting effect is clear in e-commerce growth, even after the "reopening" of the economy. Since 2020, Greek consumers turned to e-commerce increasing the sector's turnover by 77% (base 2019) and overall purchases to 59% (51% in 2019) [14]. The pattern persisted in 2021, with 95% of major Greek urban centers residents making at least one online purchase per year [15]. 52% of the total annual transactions refer to food, clothing, pharmacy or electronics, with electronics and food having the highest penetration. During 2021, all product categories recorded a 6–12% sales increase [17].

Amidst the swift e-commerce expansion in Greece, the courier industry found itself compelled to adjust and cater to the evolving demand. The pandemic exposed the sector's pain-points, which proved unprepared. Due to insufficient resources, low service levels were the main challenge, leading to extreme delivery times (from 3–5 days before to almost a month). This gave rise to customer discontent and placed considerable stress on retailers. City logistics providers operated amidst intense competition, rapidly evolving technology, intricate operations, and an urgent necessity for greater sustainability. The Greek e-commerce and last-mile delivery landscape poses a formidable challenge to the involved actors. Hence, persistent efforts are required to enhance efficiency, focusing on aspects like shorter times and ecological impact, increased reliability, flexibility, tracking, and resource utilization. 95% of consumers surveyed state that transport costs and delivery times are factors that hinder their purchases [17].

5 Analysis and Discussion

Key to the study was to understand the online purchasing routines of the consumers and retailers in the city. Purchasing frequency and product type are indicators of the demand for city logistics services (deliveries) that could dictate the requirements for an efficient city logistics system. Most consumers (58.2%) order online at least once per week or every two weeks, with the rest ordering a few times or once per year. 74.5% of them usually buy clothing, while 60.9% appliances and 30% pharmaceuticals or books. Significantly, the highest share (82.7%) refers to purchases of prepared food, however, this type of product is not in scope in this study. To fulfill their orders, 9/10 consumers choose to have them delivered to a place of their choice (e.g., home or work, etc.); the rest pick up the products from designated points. The consumer preference distribution reveals significant opportunities in under-served market segments that lack specialized express delivery services (e.g., apparel, pharmaceuticals, pet supplies, books, etc.).

Corresponding to the analysis of consumer expectations, the relative importance of delivery factors that influence overall shopping experience was analyzed. Results analysis show that consumers expect accurate (66.4%), flexible (64.5%) and speedy (57.3%) deliveries. Accuracy refers to both deliver-to-promise, as well as the reduction of failed delivery attempts; flexibility reflects the choice of pick-u/drop-off points at the chosen place and timeframe; and shipping speed is the required time from order placement to drop-off (with 75.3% preferring same day shipping). Return policy scored lower (40%), while on-demand options and the overall delivery cost are not considered as important. The cost of transportation is another important aspect, as it could determine the city logistics provider choice. When asked what influences most their overall purchasing experience delivery-wise, the consumers responded to the delivery costs and timeframe. As mentioned earlier, most companies that participated in the survey facilitate both physical and online sales; most of them (88%) sell exclusively one product type (e.g., clothing). On average, companies ship 4–10 orders daily; single-order deliveries (40%) or combined up to three (28.6%) and more than three (14%). 74% of them deliver at least 25% of the total online sales 'to the door' of customers, while 31.4% deliver at least half. The rest of the orders are usually picked up at a local pick-up point. The orders are primarily shipped directly from the store (69%) (distribution center 3%, local warehouse 17%, supplier's warehouse 11%).

As stated by the retailers, the shipping timeframe that they offer to their customers varies between same day delivery (31%), 1–2 (31%), and 3–5 days (26%). Delivery in one day is an important milestone, as the options for delivery in a time greater than or less than one day gather percentages of 49% and 51%, respectively. However, this is a finding that is not supported by the consumer side. The study identified that 1 in 2 consumers state that they usually receive their products within 3–5 days and 86.7% need at least 2 days to receive them. Only 5.5% receive within 24 h, 1.8% on the same day and

6.4% within 2 h. Consumers' demand for speed is not met by the existing options in the market, as only 8.2% state that they usually receive within the day at the latest. Therefore, the delivery timeframe can be identified as an element with potential to become a strong differentiator among city logistics providers and their competition.

6 Conclusions

In this study, the expectations and demands of consumers and online retailers concerning city logistics provision were captured. A questionnaire survey was carried out, addressing independently the two target groups focusing on the market routines in Thessaloniki, Greece. The purpose was to record and analyze the market needs to identify niche areas that are under-served, and their service will maximize sustainability and the overall benefit for the local users and the society.

The comparative examination of the findings revealed areas of disagreement as well as points of agreement between the user categories. It was recorded that delivery speed, reliability and flexibility are essential for both categories. Domestic competition is a particularly important decision criterion and competition differentiator, able to determine the services that are provided in a market (e.g., under-served segments like pharmaceuticals, delivery less than same day). For each aspect, the following are suggested to city logistics practitioners and researchers: Speed (1) Delivery within day or even hours; (2) Integration to business ERPs for real-time inventory management; (3) Cargo bundling and delivery routing using technology (AI/ML). Reliability (1) Real-time tracking to eliminate unsuccessful deliveries; (2) Constant customer communication (e.g., messages, calls); (3) Electronic proof of receipt/delivery/payment. Flexibility (1) Delivery timeframe selected by end users; (2) Drop-off point selected by end users using geofences; (3) Bundle shipments from various sources (consumers, inventory replenishment, etc.); (4) Fully functional reverse supply chain to cover returns.

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References

1. World Economic Forum: The Future of the Last-Mile Ecosystem. Transition Roadmaps for Public- and Private-Sector Players. https://www.weforum.org/reports/the-future-of-the-last-mile-ecosystem/. Accessed 19 Sept 2023
2. Marcucci, E., Gatta, V., Lozzi, G.: City logistics landscape in the era of on-demand economy: main challenges, trends and factors influencing city logistics. LEAD project (2020). https://civitas.eu/sites/default/files/lead_d1.1_city-logistics-landscape-in-the-era-of-on-demand-economy-1_0.pdf
3. Mazareanu, E.: Global last mile delivery market size 2020–2027. https://www.statista.com/statistics/1286612/last-mile-delivery-market-size-worldwide/. Accessed 19 Sept 2023

4. Buldeo Rai, H., Dablanc, L.: Hunting for treasure: a systematic literature review on urban logistics and e-commerce data. Transp. Rev. **43**(2), 204–233 (2023)
5. Boysen, N., Fedtke, S., Schwerdfeger, S.: Last-mile delivery concepts: a survey from an operational research perspective. OR Spectr. (2020). https://doi.org/10.1007/s00291-020-00607-8
6. Dolati Neghabadi, P., Evrard Samuel, K., Espinouse, M.-L.: Systematic literature review on City logistics: overview, classification and analysis. Int. J. Prod. Res. **57**(3), 865–887 (2018). https://doi.org/10.1080/00207543.2018.1489153
7. United Nations, 68% of the world population projected to live in urban areas by 2050. UN Department of Economic and Social Affairs. United Nations (2018). https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html
8. Olsson, J., Hellström, D., Pålsson, H.: Framework of last mile logistics research: a systematic review of the literature. Sustainability **11**(24), 7131 (2019)
9. Malindretos, G., Abeliotis, K.: Sustainable City Logistics practices for goods and waste. Mark. Bus. Sustain., 51–71 (2015)
10. Gevaers, R., Van de Voorde, E., Vanelslander, T.: Characteristics and typology of last-mile logistics from an innovation perspective in an urban context. City Distrib. Urban Freight Transp. (2011). https://doi.org/10.4337/9780857932754.00009
11. Julien, H., Given, L.M. (ed.): The Sage Encyclopedia of Qualitative Research Methods. Sage Publications, Thousand Oaks (2008)
12. Mills, A.J., Durepos, G., Wiebe, E. (eds.): Encyclopedia of Case Study Research. Sage Publications, Thousand Oaks (2009)
13. ELTRUN, Press Release | Semi-Annual B-C E-Commerce Survey. https://eltrun.org/5η-εξαμηνιαία-έρευνα-καταγραφής-online-κατα/. Accessed 13 Sept 2023
14. Manifava, D.: E-commerce: Greece is the champion in Europe, KATHIMERINI. https://www.kathimerini.gr/economy/561512356/protathlitria-sto-ilektroniko-emporio-i-ellada-stin-eyropi. Accessed 13 Sept 2023
15. truthberries: Investigating B2C E-Commerce in Greece: Quantitative Research Results (2021). https://www.greekecommerce.gr/wp-content/uploads/2022/02/GRECA-Report-B2C-J0160-presentation-1.pdf
16. Business News, E-Commerce Research: How Much It Has Grown After the Pandemic. https://www.businessnews.gr/epixeiriseis/item/225165-erevna-gia-to-ilektroniko-emporio-poso-afksithike-meta-tin-pandimia?ref=503. Accessed 13 Sept 2023
17. Competition Commission, Industry Research in E-Commerce (2022). https://www.epant.gr/files/2022/FINAL_ECOMMERCE.pdf

A New Concept for Resilient and Green Freight Transport and Logistics Networks Against Disruptive Events

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Abstract. In 2021, economic losses due to supply chain disruptions in the Eurozone amounted to €112.7 billion Euro: Natural catastrophes (e.g., hurricanes, earthquakes, floods, and wildfires) multiply in the wake of climate change. The risks of pandemics, trade restrictions, cyber-attacks, and geopolitical conflicts are omnipresent. Hence, the threat of disruptive events to the European transport network grows ever greater. Additionally, GHG emissions can drastically increase by up to 50% if disruptions are not treated efficiently. Here, the project "Resilient multimodal freight transport network" (ReMuNet) comes into play: ReMuNet will enable the multimodal freight network to react and respond 20% more quickly to disruptive events and help to reduce European inland transport emissions on the main run by over 50% by 2026.

As a trailblazer for the Physical Internet, the project pursues the vision to enable and incentivize synchro-modal relay-transport on European rail, road, and inland waterways to increase holistic network resilience. ReMuNet can identify and signal disruptive events and assess their impact on multimodal transport corridors. It reacts quickly to disruptive events in real time. It supports TMS providers to improve route planning resilience by communicating alternative, pre-defined, multimodal transport routes. ReMuNet orchestrates route utilization, suggests transshipment points, and optimizes capacity allocation, minimizing damage and shortening the recovery time. This paper introduces ReMuNet and its vision, objectives, and expected results.

Keywords: supply chain disruptions · resilient networks and operations · synchromodality · Reinforcement Learning

1 ReMuNet's Vision

1.1 Introduction

ReMuNet is a research and innovation action project, funded by the European Commission in Horizon Europe, that aims to enhance European freight transport resilience through synchromodal routing and event-based relay-transportation. Synchromodal

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transportation is defined as a multimodal approach that uses multiple modes of transport to move goods efficiently by using live data to provide demand-driven transport services, combining several transport modes [1]. In a synchromodal context different modes of transport can be used in relay models, e. g. railway or inland waterways [5]. Relay-transportation originally describes the process of two truck drivers swapping trailers at a transshipment point and carrying the new loads back to their home terminals, subsequently closing the distance to the cargo's final destinations [3, 4]. Within ReMuNet the concept of event-based synchromodal relay transport is used as a swift response to disruptive infrastructure failures increasing holistic network resilience while significantly reducing emissions.

ReMuNet identifies and signals disruptive events, such as natural disasters, traffic jams, and strikes, and assesses their impact on multimodal transport corridors. It then reacts quickly and seamlessly to disruptive events in real-time and supports TMS providers[1] to improve route planning resilience. ReMuNet communicates alternative, pre-defined, multimodal transport routes to logistics operators and subsequently to truck drivers, locomotive drivers, and barge captains, enabling a faster and more adaptive multimodal network response. Moreover, ReMuNet orchestrates route utilization, suggests exchange nodes for multimodal transport modes, and optimizes capacity allocation, minimizing damage and shortening the recovery time. This leads to more sustainable responses to disruptive events in the Eurozone.

1.2 Core Functionalities

ReMuNet's four core functionalities comprise:

1) A **standardized methodology to describe multimodal transport networks**. This standard is based on existing approaches and has been developed with various stakeholders to ensure practicability and acceptability across Europe. It can be easily transferred into appropriate regulatory frameworks and ensures better operational stakeholder interconnectivity. The standard will simplify communication and information-sharing between actors in the freight transport ecosystem.
2) An **algorithm to calculate multimodal route alternatives and capacity utilization** in the face of disruptive events to keep the freight transport network running smoothly. It uses real-time data to dynamically plan synchromodal alternative routes. Disruptive events can include pandemics, natural disasters, geopolitical conflicts, and construction sites.
3) A **collaborative platform that connects relevant logistics operators and enables them to manage disruptions.** This platform provides secure and resilient digital logistic and network management tools, including alternative route planning and orchestration of event-based synchromodal relay transportation. Easy data exchange enables efficient collaboration to keep the supply chain moving.
4) The use of **AI (Reinforcement Learning) to model and evaluate alternative courses of action.** This provides the basis for a self-learning, adaptive multimodal European freight transport and logistics network that strengthens the resilience of

[1] Transport management system.

European trade. Thus, ReMuNet can learn and adapt to changing conditions, making it even more effective in transport orchestration.

2 ReMuNet's Objectives

The concept of the Physical Internet foresees a seamless network where resources and assets can be shared openly and efficiently. ReMuNet's **main objective is to support the achievement of this vision by giving the transport network the ability to prepare, respond, and adapt to disruptive events**.

In practice, ReMuNet uses digital technologies to holistically improve the resilience of the logistics and freight transport network. This includes making planning more robust and secure, reducing response times, and speeding up system recovery. ReMuNet also takes environmental aspects into account and aims to provide synchromodal transport options with the lowest emissions. This contributes to the implementation of the Physical Internet and helps to reduce the environmental impact of freight transport.

Hence, ReMuNet identifies and signals disruptive events while assessing their impact on transport corridors. To enable a faster network response, ReMuNet orchestrates route and capacity utilization. It communicates alternative multimodal transport routes to logistics operators and subsequently to truck drivers, train drivers, and barge captains.

3 ReMuNet's Methodology

ReMuNet's methodology centers on fostering the evolution of a finely tuned multimodal transport infrastructure capable of withstanding conflicts. These conflicts typically manifest during route planning, particularly when disruptive events occur (see Fig. 1). For this, we propose synchromodal relay transport to ensure resilience by design.

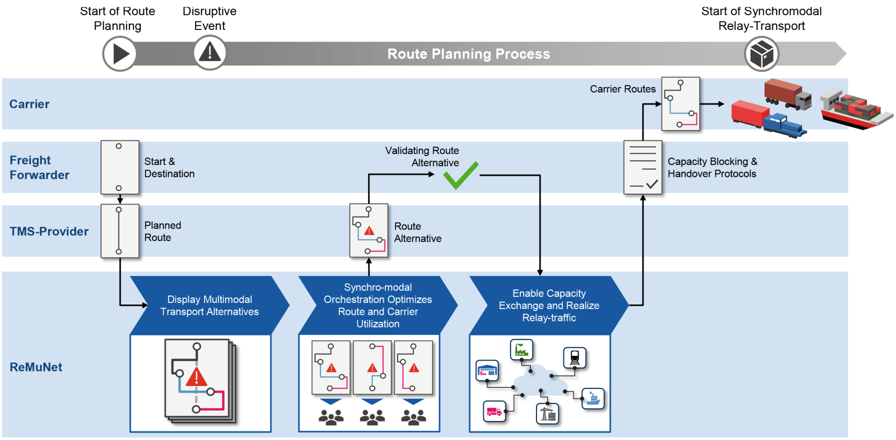


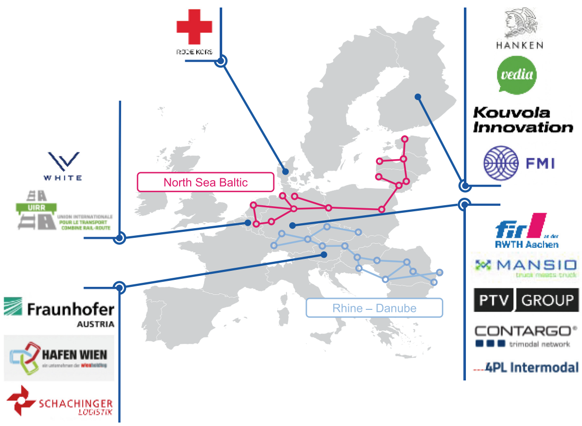
Fig. 1. ReMuNet thrives on collaboration of multiple logistics stakeholders

Within its open framework, the collaborative ReMuNet platform will effortlessly assimilate into the European concept of the Physical Internet. Presently, freight transport networks are fragmented and predominantly overseen by forwarders, shippers, or logistics service providers, lacking a cohesive operational transport network. Synchromodal transport emerges as a facilitator for such a unified transport network, constituting a pivotal element of the overarching "Physical Internet" vision. As a foundational component for synchromodal, resilient, and capacity-optimized transport routing, ReMuNet assumes a significant role within the framework of the Physical Internet.

The ReMuNet's idea starts off with a freight forwarder, delivering goods from point A to point B uses modern TMS-software to calculate the most efficient route and mode of transportation,

1. when an unforeseen event disrupts his/her planning process.
2. Classical TMS-systems offer alternative routes that require longer times, but do not consider the disruption impact, emissions, costs, or synchromodal potentials.
3. NOW: The ReMuNet platform displays multimodal transport alternatives that offer higher resilience (e.g., switching from road-based to rail-based) and are more sustainable by design. The information is communicated to the driver/means of transport via navigation system interface and messaging.
4. In a second step, ReMuNet anticipates the predicted impact of disruption and orchestrates route and carrier utilization by offering system-optimized route-based alternatives for each stakeholder.
5. As effect, ReMuNet enables synchromodal capacity exchange and realizes cross-actor relay-transport.

We defined two pilot corridors, each with distinct objectives. The North Sea Baltic pilot endeavors to establish a resilient and sustainable route for supplying goods to Ukraine, while the Rhine-Danube pilot emphasizes an ecological multimodal approach. Consequently, ReMuNet's use cases concentrate on addressing geopolitical concerns in the North Sea Baltic region and ecological, climate-resilient disruptive events along the Rhine-Danube corridor. Lessons gleaned from the COVID-19 pandemic are pertinent to both scenarios. Unlike disasters and conflicts that directly impact transport and communication infrastructure, the pandemic disrupted transport networks due to workforce shortages, leading to the closure of critical facilities such as warehouses, manufacturing plants, ports, and airports. Additionally, political decisions resulted in the shutdown of national borders and transportation modes, including air traffic.



Regarding the development and implementation of ReMuNet's four core functionalities, three constitutive technological work streams have been defined (see Fig. 2).

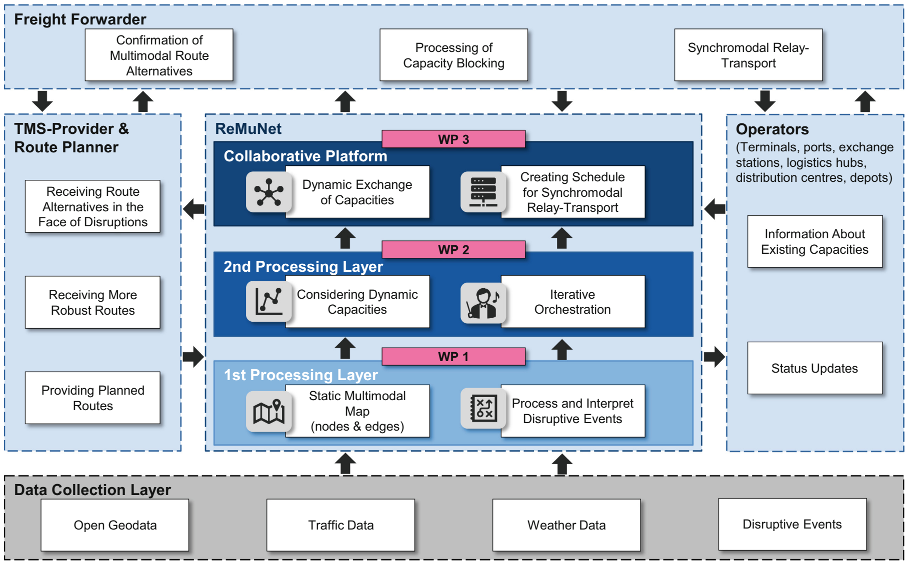


Fig. 2. Conceptual and simplified architecture of ReMuNet

Firstly, we amalgamate existing standards detailing multimodal transport nodes and edges with data on disruptive events. This fusion facilitates the creation of a cohesive data repository serving as input for the initial processing layer. The outcome is a consolidated description standard integrated into a static multimodal map. Additionally, we formulate a typology discerning various disruptive events affecting multimodal freight transport. Secondly, we construct a reference model delineating multimodal transport networks and devise an algorithm for presenting alternative transport options during disruptive events. This reference model displays the impacts of disruptive events, establishes the groundwork for intelligent routing algorithms, and thereby supports the collaborative platform. By enabling an examination of disruptions based on events and their effects on transportation chains, genuine resilience is instilled into the system through intelligent route planning and dynamic capacity allocation. These capabilities will be unified within the collaborative ReMuNet platform. The comprehensive suite of functionalities is underpinned by a foundational data layer that amalgamates data from operators across various levels.

Initially, ReMuNet relies on four distinct data sources: static, dynamic, disruptive, and operator data, each contributing to various functionalities. Static data encompasses infrastructure and multimodal transfer points, while dynamic data expands upon this by incorporating transport capacity, weather conditions, and traffic data. Complementary to these, disruptive data includes information about natural disasters and sudden shifts in demand, while operator data, such as that from ports and freight forwarders, further enriches the database, ensuring its robustness.

Simultaneously, the system undergoes continual enhancement through the establishment of a reinforced learning environment. This environment involves an AI-based simulation of disruptive events and a model for orchestrating routes and capacities.

4 Conclusion

The ReMuNet system is rooted in the principle of developing an optimized multimodal transport network that is resilient to conflicts. Conflicts can arise in the route planning and transport process due to disruptive events. To address this challenge, ReMuNet proposes synchromodal relay transport, which is designed to be resilient by design. The open and collaborative ReMuNet platform will seamlessly integrate into the European vision of the Physical Internet.

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References

1. Tavasszy, L., Behdani, B., Konings, R.: Intermodality and synchromodality. In: Ports and Networks (2017). eBook ISBN 9781315601540
2. Fraunhofer IML: Challenges and Potentials of a Logistics Data Space (2019). https://internationaldataspaces.org/wp-content/uploads/IDSA-LC-position_paper.pdf. Accessed 10 Oct 2023
3. Alacam, S., Sencer, A.: Using Blockchain technology to foster collaboration among shippers and carriers in the trucking industry: a design science research approach. Logistics **5**(2), 37 (2021). https://doi.org/10.3390/logistics5020037
4. Simons, J., von Stamm, J., Weichsel, L., Schröer, T., Schürmeyer, M.: Requirements for an IoT-lock enabling asynchronous physical handovers of semi-trailers in road freight relay-transport. In: Herberger, D., Hübner, M., Stich, V. (eds.) Proceedings of the Conference on Production Systems and Logistics (CPSL 2023), pp. 622–628 (2023). https://doi.org/10.15488/13482
5. Hoffa, P., Pawlewski, P., Nielsen, I.: Multimodal processes approach to supply chain modeling. In: Omatu, S., Bersini, H., Corchado, J., Rodríguez, S., Pawlewski, P., Bucciarelli, E. (eds.) Distributed Computing and Artificial Intelligence, 11th International Conference. AISC, vol. 290, pp. 29–37. Springer, Cham (2014). https://doi.org/10.1007/978-3-319-07593-8_4

Estimating a Detailed Trans-European Origin-Destination Matrix of Road Freight Transport

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Abstract. Detailed data regarding the types and quantities of goods transported, both regionally and internationally, plays a pivotal role in developing sustainable freight transport strategies. However, such data is currently lacking. This paper presents a method based on Iterative Proportional Fitting for creating comprehensive Origin-Destination (OD) matrices representing European road freight transport flows. The approach integrates publicly available statistical data on freight transport, including international transport flows between countries, the total volumes of goods loaded and unloaded in all NUTS 3 regions, the distribution of transport distances and the shares of different types of cargo. The proposed methodology addresses data inconsistencies and missing information. The resulting demand matrices provide detailed insights into the volumes and types of freight exchanged via road transport between NUTS-3 regions throughout Europe.

Keywords: Road freight transport · Transport demand · Iterative Proportional Fitting

1 Introduction

In Europe, road transport stands as the primary source of emissions within the transportation sector, with heavy-duty vehicles (HDVs) accounting for approximately a quarter of these emissions[4]. To devise strategies for more efficient and sustainable freight transport, e.g., shifting transport to more efficient modes or optimizing the trans-European transport network (TEN-T), it is essential to have detailed knowledge of the quantities of solid and liquid bulk goods, palletized goods, and freight containers being transported. This information needs to encompass both international and regional transports with the highest possible level of precision. However, such data is currently not readily available. Existing methods use toll data and traffic counts to estimate freight transport

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demand [1] but don't include details about the origin, destination, and types of goods. The statistical office of the European Union (EuroStat) collects data on the quantities of goods transported between countries, which can be accessed through an online database[5]. Additionally, data is available on loaded and unloaded goods at the NUTS-3 regional level, the distribution of transport distances, and the proportions of various cargo types. However, this data only offers a limited perspective on freight traffic flows, corresponding to marginal totals in the origin-destination (OD) matrix. Iterative Proportional Fitting (IPF) is a method employed in economics and survey statistics for aligning a distribution provided in one dataset with the totals reported in various other datasets. It serves to refine data tables in situations where information is either incomplete, erroneous, outdated, or based on a sample [6]. For instance, IPF finds applications in determining passenger origin-destination flows on bus routes using boarding and alighting data [7], and in generating socioeconomic attributes for a synthetic population in Activity-Based travel demand modeling, leveraging a sample of cross-tabulated attributes from one zone and marginals of other zones[2].

In this paper, we present a method based on IPF for creating a detailed tabulation of European road freight transport flow volumes (OD matrices) by using publicly available freight transport statistics. The proposed approach reconciles the available data into a coherent result and handles potential inconsistencies between the data sources by minimizing the error. The resulting demand matrices provide insights into the volume of goods transported nationally and internationally between NUTS-3 regions, while also distinguishing between different types of cargo.

This paper is organized as follows: Sect. 2 describes the data sources used in this study, Sect. 3 explains the algorithm for creating the OD matrices, Sect. 4 presents the results, and Sect. 5 concludes this study.

2 Data Sources

EuroStat collects road transport statistics on the transport of goods with heavy goods vehicles [5]. Data collection consists of annual and quarterly datasets from each member state on vehicles registered within their borders, capturing loaded journeys and information about the transported goods, typically over a one-week observation period. The collected information includes metrics such as tons, tonne-kilometres, vehicle-kilometres, and the number of journeys. Cargo types are classified into: liquid bulk goods, solid bulk goods, large freight containers, other freight containers, palletized, pre-slung, mobile self-propelled units, other mobile units, and other cargo types.

For our study, we use the following Eurostat data: International road freight transport by country of loading and unloading (table *road_go_ia_rc*), Total road freight transport by region of loading (table *road_go_ta_rl*), Total road freight transport by region of unloading (table *road_go_ta_ru*), Total road freight transport by type of cargo and distance class (table *road_go_ta_tcrg*), and the Distance matrix between NUTS-3 regions [3].

In this study we focus on the annual amount of transported goods in thousand tons and we only extract the corresponding variable. However, the methods described here can also be applied using the number of journeys instead.

It is important to note that these data stem from sample surveys and are subject to sampling errors and bias. Moreover, detailed breakdowns reduce sample sizes and amplify errors. In the Eurostat tables, a specific code is used to indicate that the micro-data observations are fewer than 10. These codes can be replaced with zeros for estimation purposes, which will, however, introduce disparities between aggregated and disaggregated data. Another code is used to indicate that data is missing. Data imputation approaches, such as extrapolation from previous years, can generate additional inconsistencies in the data, which have to be reconciled, when computing the OD matrix.

3 Method

The method employed to estimate a detailed road freight OD matrix relies on an approach known as Iterative Proportional Fitting (IPF). IPF is a mathematical technique used to adjust a matrix to align with predefined totals (marginals). This adjustment process consists of scaling along different dimensions, typically rows and columns, to match the desired marginals. Since each adjustment step may disrupt the alignment achieved in the previous step, IPF iteratively repeats these adjustments in cycles until all specified marginal totals are satisfactorily approximated.

To describe the available and desired data in a formal way, we first introduce the following definitions:

C_R is the set of reporting countries.
C is the set of countries of loading (origin) or unloading (destination).
R is the set of NUTS-3 regions of loading (origin) or unloading (destination).
$R_c \subset R$ is the set of NUTS-3 regions of country $c \in C$.
T is the set of cargo types.
L is the set of distance classes ($<$ 50km, 50km$-$149km, 150km$-$299km, 300km$-$499km, $>$ 500km).

The desired OD matrix can be written as a function $m : R \times R \times C_R \times T \to \mathbb{R}$ such that $m(o, d, c_r, t)$ is the amount of cargo of type t that is transported by road from origin o to destination d using a vehicle registered in country c_r.

The distance matrix is a function $\delta : R \times R \to L$.

Table *road_go_ta_rl* (total road freight transport by region of loading) is a function $f_l : K_l \subseteq R \times C_R \to \mathbb{R}$ defined by

$$f_l(o, c_r) = \sum_{(d,t) \in R \times T} m(o, d, c_r, t). \tag{1}$$

Table *road_go_ta_ru* (total road freight transport by region of unloading) is a function $f_u : K_u \subseteq R \times C_R \to \mathbb{R}$ defined by

$$f_u(d, c_r) = \sum_{(o,t) \in R \times T} m(o, d, c_r, t). \tag{2}$$

Table *road_go_ia_rc* (international road freight transport by country of loading and unloading) is a function $f_{lu} : K_{lu} \subseteq C \times C \times C_R \to \mathbb{R}$ defined by

$$f_{lu}(c_o, c_d, c_r) = \sum_{(o,d,t) \in R_{c_o} \times R_{c_d} \times T} m(o, d, c_r, t). \tag{3}$$

This table only contains international transport and cabotage such that $K_{lu} \subseteq \{(c_o, c_d, c_r) \in C \times C \times C_R \mid c_o \neq c_d \vee c_o \neq c_r \vee c_d \neq c_r\}$.

Table *road_go_ta_tcrg* (total road freight transport by type of cargo and distance class) is a function $f_{td} : K_{td} \subseteq T \times L \times C_R \to \mathbb{R}$ defined by

$$f_{td}(t, l, c_r) = \sum_{(o,d) \in R \times R:\ \delta(o,d) = l} m(o, d, c_r, t). \tag{4}$$

The goal is to align $m(o, d, c_r, t)$ with the aggregate functions defined in Eqs. (1) to (4). To this end, we generalize IPF to scaling arbitrary parts (subdomains) of m instead of just scaling rows and columns. The domains K_l, K_u, K_{lu}, and K_{td} of the functions define the available marginals. Note that the domain definitions address missing data by allowing the domains to be subsets of the complete domains. For instance, $K_l \subseteq R \times C_R$ means that for some regions and reporting countries the information on the quantity of goods loaded might be missing. To prevent oscillations in the presence of inconsistencies in the input data, we introduce a *learning rate* $\alpha_i \in [0, 1]$ to control the size of adjustments made by IPF. To balance rapid convergence and stability, the learning rate can be gradually reduced throughout the iterations.

The procedure for calculating an estimate for m is as follows:

Initialize $m^{(0)}$ with small positive numbers and repeat the following steps for $i = 0, 1, 2, \ldots$ until convergence:

1: $\hat{f}_l^{(i)}(o, c_r) := \sum_{(d',t') \in R \times T} m^{(4i)}(o, d', c_r, t')$

$s_l^{(i)}(o, c_r) := \begin{cases} f_l(o, c_r) \div \hat{f}_l^{(i)}(o, c_r) & \text{if } (o, c_r) \in K_l; \\ 1 & \text{if } (o, c_r) \notin K_l. \end{cases}$

$m^{(4i+1)}(o, d, c_r, t) := m^{(4i)}(o, d, c_r, t)(\alpha_i(s_l^{(i)}(o, c_r) - 1) + 1)$

2: $\hat{f}_u^{(i)}(d, c_r) := \sum_{(o',t') \in R \times T} m^{(4i+1)}(o', d, c_r, t')$

$s_u^{(i)}(d, c_r) := \begin{cases} f_u(d, c_r) \div \hat{f}_u^{(i)}(d, c_r) & \text{if } (d, c_r) \in K_u; \\ 1 & \text{if } (d, c_r) \notin K_u. \end{cases}$

$m^{(4i+2)}(o, d, c_r, t) := m^{(4i+1)}(o, d, c_r, t)(\alpha_i(s_u^{(i)}(o, c_r) - 1) + 1)$

3: $\hat{f}_{lu}^{(i)}(c_o, c_d, c_r) := \sum_{(o',d',t') \in R_{c_o} \times R_{c_d} \times T} m(o', d', c_r, t')$

$s_{lu}^{(i)}(c_o, c_d, c_r) := \begin{cases} f_{lu}(c_o, c_d, c_r) \div \hat{f}_{lu}^{(i)}(c_o, c_d, c_r) & \text{if } (c_o, c_d, c_r) \in K_{lu}; \\ 1 & \text{if } (c_o, c_d, c_r) \notin K_{lu}. \end{cases}$

$m^{(4i+3)}(o, d, c_r, t) := m^{(4i+2)}(o, d, c_r, t)(\alpha_i(s_{lu}^{(i)}(c_o, c_d, c_r) - 1) + 1)$

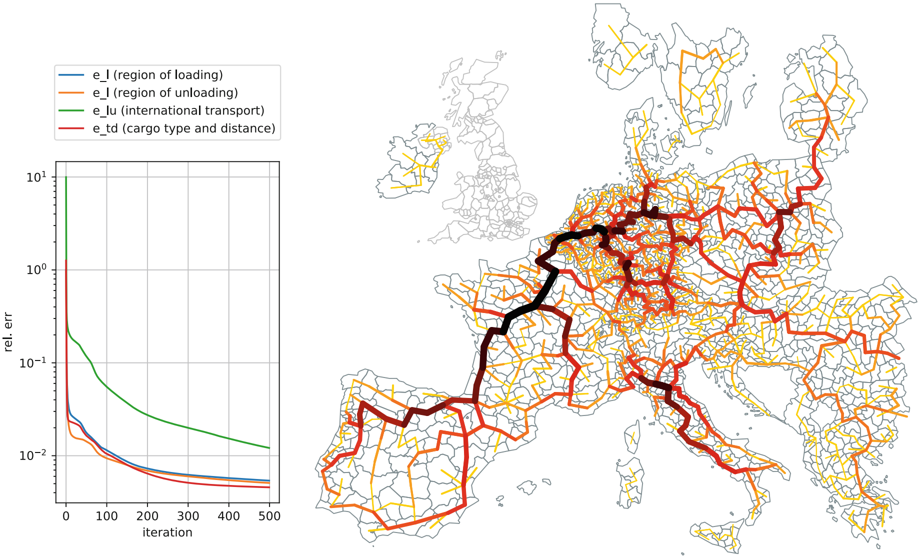
4: $\hat{f}_{td}^{(i)}(t, l, c_r) := \sum_{(o',d') \in R \times R:\ \delta(o',d') = l} m(o', d', c_r, t)$

$s_{td}^{(i)}(t, l, c_r) := \begin{cases} f_{td}(t, l, c_r) \div \hat{f}_{td}^{(i)}(t, l, c_r) & \text{if } (t, l, c_r) \in K_{td}; \\ 1 & \text{if } (t, l, c_r) \notin K_{td}. \end{cases}$

$m^{(4i+4)}(o, d, c_r, t) := m^{(4i+3)}(o, d, c_r, t)(\alpha_i(s_{td}^{(i)}(t, \delta(o, d), c_r) - 1) + 1)$

The initialization acts as a ‘prior,’ guiding IPF to a solution close to $m^{(0)}$ that aligns with available marginals while resolving discrepancies. Assuming that missing information likely suggests minimal goods flow, in particular for cross-trade and cabotage, we employ very low priors: 10^{-6} for cross-trade and cabotage, and 10^{-3} for all other transport operations.

4 Results and Discussion



(a) (b)

Fig. 1. Evolution of the relative errors over iterations of IPF (a), and the resulting road freight flows visualized as paths along neighbouring regions (b).

We applied the method to data of the year 2022. The evolution of the relative marginal errors $e_\cdot^{(i)} = \frac{\sum_{K_\cdot} |\hat{f}_\cdot^{(i)} - f_\cdot|}{\sum_{K_\cdot} f_\cdot}$ over the IPF iterations are shown in Fig. 1(a). After 500 iterations, the errors are $e_l = 0.5\%$, $e_u = 0.5\%$, $e_l u = 1.2\%$, and $e_t d = 0.4\%$. The resulting road freight flows are visualized as paths along neighbouring NUTS-3 regions in Fig. 1(b).

It is important to note that the available statistical data used in this study do not fully determine the OD matrix. For example, cargo type information is limited to the reporting country and distance. However, there may be dependencies on specific origin and destination regions, currently addressed only through statistical relationships between reporting countries and regions. Nonetheless, the methodology is expandable, and incorporating more data sources can reduce ambiguities and enhance result reliability. One approach is to include tonne-kilometers in addition to transported tonnes for loaded and unloaded goods, providing a new aggregate as input for the estimation: dividing tonne-kilometers by tonnage yields total distances traveled for each source or destination region. Another improvement approach involves reassigning current origin-destination flow estimates on the road network in each iteration, adjusting traffic volumes using data from traffic sensors or toll systems.

5 Conclusion

We presented an IPF-based method to estimate a comprehensive OD matrix for road freight transport at the NUTS-3 level across Europe. The resulting matrix aligns with all existing aggregate statistics and reconciles potential disparities among data sources. These outcomes provide a solid basis for developing strategies aimed at improving the efficiency and sustainability of freight transport.

References

1. Afandizadeh, Z.S., Yadi, H.S.: Estimation of freight od matrix using waybill data and traffic counts in iran roads. Iranian J. Sci. Technol. – Trans. B-Eng. (2006)
2. Choupani, A.A., Mamdoohi, A.R.: Population synthesis using iterative proportional fitting (ipf): a review and future research. Trans. Res. Proc. **17**, 223–233 (2016)
3. European Commission: TERCET flat files — gisco-services.ec.europa.eu. https://gisco-services.ec.europa.eu/tercet/flat-files/. Accessed 10 June 2023
4. European Environment Agency: Reducing Greenhouse Gas Emissions from Heavy-duty Vehicles in Europe. Publications Office of the European Union, EEA briefing (2022)
5. Eurostat: Eurostat Database. https://ec.europa.eu/eurostat/web/main/data/database. Accessed 10 June 2023
6. Lomax, N., Norman, P.: Estimating population attribute values in a table: "get me started in" iterative proportional fitting. Prof. Geogr. **68**(3), 451–461 (2016). https://doi.org/10.1080/00330124.2015.1099449
7. McCord, M.R., Mishalani, R.G., Goel, P., Strohl, B.: Iterative proportional fitting procedure to determine bus route passenger origin-destination flows. Transp. Res. Rec. **2145**(1), 59–65 (2010)

Data-Driven and Dynamic Land Use for Physical Internet-Led Urban Logistics and Planning

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Abstract. DISCO is an innovation action project co-funded by the European Commission, focused on upscaling urban logistics and smart planning, accelerating the transition to decarbonized and digital cities by changing the logistics paradigm using a Physical Internet (PI) led approach. DISCO leverages the PI and Urban Cloud concepts to demonstrate the value of dynamic allocation of city infrastructures. The 5 DISCO-X measures employ sensor enabled infrastructures using PI collaboration protocols and an Urban Cloud model to enable the efficient and effective allocation of city infrastructures to users. In order to guide the cities towards the digital transformation and thus allowing them to build an ecosystem of logistics players that are willing to stay interconnected, three actions are necessary: (i) Influential market players register last-mile delivery capacities in an Urban Freight (UF) Data Space and establish trusted data sharing with planners for smarter, effective, functional, and real-time planning; (ii) The Meta Model Suite delineates optimal paths to achieve concrete transformation in Living Labs acting as PI networks; (iii) all involved actors comply with certain IT standards and protocols. In UF Data Space, DISCO will know all freight transport capabilities and space available in the city, in real-time and in advance and will support operational efficiency, dynamic planning, optimal use of available infrastructures, network and asset and better user experience. DISCO will deploy a demonstration involving 4 Starring Living Labs + 4 Twinning Living Labs and a package of 23 innovation measures, along 5 DISCO-X innovations, layered as digital, physical and business.

Keywords: Urban Logistics · Physical Internet · Data Space

1 Introduction: The DISCO Vision

Priorities of the EU Green Deal [1] to reduce climate emissions by 55% by 2030 and for cities to become climate-neutral by 2050 cannot be met only by setting vehicles' decarbonisation targets. To achieve these goals, urban space, logistics services and transportation systems need to be re-designed, adopting a dynamic and optimal space allocation

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approach that integrates urban freight within an efficiently operated network-of-networks that exploits underused land based on throughput demands. Cities are complex entities composed of multiple interacting networks of actors, systems, technologies, and regulations [2]. As a structure built from the interaction of multiple networks, a city is not a planned construct, but an emergent concept reflecting the multitude of interactions between its underlying components (e.g., [3]). Historically, the approach cities have taken to managing this complexity has been to organize functionally and, within function, to focus on either technical or geographic components of the function [4]. Unfortunately, such a structure has encouraged the development of "silo" thinking, which ignores the interconnections of the various networks that operate within a city. As cities have grown, the services that they are expected to deliver to their citizens have also grown. These services, provided by numerous city functional departments and external commercial entities, intersect, facilitate, and constrain the various recipients of the services in an emergent manner that no individual city department or company can foresee or control. Given the city's inability to systemically control or understand what is happening at the operational level means that the efficient and effective use of city infrastructures is not possible resulting in user frustration, loss of good will, and fair allocation. Another approach to managing the operations of the city's infrastructure is required. One such approach uses the Internet as an example of how intelligent objects and resources might be managed. If every physical entity is instrumented with a real time sensing and communications device, why can't these physical entities be managed like resources on the Internet? A "Physical Internet" concept [5–8] is a particularly useful model for thinking of city infrastructures like computing resources that can be provisioned "on demand" through cloud like "Infrastructure as a Service" (IaaS) concepts [9]. It is also a useful approach to managing freight and mobility services, which resemble the flow of packets over the Internet [10]. By abstracting its infrastructure through an "Urban Cloud" model, the city would provide convenience to its citizens and businesses. These users would no longer have to seek out open areas for parking, dropping off, or picking up items. They could schedule the abstract space through applications built on top of the city's IaaS services and be assured that they could use the space for the duration that they have scheduled it.

DISCO leverages the PI and Urban Cloud concepts to demonstrate the value of dynamic allocation of city infrastructures. The DISCO-X (X = Curb, Proxi, Bay, Estate, and Collection) measures employ sensor enabled infrastructures using Physical Internet collaboration protocols and an Urban Cloud model (city infrastructure managed as a service and a digital twin platform connecting to the infrastructure, linking federated dataspaces, and providing modeling and analytic tools to predict behavior and build additional services as a Platform as a Service) to enable the efficient and effective allocation of city infrastructures to users.

2 Methodology: The DISCO Approach

The DISCO relies on four subsequent methodological steps of a journey to scale up and accelerate to a climate-neutral data-driven value destination to 2030. This route is with the following methodological paths (Fig. 1):

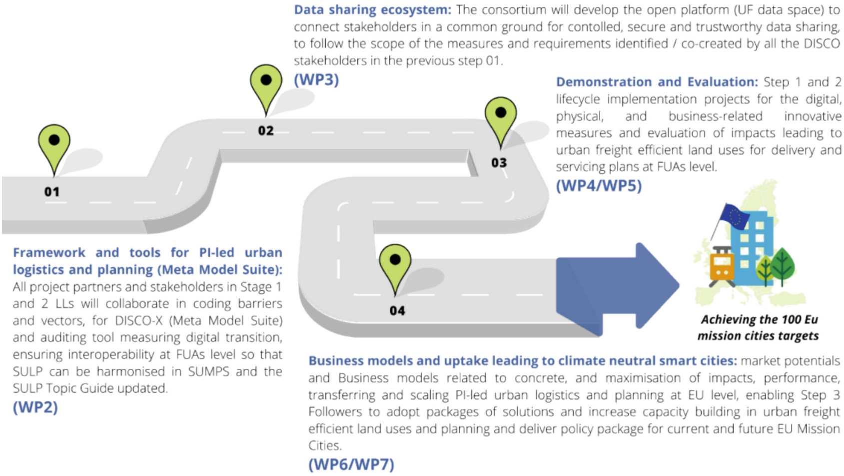

Fig. 1. Route to digital transformation in urban logistics and planning

In order to guide the cities towards the digital transformation and thus allowing them to build an ecosystem of logistics players that are willing to stay interconnected, three actions are necessary:

Action 1: Influential market players, from big carriers to cargo-bike couriers, register last-mile delivery capacities in an Urban Freight (UF) Data Space (IT platform) and establish trusted data sharing with planners for smarter, effective, functional, and real-time planning. Operators can benefit of dynamic (on-demand) and optimal use of (underexploited or strategically positioned) lands/space and adoption of zero-emission vehicles (e.g., e-bike to LEFV) and roll out of sustainable modes (waterborne / rail).

Action 2: The Meta Model Suite delineates optimal paths to achieve concrete transformation in Living Labs (LL) acting as PI networks, running packages of innovative digital, physical, and business measures, co-designed and enabled by multi-stakeholders' connectivity. Digital maturity is measured by Assessment Toolkit so that measures are widely accepted, scaled and to be considered in SULPs.

Action 3: All involved actors comply with certain IT standards and protocols, and ideally also on shipment sizes that are modular enough so that they can be flexibly and dynamically combined to allow a certain interconnection of the different parties to perform efficiently. In UF Data Space, DISCO will know (stream) all freight transport capabilities and space available in the city (e.g., freight hotels), in real-time and in advance and will support operational efficiency, dynamic planning, optimal use of available infrastructures, network and asset and better user experience. DISCO will be at the service of cities and operators, co-designing, simulating, monitoring, evaluating and scaling-up the DISCO innovative measures, belonging to different DISCO-X. These measures will be demonstrated by adopting the Meta Model Suite, enabled by the UF Data Space, empowering uptake, and replicability at different phases of design and implementation, and ensuring stakeholder's participation.

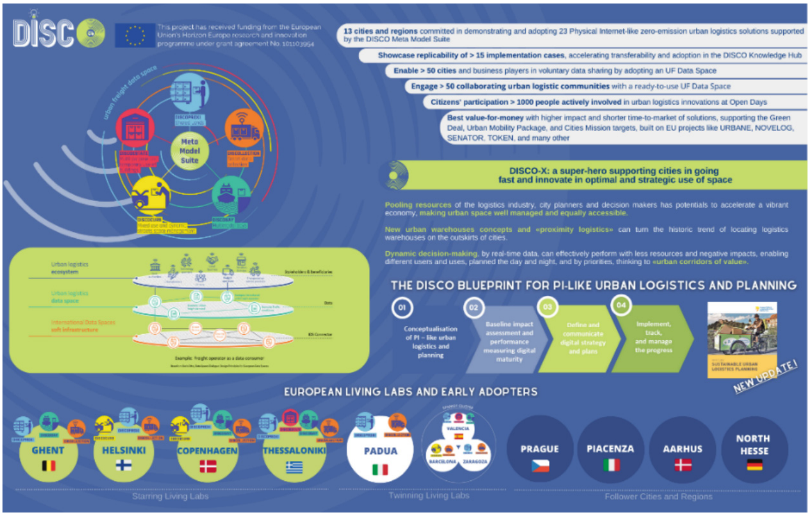

Fig. 2. DISCO overall approach

Meta Model Suite: The Meta Model Suite is a novel framework that supports the implementation and adoption of green last-mile delivery solutions in urban areas, based on the PI-led DISCO-X innovations listed below:

DISCOCURB - *Mixed use and dynamic streets space management* - Smart and flexible use of curb side, for parking slots, pick up points and network management.

DISCOPROXI - *Shared Lands* - Urban corners or lockers for nearby deliveries and omnichannel shipments, to optimise multiple collection and delivery solutions.

DISCOESTATE - *Multi-purpose, flexible and temporary use of building space* - Retrofitting building space for multi-tenant and temporary logistics use and enhance the reliability of last mile deliveries.

DISCOBAY - *Multimodal bays* - Mutualised and multimodal (e.g., rail/waterborne) distribution centres pooling green last mile delivery.

DISCOLLECTION - *Smart data collection methods* - Advanced access control and real time routing for optimised and prioritized, incentivised and dynamic access permission enabling smart network management upon priorities and functional areas.

These innovations aim to promote the adoption of shared green last mile solutions by considering physical, digital, and operational aspects. The suite consists of four main functionalities: (1) guidance to cities on the different DISCO innovations and their requirements, (2) definition of the transition path for each DISCO city to achieve a smooth transition to PI-led innovations and incorporate them into their SULP, (3) planning and operational tools for designing and implementing the different DISCO-X solutions, and (4) guidance to cities on the data requirements of each DISCO-X and how to develop their own dataspaces.

Urban Freight Data Space: The DISCO UF Data Space is the underlying digital enabler for the deployment of data-driven collaborative planning services. It provides a trustworthy framework for sharing data related to transportation, delivery, space use, and supply chain operations in urban areas across decentralised networks, whilst introducing semantic interoperability. The latter is particularly critical for establishing a common understanding of data meaning and context across diverse sources and the DISCO-X applications. Through the DISCO UF Data Space data sovereignty, transparency and fairness are ensured, creating the ground for stakeholders' onboarding. Data connectors will facilitate seamless data exchange services while incorporating robust data security enforcement mechanisms. A catalogue of key reusable services will further support the development of sustainable urban logistics strategies.

The Adaptive Blueprint for PI-Like Urban Logistics and Planning: The Adaptive Blueprint process will run across 4-Phases that will help cities and communities in undertaking a successful digital transformation with a simple stepwise approach, as initially planned in the Fig. 2. It will intensify the dialogue on SULPs and will provide insight in relation to urban logistics system of the future, the main planning requirements for promoting the shift towards PI-led solutions.

3 Preliminary Results and Discussion

At the final submission stage of this paper, the project hasn't reached yet one year of life. However, preliminary results showed: (i) Cities are confronted with a vast array of data types, originating from various platforms and in different formats. This heterogeneity, stemming from the unique requirements of the five DISCO-X categories, underscores the need for a specialized data aggregation tool or add-on within the urban dataspace; (ii) A preliminary version of the Meta Model Suite was introduced. This tool is envisioned as a comprehensive resource for cities embarking on the journey towards PI-enabled infrastructure management, offering a unified framework for the effective implementation of PI principles in urban logistics and infrastructure planning.

The DISCO impact domain underpinning PI-led urban logistics land use and planning in which innovation must be placed at the service of cities are: ***Shared Solutions***: Ability to create asset-less solutions by crowdsourcing platforms bringing various stakeholders under a common platform and creating value in terms of the economy of scale expected to generate. They can collaborate around technology to provide on-demand deliveries when it comes to their last-mile logistics. ***Connected logistics***: Ability to leverage key trends towards a data-centric approach and use analytics to manage fleets and regroup deliveries to take critical decisions pertaining to key logistics functions. Incorporating analytics to optimise routes and fuel usage, control emissions and monitor operational efficiency and performance, as well as for predictive deliveries to understand where an order would be. ***Smart logistics***: Ability to offer authorities opportunities to improve dynamic traffic management and improve enforcement of local rules, e.g., in terms of accessibility of a city centre. Smart logistics offer business opportunities to logistics companies and customers, improve efficient transport and warehousing, and facilitate (inter)connectivity among logistics networks, e.g., exchange of transport orders between different parties and/or modalities. Equal sharing costs / benefits models remain a hot topic. The exchange of traffic and logistics trip data between companies / authorities enables parties to improve operations. Smart logistics solutions create new connections and enable LSP's to collaborate. ***Urban network management***: Ability to adopt flexible and smart use of networks, dynamic access regulation, low emission zones regulation and monitoring, parking space management, dynamic routing. ***Agile storage and last-mile distribution:*** Ability to improve the delivery process and manage loading and unloading areas (scarce space management, in a flexible and integrated way, and of the contested curb side); to improve consolidation of goods and management of flows; to introduce new technologies that can make the freight distribution process more efficient through automation and data analysis.

4 Future Research

DISCO project will run for a total of four years, being yet at the first year only the initial phase of DISCO-X innovation in urban areas has been delineated together with a PI-operational paradigm offering a guidance for cities in implementing DISCO-X strategies effectively. In the next months/years for each DISCO-X, specific tools will be developed to enable the operation of the DISCO-X solutions to each city. The Urban Freight Data Space will facilitate the tools deployment by providing the good organization of the data needed for the implementation of each DISCO-X in the cities and utilize the meta data flows of the Urban Freight Data Space to obtain information sufficiently covering their needs.

Disclaimer DISCO is funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.”

References

1. European Commission, S.-G.: Communication and roadmap on the European Green Deal. Brussels (2020)
2. Batty, M.: The New Science of Cities. MIT press (2013)
3. Fromm, J.: The Emergence of Complexity. Kassel University Press GmbH (2004)
4. Minett, J.: If the city is not a tree, nor is it a system. Planning Outlook **16**(1–2), 4–18 (1975)
5. ALICE.: Roadmap to Physical Internet 2030–2040. https://www.etp-logistics.eu/wp-content/uploads/2022/11/Roadmap-to-Physical-Intenet-Executive-Version_Final-web.pdf
6. Dong, C.: From the digital Internet to the physical Internet: a conceptual framework with a stylized network model. J. Business Logistics **42**(1), 108–119 (2020)
7. Sharma, V.R.: Advancements in urban logistics toward smart, sustainable reforms in developing enabling technologies and markets. Kybernetes **51**(3), 1038–1061 (2021)
8. Ambra, T.C.: Towards freight transport system unification: reviewing and combining the advancements in the physical internet and synchromodal transport research. Int. J. Prod. Res. **57**(6), 1606–1623 (2019)
9. Franklin, J.I.: The Urban Cloud: Linking city services, cloud computing, and the Physical Internet to achieve smart city objectives. Proceedings of the 9th International Physical Internet Conf. (2023)
10. Montreuil, B.: Towards a physical internet: meeting the global logistics sustainability grand challenge. Logistics Research **3**(2–3), 71–87 (2011)

Food Delivery Services Influence on Urban Mobility – A Systematic Literature Review

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Abstract. Food delivery services have more than tripled since 2017, further driven by the implications of the COVID-19 pandemic. This increase and digitalization have paved the way towards a new urban mobility and logistics scenario. This research investigated the recent impact of food purchase/delivery on mobility, such as the replacement of individual private mobility to physical stores by the use of online platforms and delivery transport modes. A systematic literature review was carried out to identify how business operations affect urban mobility and the challenges behind these changes, by understanding the effects that food delivery can have on urban mobility and the transport system. The study was based on a PRISMA analysis, selecting papers from SCOPUS and Web of Science between 2012 to 2022. The review concluded a knowledge gap with only 20 papers, highlighting the implications of food delivery services on traffic congestion, road safety, policies, and infrastructure. The study concluded the need for changes on the urban planning perspectives by offering insights to the academic environment and outlining directions to future research. It also underlines planning deficiency between urban mobility and urban logistics under the umbrella of food delivery.

Keywords: Food delivery · transport · urban mobility · logistics · delivery route · on-demand transport services

1 Introduction

The food delivery services have become viral worldwide, particularly the online food delivery, which has altered the last-mile segment with substantial impacts on the transport and logistics network by a demand that is extremely dynamic in space and time [1]. Every year, especially in the wake of the COVID-19 pandemic, more consumers use delivery services for a variety of reasons, which highlights questions about the impact of these types of work on physical spaces and mobility practices, which can range from security, traffic, to carbon-footprint and beyond [2].

Although over 160 research papers have focused on consumer behaviour/experience, food delivery platform workers (couriers), and new technologies to improve the food delivery apps, such as route optimization, few papers have addressed current research

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and trends towards the impact of this segment on the urban mobility, but not one focused on it entirely. Thus, this study offers opportunity to contribute to the literature on a less-explored domain of food delivery services, by reviewing the literature published from 2012 to 2022, to analyse the extent of the impacts on urban mobility caused by food delivery, and the change in food purchase behaviour. For this, the following questions will be answered: to what extent is the food delivery service affecting the urban mobility? What can be learned from the research that have taken place? Focusing on the opportunities and challenges these impacts pose.

2 Methodology

This research follows the PRISMA guidelines, to ensure a transparent search, which will focus on a clearly defined topic, following pre-determined criteria, to achieve scientific accuracy. The search for documents was carried out until May 2023, with the strategy of using two different database, SCOPUS and Web of Science, and analysing documents from 2012 to 2022 in English and in Portuguese (Table 1). These two databases provide high-quality documents and are widely used. The searching strategy was based on the terms "food AND delivery AND transport", three strings separated by proper Boolean operators, and was later refined by title, abstract and keywords related considerations. This resulted in 290 documents, being 28 from SCOPUS and 262 from Web of Science.

Table 1. Paper selection criteria.

Items	Description
Database	Scopus and Web of Science
Language	English and Portuguese
Time interval	2012 - 2022
Inclusion criteria	Food AND delivery AND transport; Open access; SCImago Q1 and Q2

The next phase was to remove the duplicated documents (11), papers with journals ranked at SCImago as Q3 and Q4 (17 documents), and with no open access (12 documents), resulting in 250 documents. An eligibility criterion was made by the examination of the abstracts focusing on the relationship and impacts that the food delivery service is imposing on the urban mobility transportation system. This culminated on the classification between relevant and not relevant documents to this study, excluding 217, as many of them focused mainly on delivery app platforms (67), customer behaviour (54), route optimization (21), and drones as the goal for the future (23). The remaining 33 documents were then analysed one by one in their full text, from which another 13 documents were also excluded, since they did not add direct value to the subject by not covering the impacts of food delivery on urban mobility, leaving 20 documents at the end (Fig. 1).

The final step was the analysis of the selected papers for their categorization and scope examination. The categorization was made in 10 areas of study based on: platform-based delivery personnel, mobility practices of the couriers, road safety, traffic regulations, traffic, conditions, sustainability, pollution, urban mobility plan/infrastructure, parking/loading, and KPI/new technology. The studies were carried out in China, Canada, France, India, Colombia, Malaysia, Taiwan, Italy, and Australia.

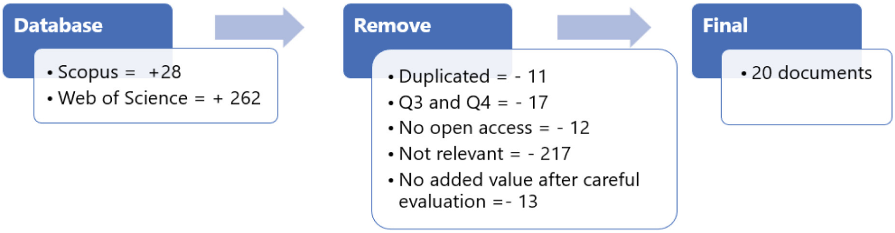

Fig. 1. PRISMA analysis

3 Results

It is possible to observe a growing trend in the publication of articles per year in this segment, as 80% of them were published in 2020–2022 (Fig. 2). Nevertheless, to accommodate the current and future delivery configuration, the articles still maintain the impacts of deliveries and the need for solutions and changes, within the scope of mobility, as a supporting actor in studies, and not as the lead protagonist. They highlight problems with the platform-base delivery personnel (9), their behaviour on traffic (16), road safety (15) and traffic conditions as the main objective, which may set the scene to point out vaguely about the urban mobility constraints in the document (Fig. 3).

The working personnel profile, behaviour and perspective is highlighted in some of the papers [2, 3], as a segment dominated by young males, who may be facing problems accessing the labour market, they usually are independent contractors paid by delivery and seeking to have the freedom to choose the day and time of work. Nevertheless, the idea behind platform workers having freedom and malleability during their work has been proven as fictitious, as companies are increasing daily control over their labour and dodging their employer obligations [2, 4, 5], especially when there is an algorithm management system which promotes lack of transparency, invisible managers, and limited control over work process, increasing the pressure over the workers and consequently their willingness of risk-taking actions, putting their lives and others in danger.

Based on the mobility practices of workers in the food delivery segment, the articles mentioned that they tend to prefer the use of bicycles and two-wheeled motorized vehicles around the world due to their speed, carrying out long hours of work on the roads using smartphones, finding themselves distracted when driving, and violating traffic regulations to meet their demands on time, by speeding, changing lines illegally, and driving in the opposite direction [2–8]. Understanding traffic conditions, driver behaviour and the environments they are subjected to is important for business success [9–13] and can implicate in more safety and efficiency.

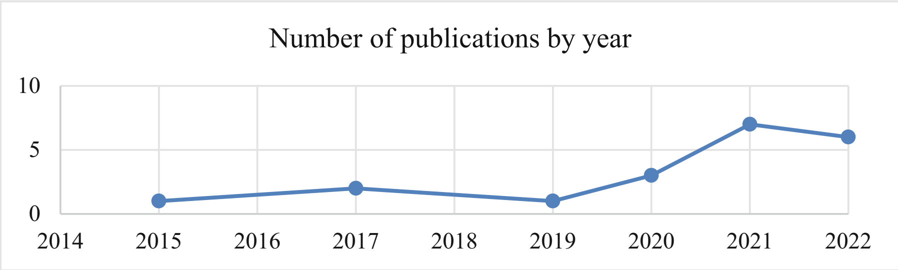

Fig. 2. Number of publications by year

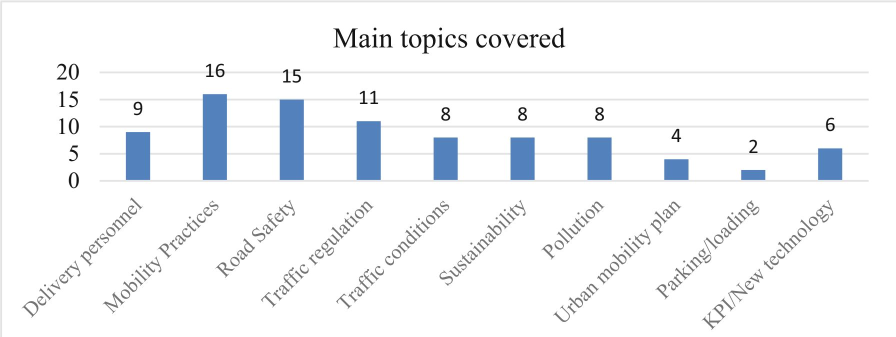

Fig. 3. Categorization of papers by topics covered.

Sustainability and pollution are stated as consequences of this work modality, as it is generating more congestion and pollution due to the increase on the number of workers and use of motor vehicles to speed the process [2].

A few studies indicate the linkage between food delivery services practices and demand with urban policies and plan. Regarding the policies, "city logistics measures are not easy implemented by local authorities, and readily accepted by stakeholders" [14], as there are different needs and expectations. It is essential to propose government traffic regulations to improve the safety of drivers and control delivery services business, as policymakers are not considering all the stakeholders (specially the delivery personnel) in their city decision-making [4, 5, 15–17]. It also highlights that the streets and cycling network can improve the delivery activity and make it less dangerous [2], by safeguarding the cycle lanes and adding advanced stop lines which will reduce the negative behaviour towards bicycle riders [3].

4 Discussion

Getting to know the profile, perspectives, and behaviour of the working personnel of these delivery services helps understand and research solutions for the problems caused by this sector. The consequences of lack of training and high life-threatening situations due to couriers working conditions, together with the carbon-footprint increase, endorses the exploration of new solutions such as bicycles and electric bikes, cargo-bikes and drones [6, 18, 19], assuming in great number as the answer for the mobility problems. Although, research about the urban mobility impact and consideration is left aside by many.

Thinking on a different scale, another actor involved in this process are the companies responsible for providing delivery services, which can help with the safety of their employees and road users, relieving time pressure on workers by reducing their burden on number of deliveries, making them more efficient, providing more human work and, consequently, helping the traffic system, as drivers can act less recklessly.

The inherent externalities of this last-mile logistic influences on the reduction of logistics spaces and road safety, increases the traffic congestions and carbon-footprint, and alter the urban mobility planning scope. It is important to bear in mind that the urban mobility infrastructure providing good traffic conditions, policies and regulations can act positively towards a more ideal scenario. For example, thinking on a cyclist perspective, it is crucial to have adequate regulation for road sharing and road safety, education on how to share streets, a positive attitude towards cyclists, and an infrastructure that prioritize the cyclists [7]. People's willingness to change consumption behaviour [20] and the practice of workers in carrying out their tasks plays an important role in achieving an urban planning that entails this boom in food delivery.

There is a need to focus on studies and attitudes that can bring changes to planning and regulating cities, assuming last-mile delivery is one of the most crucial logistic segments, the improved fit of food delivery trend in the mobility system is paramount.

5 Conclusion

Although this study contributes to the food delivery and urban mobility literature, it suffers from a few limitations, as we have used specific inclusion and exclusion criteria to select the academic literature for the review, limiting the generalisation of findings. Whilst we endorse interventions developed by researchers with the urban mobility in mind, it is time to contemplate urban mobility planning more holistically, avoiding the technological solutions and pillared approach that ignores the broader dimensions of urban mobility and its rebounds. As the research trend is leading us to solutions such as drones and route optimization, it is more urgent to focus on the mobility aspects (e.g. lack of infrastructure, improvement of green modes of transport), and logistic challenges (e.g. how to make it more effective and sustainable, in a regulated manner).

The extent impacts on urban mobility caused by food delivery remain uncertain, opening an array of unresolved research questions. To move forward, stakeholders must evaluate how best can the negative aspects be mitigated and the positive promoted, ensuring a good urban mobility environment. Researchers may investigate solutions that will be best suitable for this gig economy in a planning aspect, and the challenges behind implementing technologies on the urban mobility environment. Also, governments must take actions based on studies and data collection, to improve their regulation in a sense that includes and restricts the delivery personnel, promote learning channels, and implement good infrastructure to their cities.

References

1. Lord, C., et al.: The sustainability of the gig economy food delivery system (Deliveroo, UberEATS and Just-Eat): histories and futures of rebound, lock-in and path dependency. Int. J. Sustain. Transp. **17**, 490–502 (2023)
2. Aguilera, A., et al.: A digital work and urban delivery: profile, activity and mobility practices of on-demand food delivery couriers in Paris (France). Information **13**, 433 (2022)
3. Oviedo-Trespalacios, O., et al.: Risky business: comparing the riding behaviours of food delivery and private bicycle riders. Accid. Anal. Prev. **177**, 106820 (2022)
4. Fan, B., et al.: Online platform's corporate social responsibility for mitigating traffic risk: dynamic games and governmental regulations in O2O food delivery industry. Comput. Ind. Eng. **169**, 108188 (2022)
5. Moncef, B., Monnet Dupuy, M.: Last-mile logistics in the sharing economy: sustainability paradoxes. IJPDLM **51**, 508–527 (2021)
6. Li, C., et al.: Review of online food delivery platforms and their impacts on sustainability. Sustainability **12**, 5528 (2020)
7. Lachapelle, U., et al.: A framework for analyzing collisions, near misses and injuries of commercial cyclists. J. Transp. Geogr. **90**, 102937 (2021)
8. Lin, P.C., et al.: Spatial analysis of accidents involving food delivery motorcycles in Taiwan. Transp. Plan. Technol. **45**(4), 335–357 (2022)
9. Dong, H., et al.: The relationships between traffic enforcement, personal norms and aggressive driving behaviors among normal e-bike riders and food delivery e-bike riders. Transp. Policy **114**, 138–146 (2021)
10. Sinha, D., Pandit, D.: A simulation-based study to determine the negative externalities of hyper-local food delivery. Transp. Res. Part D: Transp. Environ. **100**, 103071 (2021)
11. Rusli, R., et al.: A comparison of characteristics between food delivery riders with and without traffic crash experience during delivery in Malaysia. Case Studies on Transport Policy **10**(4), 2244–2250 (2022)
12. Pan, S., et al.: Using customer-related data to enhance e-grocery home delivery. Ind. Manag. Data Syst. **117**(9), 1917–1933 (2017)
13. Xue, G., et al.: Optimization of rider scheduling for a food delivery service in O2O business. J. Adv. Transp. **2021**, 1–15 (2021)
14. Fancello, G., et al.: Investigating last food mile deliveries: a case study approach to identify needs of food delivery demand. Res. Transp. Econ. **65**, 56–66 (2017)
15. Fan, J., et al.: Food-delivery behavior under crowd sourcing mobility services. Journal of Traffic and Transportation Engineering (English Edition) **9**, 676–691 (2022)
16. Morganti, E., Gonzalez-Feliu, J.: City logistics for perishable products. the case of the parma's food hub. Case Studies on Transport Policy **3**(2), 120–128 (2015)
17. Wang, Z., He, S.Y.: Impacts of food accessibility and built environment on on-demand food delivery usage. Transp. Res. Part D **100**, 103017 (2021)
18. Kim, J.J., et al.: A change of perceived innovativeness for contactless food delivery services using drones after the outbreak of COVID-19. Int. J. Hosp. Manag. **93**, 102758 (2021)
19. Galati, A., et al.: Contribution to the sustainability challenges of the food-delivery sector: finding from the deliveroo Italy case study. Sustainability **12**(17), 7045 (2020)
20. Xie, J., et al.: Environmental impact of express food delivery in China: the role of personal consumption choice. Environ. Dev. Sustain. **23**, 8234–8251 (2021)

Monitoring and Assessing Heavy Traffic Loads: Feedback from French Initiative and Data Analysis

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Abstract. The usage of road networks by road freight transport has grown since the first generation of pavements and structures, it is still growing, and regulations concerning weights and dimensions have widely evolved. These developments might accelerate the wear of infrastructure, therefore costs for infrastructure maintenance, repair and strengthening increases. For a National Road Authority or road manager, these effects are obvious, although not easily monetized. To be able to make effective policy, it is very important that the information about these effects is understandable for policymakers, contains the correct details and that the costs are transparent with a certain degree of reliability.

To deal with this issue, Cerema -which is the French national institute for road maintenance and assessment- has proposed a new service for road managers, which is the comprehensive monitoring of traffic loads and/or structures. Depending on the needs of the infrastructure managers, the traffic loads are being recorded and analyzed, and some vulnerable infrastructure elements (bridge or pavements) can be instrumented for better assessment and residual life estimation.

This paper will detail this innovative technical solution, by focusing on the sensing techniques that are being used and the processed information that is provided to the NRAs. For that, the implementation on an existing, integral, concrete bridge will be described.

Keywords: Heavy traffic loads · Weigh-in-Motion · data analysis · re-assessment of structures

1 Introduction: Problem Statement and Proposed Solution

The usage of road networks by road freight transport has grown since the first generation of pavements and structures, and is still growing, and regulations concerning weights and dimensions have widely evolved [1]. For example, the transport sector has to reduce emissions to contribute to the reduction of global warming, which led in some countries to larger vehicles that carry more goods with relatively less fuel. But other measures to reduce emissions and measures to meet the shortage of truck drivers can also lead to an average higher vehicle weight, such as powertrains for alternative fuels or better

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loading to reduce the number of journeys. These developments might accelerate the wear of infrastructure [2], there-fore costs for infrastructure maintenance, repair and strengthening increases. For a National Road Authority or road manager, these effects are obvious, although not easily monetized. To be able to make effective policy, it is very important that the information about these effects is understandable for policymakers, contains the correct details and that the costs are transparent with a certain degree of reliability.

Numerous sensitive structures and infrastructures, which may be off-limits to the heaviest vehicles, are subject to conditions that exceed the conditions of use. These overloads are not without consequences: premature aging, inability to use, even collapse. By implementing preventive measures, infrastructure managers can considerably reduce risks and impacts.

With the help of traffic analysis and hazardous vehicle identification tools, guidance in decision-making on monitoring and protection measures is proposed:

- **Establish a diagnosis of the traffic using the (infra)structure:** identification of data and its caracteristics to be processed according to the structure and its condition, inventory of existing (traffic) data, initial analysis of the structure's situation,
- **Design a device for monitoring and measuring overload:** Proposal of a device adapted to the technical context and environment, definition of relevant indicators for maintenance of the structure, design of infrastructure instrumentation to quantify and/or anticipate disorders, proposal of an intervention program if disorders appear,
- **Assisting the road owner or manager in its management strategy, both of the infrastructure and the monitoring solutions:** support in defining the monitoring and protection strategy (information, education, repression, etc.), purchase and deployment of monitoring and operating equipment (installation, initialization control, maintenance), monitoring and analysis of indicators, capitalization of results and definition of a traffic monitoring policy, training for the usage of these monitoring tools.

It is in fact very important to provide both information and indicators on the traffic and its agressivity to the infrastructure (as it is the only possibility for traffic management and it is what road managers often work with) and information and indictors on the structural health of the infrastructure and its evolution (as it is the real, measured time-dependent impact of the traffic and other actions on the structure).

In the following, we will briefly describe the implementation of this technical solution on an existing, concrete bridge.

2 Example of Traffic and Structural Response Monitoring

The example which is presented here is linked to an issue encountered by the public road manager, Alsace Collectivité européenne: Indeed, they need to weigh and monitor the abnormal loads and their effects, which carry gas turbines from Belfort to the harbours of Alsace [3]. Indeed, Alstom and General Electric manufacture and export gas turbines, which represent a high economic value. Despite the measures taken in terms of passage of the abnormal loads, surrounding traffic management procedures and the reinforcement of bridges, the frequency and weight of these convoys (800 tons) have led to track deterioration.

It has therefore been proposed to identify and weigh the most aggressive convoys (which are generally those with more than 25.5 tons per axle) on a weighing station at Herrlisheim-près-Colmar.

On the basis of these analyses, and with a view to anticipating maintenance operations, an ageing rule for structures as a function of actual traffic, has been proposed, based on traffic and structural measures at a concrete bridge (Fig. 1).

Fig. 1. Bridge monitored in both loadings and structural effects.

This bridge, whose structural type is quite usual in France (over 5000 bridges of this type) shows a certain number of defects: extensive transverse cracking and discontinuous longitudinal cracks on the underside of the slab, inclined cracks on the intrados in the corners, presence of moisture, longitudinal cracks and “hollow-sounding” areas on the lower surface at free edges, cracking of abutments with presence of moisture, water seepage between cornice and slab flanks, east and west, and even through cornices, characterized by active calcite concretions and detachment or flaking of repair plaster, etc.

Therefore, the main recommendations during the periodic inspection has been to monitor the evolution of the cracks on the intrados and abutments (length and width), but also to monitor the opening of longitudinal and transverse cracks during the passage of an abnormal load.

To implement that dynamic weigh-in-motion stations have been installed both on the bridge and on the pavement ouside of it (Fig. 2), and several cracks are monitored by displacement sensors.

3 Traffic-Induced Damage Detection: Some Elements of Assessment and Prediction

Traffic monitoring has been proved to be quite a challenge, as current, commercial weighing systems are not supposed to deal with such high loads. Therefore the accuracy was not as good as expected (for “normal” traffic, the accuracy of conventional WIM systems is traditionally around $\pm$ 10% for GVW).

Fig. 2. Layout and installation of weigh-in-motion stations.

Nevertheless, it could be noticed that there is quite a disparity in terms of measured Gross Vehicle Weight (Fig. 3), axle loads and distance to the closest axle (Fig. 4).

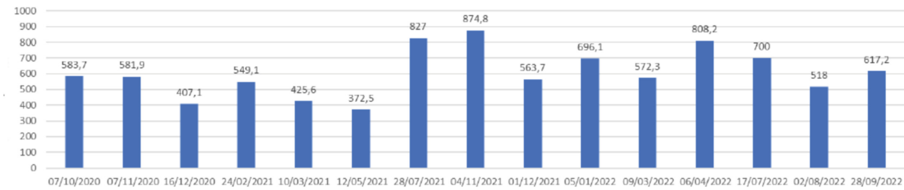

Fig. 3. Measured GVWs for individual abnormal loads.

Fig. 4. Measured axle loads with correspond axle distances (distance to teh closest axle).

When considering the opening of the cracks, it has been found, quite obviously that the effect of the temperature is the major component and needs to be removed (Fig. 5).

Moreover, after removing the effect of the temperature, the exponential effect of these abnormal loads is visible (Fig. 6): in fact, it has been shown that after some passages of abnormal loads, some cracks do not close anymore which means that the structure has reached its plastic limit.

The work is ongoing, and is dealing with in-time data analysis for abnormal load effect assessment and time series prediction, for guidance in terms of traffic and infrastructure management.

From a practical perspective, a link between the measured damage sign (crack width) and characteristics of the vehicle (GVW, axle loads, travel speed) has been assessed: as expected for this type of short-span structure, the GVW has little impact, but axle loads

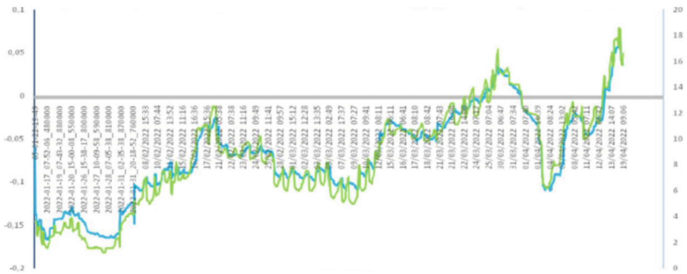

Fig. 5. Evolution of crack width (blue line) and temperature (green line) with time.

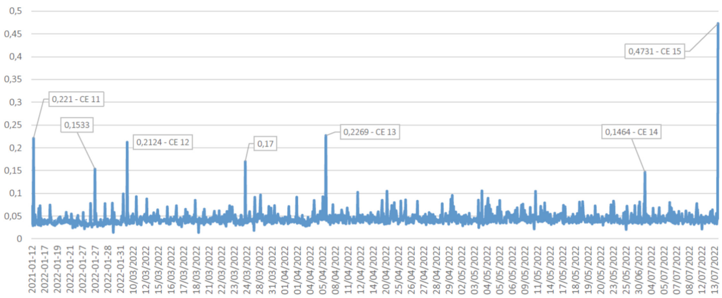

Fig. 6. Crack evolution in link with traffic loads

and travel speeds are important parameters to be monitored for global assessment of the wear of the structure (Fig. 7).

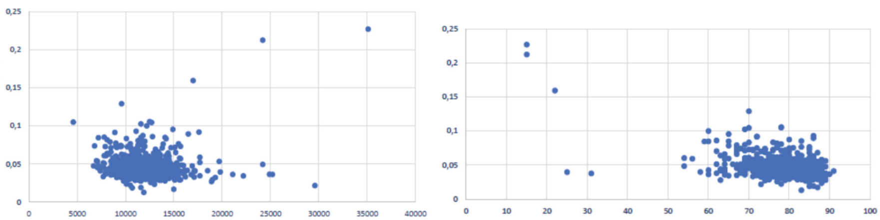

Fig. 7. Measured crack width as a fonction of the highest axle load of the vehicle (on the left, in kg) and the speed of the vehicle (on the right, in km/h).

4 Conclusion

Monitoring traffic and its influences on infrastructures is more and more needed today, because of the evolution of traffic loads and the ageing of the infrastructure. This paper has presented a technical solution, and some major conclusions that have been drawn.

Current works are linked to voluminous data analysis and time series prediction.

References

1. Schmidt, F., Jacob, B., Domprobst, F.: Investigation of truck weights and dimensions using WIM data. Transportation Research Procedia **14**, pp. 811–819
2. Zhou, X., Schmidt, F., Jacob, F.: Extrapolation of traffic data for development of traffic load models: assessment of methods used during background works of Eurocode, IABMAS2012. 6th Conference on Bridge Maintenance, Safety and Management
3. Aubert, G., Klein, E., Nicolle, M.: Réponse du Cerema à la surveillance et à la protection d'ouvrages sensibles et stratégiques dont les convois exceptionnels. ATEC ITS France (2023)

Road Freight Models to Accelerate Green Transition in Europe

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Abstract. Finland's aim is to halve transport emissions by 2030 and eliminating them completely by 2045. One of the ways to reduce freight transport emissions is by linking and analyzing characteristics, like general freight transport volumes, time management and energy generation and use, to generate a road freight model as a policy support tool to assess development towards the zero-emission goals. The purpose of this study is to understand how to integrate electric freight vehicles in the future national road freight model of Finland. The study answers questions on identifying the current road freight transport models, methods of road freight transport model development, their purposes, and including electric freight vehicles in road freight transport models. Through literature review, we found out that there are number of studies providing overviews about the freight transport modelling, but only a few, which consider the electric freight vehicles as a part of modelling. Freight transport models are mainly used to provide support for decision-making at national or regional levels, and model to understand the relationship between transportation and economic activity and connecting the traffic flows with the networks.

Keywords: Road Freight Transport · Electric Freight Vehicles · Green Transition · Freight Demand · Freight Transport Model

1 Introduction

There is now a sense of urgency to decarbonize the transportation sector. The transportation sector is the second highest greenhouse gas-producing area with a 24% share of CO2 emissions in year 2017 [13]. About 5.5% of the global GHG emissions come from logistics activity. 90% of this is generated by freight transport, of which two-thirds are produced by trucks and vans [14].

Transportation planning plays an important role in an economy, especially using macro-level planning techniques. For example, by including population figures, proper capacity planning can be conducted [13]. Additionally, modelling of the road freight transport is necessary, and is a part of future studies since it is about prediction and planning [13]. Some of the variables that can be included in modelling road freight transport are the average cost and distance of freight transportation, population, area, number of cities and villages, average household income, and GDP of the province [13].

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Through the method of literature review, our purpose is to understand how to integrate electric freight vehicles in the future national road freight model of Finland. We aim to identify and describe the existing road freight transport models and road freight traffic flows in different European countries. The study answers the following research questions: 1) What are the current road freight transport models? 2) How are the road freight transport models developed and for what purposes are they used? 3) How can electrified road freight transport be modelled to strengthen the green transition by adoption of electric freight vehicles?

2 Freight Models

Freight transport is a necessary part of the economic development of a region due to its role of moving goods [1]. Additionally, planning of road freight transport is very crucial in a country, and should include traffic flow on the roadway networks, as proper planning can lead to operational flexibility and availability [13]. It must be noted that inefficient logistics operations cause high costs to be incurred, which would in turn limit the growth and the competitiveness of an economy [7]. Furthermore, increase in traffic causes road congestions, which reduces the productivity of freight transport operations and also deteriorates the reliability of deliveries. The "sequential four-step model" for passenger transport planning was redefined for freight demand modelling as supply-demand (monitoring the economic activities), distribution (modelling freight flows from origin to destination), modal split (assigning the freight flows on different modes), and assignment (change freight flows to vehicle units and assigning them to networks) [6]. Freight transport modelling is associated with the following actors: producers make the goods to move, shippers manage the movement, carriers haul the goods on the roads, hauling companies handle their fleet on the roads, and consumers create demand for goods and thereby causing transportation demand [11]. Moreno-Quintero [10] argues that the road planner, who provides road repair and maintenance services, is also a significant actor.

3 Methodology

This research compiles studies on road freight transport models and gathers data to understand the current models, how they are developed, their purposes and how electrified road freight transport can be modelled to strengthen the green transition by adoption of electric freight vehicles. Using Scopus database, 52 papers were found through the use of the following keywords "Road freight", "transport", "traffic", "modelling", "model", "flow" and "density". This number of papers were narrowed to 15 when selecting the most relevant articles for this study.

4 Results

4.1 Road Freight Transport Models

Havenga, J. H [6] said that there are many national freight demand models that have been developed in Europe, and they are being recognized and used for different purposes. SAMGODS (the Swedish model) and the Norwegian model are the most famous ones [6].

The National Freight Model or NFM for Norway is a strategic transport network model [12] that optimizes shipment sizes, "transport chains (number of legs, selection of modes and vehicle types)" [12] and transit points to reduce associated costs. The model is composed of the following components [12]: Transport Demand (the commodity flow matrices, which is the total commodity flows between suppliers and end users, between municipalities), Network Model (infrastructure of all transport modes, showing transport distance, time, and location of terminals), Cost Functions (costs associated with transport distance, time, and functions for all transport modes), and Optimization (best possible choice based on shipment size, frequency, and mode to reduce associated costs).

The national transport model Austria (Verkehrsmodell Österreich, VMÖ) is examined by Grebe et el. [5]. This new VMÖ model consists of both passenger and freight parts, and it aims to model all the transport that is relevant for transport flows on Austrian infrastructure. The freight part of the model is an Aggregated - Disaggregated - Aggregated (ADA) model with following steps: the results of an input-output-model are transformed into firm-to-firm flows, the choice of shipment size and transport chain is modelled, and the origin-destination (OD) relations are aggregated for the individual modes and assignment to the networks. The ADA model has been implemented for Sweden, Norway, and Denmark as well. The resulting model outputs are generated trips (distinct OD-matrices for each mode, travel purpose, population group, etc.), the distribution of different key variables (time, distance, cost, etc.) and transport performance both for freight and passenger transport (tonne-kilometres, passenger-kilometres).

Stock-flow model (BIG) of the Norwegian vehicle fleet differentiates vehicles into 7 types, does not consider two-wheelers, considers only vehicles that drive on roads, and further classifies vehicles based on their powertrain technologies. The values that are input into the model are the vehicle class, powertrain technology and weight of the new vehicles from the base year until year 2050. The model generates the "annual vehicle stocks, vehicle kilometres driven, tonne kilometres hauled, energy consumption by powertrain" [12] and emissions.

In the European Union (EU), an integrated transport policy analysis tool, TRANS-TOOLS, was developed in 2004, which considered the Trans-European Transport Networks (TEN-T) development and policies related to sustainability, intermodality and decoupling. The use of this tool is to support transport forecasting, infrastructure planning and policy analysis. In 2015, the HIGH-TOOL was developed as a strategic high-level transport policy assessment instrument to analyze policy scenarios and is being supported by the TRANS-TOOLS [6].

4.2 Development and Uses of Road Freight Transport Models

The classic road freight transport model, which was redefined by De Jong et al. [6], is combined with spatial general computable equilibrium models, supply chain choice models, and hypernetwork models, in recent times [1]. In France, there is a domestic road freight survey (TRM) consisting of a poll on French trucks. Three types of information are asked: targeted information (location of loading, location of unloading, category of good transported, reported tonnes, reported tonne-kilometers), sampling information (statistical weight of each truck), and contextual information (age of the vehicle, the type of vehicle, activity of the transporter and region of registration) [2]. Havenga and Pienaar [8] proposed a methodology to create and apply national freight flow model for South Africa. The proposed methodology develops a comprehensive description of South Africa's surface freight flow market space based on the definition of four definitive freight flow market segments, and these segments are used to develop national road freight flows using the annual traffic counts.

Havenga [6] lists the purpose of national freight demand modelling as: to assess the impact of different transport policies, to form policies to use multi-modal network for freight transport optimally, to develop transport infrastructure and related policies, to conduct a cost-benefit analysis on decisions regarding transport infrastructure development, and to understand spatial location demand patterns. The road freight transport model helps to understand the schedule of the goods vehicle fleet, to solve logistics challenges, to conduct integrated planning for national infrastructure development, to assess the complete transport of goods and commodity flows, to improve vehicle utilization and fuel efficiency, and to shift to alternative transport modes and lower use of carbon fuels [7]. The future vehicle fleet requirements can also be estimated, which would allow better freight transport and environmental policy development, congestion planning, fuel demand- and oil-price estimation [7]. The model also helps the authorities to make informed decisions on investments in certain transport modes [7]. In South Africa, the annually gathered freight-flow information could be used to infrastructure planning, optimal network development and market structuring. The new South African model gives the total surface freight transport flows, which defines the trends in movement in various metropolitan areas and rural areas [8]. Gallo and Marinelli [3] used the road freight transport simulation model, to evaluate the impact on CO_2 emissions and fuel consumption of the introduction and development of fuel cell electric vehicles (FCEVs) for long-haul freight transport. The results highlight that the simulation model could be useful to identify the optimal locations for refueling stations, which require a detailed analysis of traffic flows and should be made at a regional level and with national coordination. Loder et al. [9] studied urban traffic modelling using the unique pNEUMA drone data set from Athens, Greece, to describe and shed light on urban freight operations. The data covered vehicle stopping frequency and loading and unloading stops. One of the aims was to provide information for decision-making processes in municipalities.

4.3 Green Transition by Modelling of Electric Freight Vehicles as Road Freight Transport

Studies have shown that a system level decarbonization of road freight is possible, but it requires many initiatives and time [12]. According to Rosenberg et al. [12], GHG emissions can be reduced by electrification and by using hydrogen as fuel for long-haul freight vehicles. This can be achieved by introducing strong policies (e.g., high CO_2-taxes), and developing new technologies in the field of batteries and hydrogen. Unfortunately, battery cost, it's gravimetric energy density and lifetime are the major disadvantages for battery electric trucks (BET) [12]. The disadvantages for fuel cell electric trucks are the fuel cell costs, hydrogen tank volumes and hydrogen prices [12]. Nevertheless, many vehicle manufacturers have planned manufacture of electric heavy-duty trucks [12]. Additionally, a good charging/ refueling infrastructure is also required to function the transport fleet. González Palencia et al. [4] studied the role of powertrain electrification in achieving deep decarbonization in road freight transport in Japan as a case study, using a vehicle stock turnover model and a scenario-based approach. The results of the study can help policymakers to understand powertrain electrification to reduce CO_2 emissions from road freight transport and consequently, help them to design policies to reach environmental targets and emissions reductions in the transport sector. They highlighted the requirement of cost and supply of electricity and hydrogen to achieve powertrain electrification in road freight transport.

5 Discussion and Conclusions

In this paper, we understand the current state of road freight transport models for the integration of electric freight vehicles. Firstly, the study examined the current road freight transport models, some of which we found from literature, are: the National Freight Model or NFM for Norway (a strategic transport network model to optimize transport operations and reduce costs), the national transport model of Austria called VMÖ, (to generate trip-related factors, variables, and transport performance), the Stock-Flow Model (BIG) from Norway (to generate annual vehicle stock, vehicle kilometers driven, tonne-kilometers hauled, energy consumption by powertrain, and emissions), EU's TRANS-TOOLS (an integrated transport policy analysis tool), and EU's HIGH-TOOL (a strategic high-level transport policy assessment tool to analyze policy scenarios). Secondly, the study explored the development of road freight transport models and found that the classic road freight transport model has been redesigned to combine spatial general computable equilibrium models, supply chain choice models, and hyper-network models. Thirdly, we investigated the purpose of road freight transport models to find that they are developed to assess the impact of policies, make decisions on transport infrastructure development, assess goods and commodity flows, estimate future vehicle fleet requirements, and plan to avoid congestions. Lastly, we delved into integration of electric freight vehicles in road freight transport to know that road freight transport models can be used for designing policies, planning for green technologies, calculating emission reduction, and estimating the cost- and planning the supply of electricity and hydrogen for the transport fleet.

The practical implication of this paper is that it gives information to authorities and other transport industry stakeholders, to plan the transition to electric freight vehicles. However, a limitation of this study is that there were only a few journal articles on integration of electric freight vehicles and road freight transport models. In the future, our aim is to create a national road freight transport model in Finland to facilitate green transition. This paper is part of the research project SIX HOVE (Sustainable industry X – Heavy on-road vehicles ecosystem), which is being conducted in Finland. The aim of the research project is to produce a roadmap for the promotion of electrification of trucks in Finland.

References

1. Arbués, P., Baños, J.: A dynamic approach to road freight flows modeling in Spain. Transportation **43**, 549–564 (2016)
2. Courtonne, J.-Y., Longaretti, P.-Y., Dupré, D.: Uncertainties of domestic road freight statistics: insights for regional material flow studies. J. Industrial Ecology **22**(5) (2017)
3. Gallo, M., Marinelli, M.: The use of hydrogen for traction in freight transport: estimating the reduction in fuel consumption and emissions in a regional context. Energies **16**(1), 508 (2023)
4. González Palencia, J.C., Nguyen, V.T., Araki, M., Shiga, S.: The role of powertrain electrification in achieving deep decarbonization in road freight transport. Energies **13**(10), 2459 (2020)
5. Grebe, S., de Jong, G., Wampera, C., Obermayer, C., Pompl, R.: VMÖ – a new strategic transport model for Austria. In: 47th European Transport Conference 2019. Transportation Research Procedia **49**, pp. 95–106 (2020)
6. Havenga, J.H.: National freight demand modelling: a tool for macrologistics management. The International Journal of Logistics Manage. **29**(4), 1171–1195 (2018)
7. Havenga, J.H., le Reux, P.P.T., Simpson, Z.P.: A heavy goods vehicle fleet forecast for South Africa. J. Transport and Supply Chain Manage. **12**, a342 (2018)
8. Havenga, J.H., Pienaar, W.J.: The creation and application of a national freight flow model for South Africa. J. South African Institution of Civil Eng. **54**(1), 2–13 (2012)
9. Loder, A., Otte, T., Bogenberger, K.: Using large-scale drone data to monitor and assess the behavior of freight vehicles on urban level. Transp. Res. Rec. **2676**(11), 496–507 (2022)
10. Moreno-Quintero, E.: Optimal control of road freight flows by route choice inducement: a case from Mexico. Eur. J. Oper. Res. **175**, 1588–1604 (2006)
11. Najaf, P., Famili, S.: Application of an intelligent fuzzy regression algorithm in road freight transportation modelling. Promet–Traffic&Transportation **25**(4), 311–322 (2013)
12. Rosenberg, E., Espegrena, K., Danebergs, J., Fridstrøm, L., Hovi, I.B., Madslien, A.: Modelling the interaction between the energy system and road freight. Transportation Research Part D: Transport and Environment, p. 114 (2023)
13. Yu, Z., Khan, A.R., Thomas, G., Jameel, K., Tanveer, M., Janjua, L.: Nexuses between international trade, renewable energy, and transport services: Leading toward practical implications and trade policies. Frontiers in Environmental Science (2022)
14. Kellner, F., Schneiderbauer, M.: Further insights into the allocation of greenhouse gas emissions to shipments in road freight transportation: the pollution routing game. Eur. J. Oper. Res. (2019)

Understanding the Success of Road Freight Decarbonization Strategies. A Case-Study from Spain

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Abstract. Road freight transport decarbonization is an important element in the global agenda. There is a large body of literature addressing operational research solutions and optimization. However, it is not clear whether the actual sector can be reactive to policies to promote its decarbonization. Even more when the sector is pressured by its clients and upstream supply chain trends, and seems not to have any room for enhancement. In order to further understand the sector's potential to improve its productivity, a system's dynamics diagram is developed. Moreover, an analysis of the Spanish road freight sector with quarterly data from 2000 to 2023 is carried out using a vector error correction model. Results suggest that the sector's productivity, in ton-km, is reactive in the long-term to diesel prices, by producing a lasting reduction ton-km. However, the long-term response to an increase in transport prices might increase the total ton-km.

Keywords: Road freight · system dynamics · error correction model · econometrics

1 Introduction

Road freight transport is both a contributor to GDP as well as to GHG emissions and climate change, making its decarbonization an important element in the global agenda. It has been largely researched and operational solutions to improve its productivity have been produced. However, it seems that it faces many barriers for it to improve its productivity. As [1] puts it, transport demand is described as having a derived nature in that the client does not receive any benefit from the transport itself. It is complementary, and necessary, to the economic activity it serves (connecting geographically separated economic agents).

The logistic efficiency and the energy efficiency improved, especially in the 1990s due to the allowance of heavier trucks. Since then, no major efficiency gains have been realized (according to [2]). In relation to that, based on literature review, 6 main challenges have been identified: asset utilization ([3, 4]) consolidation, the pressure of lead time and other supply chain trends ([3, 5, 6] and [7]) backhaul, fuel efficiency and its rebound effect ([8]) and incentives ([2] and [9]).

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The sector's performance being subordinate to the demands of its clients arises the question of what transport policies can help decarbonize road freight. To analyze this, this article first, using system dynamics, depicts the whole picture of the sector and derive conclusions the potential of pricing. Second, it carries out a Vector Error Correction Model (VECM) using time-series analysis for the Spanish sector quarterly data from 2000 to 2023 in order to assess the potential impacts of transport price and diesel price on productivity (ton-km), hence aid in decarbonization.

2 System Dynamics to Capture the Complexity of the Sector and Policy Implications

In view of the intricate position of the sector, system dynamics (SD) approach is suitable for investigating the effects of policies and strategies in complex systems ([10]). Figure 1 expands on the work of ([11, 12]) in SD in freight. In general, five big lines of causalities are found towards the sector's decarbonization. These are because of demand; because of infrastructure and road freight mode share; consolidation (optimization and load matching); and fleet engine efficiency; fleet sizing; and costs (marked loops 1 to 9).

For the purposes of this conference paper, loops 1, 1' and 1", all describe the balancing loops affecting the system's fuel consumption though consolidation and reduction of total distance travelled (either ton-km or veh-km), yet each channels ton-km decline through either empty running, average distance travelled and number of shipments, respectively.

Related to that, loops 3 and 4 help understand that demand is not affected through price. First, because it can be absorbed by the carrier (freight operator's profit margin) or because (loop 4) transport costs are balanced through an optimization of the system (consolidation, decline of empty mileage, etc.). These mechanisms are important to understand whether, through the subsequent econometric analysis, it is found that the sector's output indicators are not reactive to prices.

3 Time Series Analysis of Road Freight Productivity in Spain

Stemming from the system dynamics diagram an increase in the transport costs (variable), would result in a short-term decrease in the productivity indicator. In the light of this, the question is whether such decline lasts in the long-term. That is the long-term effects of consolidation through pricing mechanisms.

For this purpose, the observatories of road freight transport from the Spanish Ministry of Transport, Mobility and Urban Agenda (MITMA, [13]) provide the necessary data in quarterly periods since 2000. Relevant indicators have been plotted in Fig. 6. Ton-km, ton transported and ton supplied (fleet size indicator) fluctuated according to the 2007 crisis. On the other hand, productivity indicators decreased (ton/ton-supply) or remain constant over time (ton-km/ton-supply). With that, it can be concluded that in term of productivity per asset, the system has resulted in a loss of efficiency or productivity. Finally, both diesel and distribution price have been increasing steadily, diesel being more volatile. That is another indication of the system's ability to absorb price variations and not pass it to the customers (see 2008–2021 period) (Fig. 2).

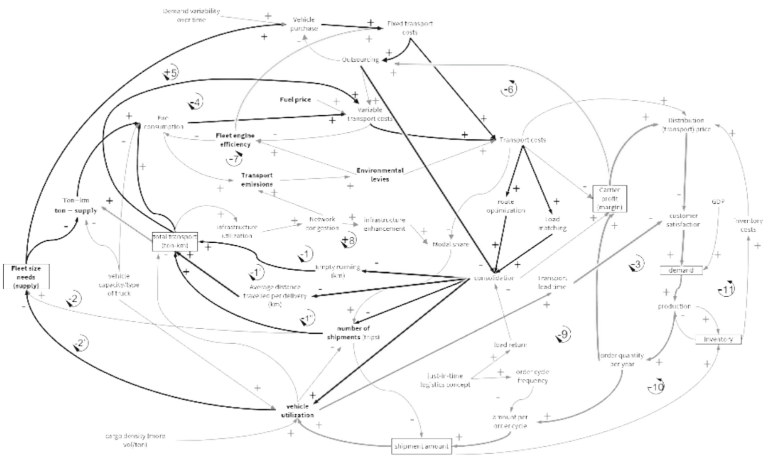

Fig. 1. System dynamics of road freight transport. Reinforcing loops marked with numbered circled arrows with positive sign, likewise for balancing loops market with a negative sign.

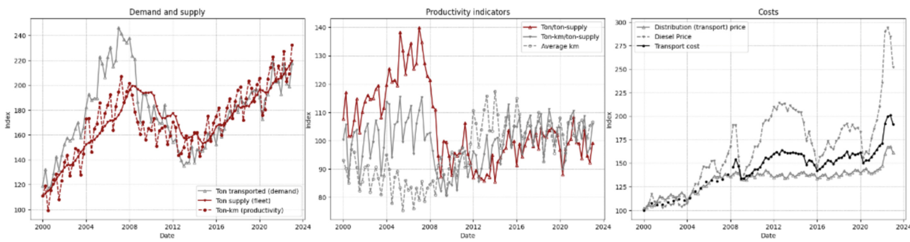

Fig. 2. Evolution of quarterly data of road freight indicators in Spain.

3.1 Vector Error Correction Model

In view of the above, this section will develop an error correction model to study the long-term relationship between variables. In particular, between ton-km, transported tons (as a demand indicator), diesel price and distribution (transport) price. Examples of ECM models are found in the literature for freight time series analysis ([1, 14–16]).

The Vector Error Correction model follows the formula in Eq. (1). In this case, it has a restricted trend with dummy variables correction for 2007 crisis (2007–2009), pos-crisis period (2009–2019) and COVID-19 period (2020–2023), given that the range of data is quarterly from 2000 Q1 to 2023 Q2. Vector $\boldsymbol{y}$ is composed of the variables mentioned above, and the error correction term is represented by the bracket component pre-multiplied by the adjustment coefficient $\boldsymbol{\alpha}$.

$$\Delta \boldsymbol{y}_t = \theta_0 + \phi t + \sum\nolimits_{i=1}^{n} \theta_i \Delta \boldsymbol{y}_{t-i} + \sum\nolimits_{i=0}^{n} \delta_i \Delta \mathbf{x}_{t-i} + \boldsymbol{\alpha}(\boldsymbol{\beta}' \boldsymbol{y}_{t-1} + \varepsilon + \tau t) + \mu_t \quad (1)$$

3.2 Results

All series are stationary of order I(1), the lag order is selected to 1 and the cointegration order is selected to be 3. With this specification the model passes the autocorrelation, heteroskedasticity, and residual normality tests.

Table 1 (model fit) shows that despite the beta coefficients of the three ECTs being significant, no alpha adjustment coefficient, neither for diesel price in the first equation, nor ton transported for the second or ton-km for the third long-term relationships are significant nor with correct sign (the product of α·β must be negative, [17]).

This is important as it suggests that the 3 cointegration equations expected cannot be found between solely ton-km and the rest of the variables. This could suggest that (in the 2000–2023 period), in the long-term, ton-km has not been affected neither by transport price nor diesel price. What this might suggest is that the equilibrium changes when there is a deviation from the equilibrium. This fact can be checked with the subsequent analysis of impulse response functions.

Table 1. Results and significance of the coefficients of the ECM $\boldsymbol{\beta}$ and adjustment vector α coefficients (p-value in brackets, *** $<$ 1%, ** $<$ 5%, * $<$ 10% and - $>$ 10%).

	$\beta1$	$\beta2$	$\beta3$
Ton-km	1	1	1
Ton transported	0	−0.55448(***)	0
Transport price	0	0	6.4776 (***)
Diesel price	0.35075(***)	0	0
Trend t_0	−0.011089(***)	−0.0029422(***)	−0.0345(***)
θ_1(constant 2007–2008)	−0.60167(***)	0.031388(-)	−2.2168(***)
Trend t_1 2007–2008	0.020205(***)	−0.00079838(-)	0.071446(***)
θ_2(constant 2009–2019)	−0.10667(***)	−0.016675(-)	−0.67722(***)
Trend t_2 2009–2019	0.0081310(***)	0.0013156(**)	0.029408(***)
θ_3(constant 2020–2023)	0.95696(***)	0.031896(-)	4.1499(***)
Trend t_3 2020–2023	−0.0044372(-)	0.00079930(-)	-0.028618(***)
	$\boldsymbol{\alpha}1$	$\boldsymbol{\alpha}2$	$\boldsymbol{\alpha}3$
Ton-km	−0.30633(***)	−0.75212(***)	−0.032087(-)
Ton transported	-	0.38082(-)	-
Transport price	-	-	−0.061016(***)
Diesel price	0.21746(-)	-	-

First, Fig. 8 shows how after an initial drop in ton-km when transport price increases, the long-term equilibrium shift to an eventual rise in the total ton-km. This might be explained because of the low effect of transport prices in the long-term that are overrun by the exogenous transport demand. Figure 10 might support that, showing that a rise in the transport prices has no effect on the demand of freight transport, but may even increase. Note, however, that the 90% confidence interval is close to zero implying that in reality there might be no effect (uncoupling of the two variables).

On the other hand, after a positive shock in diesel price, ton-km experience a rise that is quickly compensated for by a decrease in ton-km, presumably because of the pressure of truck operators to consolidate their operations (Fig. 3).

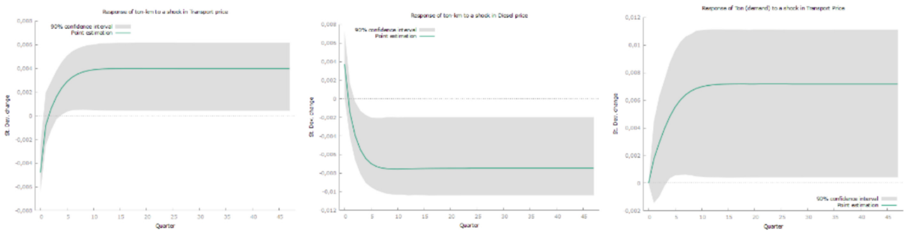

Fig. 3. IRF of productivity (ton-km) to a positive shock in transport price (left) and diesel price (middle). IRF of a positive shock in transport price upon ton transported (demand)

4 Conclusions and Policy Recommendations

This research has evaluated, through a vector error correction model (VECM), the impact of diesel and transport prices in the whole trucking industry (road freight) in Spain, from 2000 to 2023. From the statistical description of the sector's productivity indices, both mass occupancy (ton/ton-supply) and ton-km/ton-transported suggest that not only the productivity has not increased but it has decreased. This is in line with the literature position on the sector's subordination to its clients or upstream and downstream supply chain trends. Despite this, the VECM might indicate that the system's total production can be reactive to diesel price and transport prices.

Results suggest that changes in distribution (transport of cargo) prices and diesel prices might have a long-lasting response, as shown by the Impulse Response Functions analyzed. For instance, a positive shock in diesel price, after a short-term increase there is a shift to a new equilibrium where total ton-km are reduced. That is aligned with the system dynamics diagram developed where the trucking companies compensate for an increase in the transport cost by optimizing their operations under balancing loops. Secondly, an increase in transport prices, after an initial decrease in ton-km (perhaps due to a decrease in demand), demand might recover due to the exogenous economic conjuncture, carriers do not face pressure to consolidate the operations resulting in an eventual rise in ton-km.

In view of the above, it may be concluded that pricing policies on Diesel do have a positive effect because of the reduction of ton-km in the long-term. The consideration of such pricing policies must be taken with care, as the profitability of carriers must be ensured so that the sector does not become precarious. In particular, given that diesel prices are not passed to the clients as it is clear from the evolution of prices.

On the other hand, distribution (transport) prices do not turn out to be aligned with the reduction of ton-km. It means that the system dynamics of the sector and the other economic activity precursors do not have the power to transmit information to the clients and change their cargo requirements. It could be suggested that freight activity is, to some extent, uncoupled from transport prices. Consequently, demand management through pricing seems to have limited reach.

References

1. Bjørner, T.B.: Environmental benefits from better freight transport management: freight traffic in a VAR model. Transp. Res. Part D: Transp. Environ. **4**(1), 45–64 (1999)
2. Vierth, I.: Why do CO2 emissions from heavy road freight transport increase in spite of higher fuel prices? Energy and Environ. **1**, 259–276 (2016)
3. McKinnon, A., Edwards, J.: Opportunities for improving vehicle utilization. In: McKinnon, A., Cullinane, S., Browne, M., Whiteing, A. (eds.) Green Logistics: Improving the Environmental Sustainability of Logistics. Kogan Page Limited, London, United Kingdom, pp. 195–213 (2010)
4. Arvidsson, N., Woxenius, J., Lammgård, C.: Review of road hauliers' measures for increasing transport efficiency and sustainability in urban freight distribution. Transp. Rev. **33**(1), 107–127 (2013)
5. Cruijssen, F.: Horizontal collaboration: A CO3 position paper. (FP7-SST-2011-RTD-1–7.6) Deliverable D2.1 (2012)
6. Dekker
7. Kohn, C.C., Brodin, M.H.: Centralised distribution systems and the environment: how increased transport work can decrease the environmental impact of logistics. Int. J. Logist. **11**(3), 229–245 (2008)
8. De Jong, G., Schroten, A., Van Essen, H., Otten, M., Bucci, P.: Price sensitivity of European road freight transport–towards a better understanding of existing results. A report for Transport and Environment, 9012–1. SIGNIFICANCE (2010)
9. Vernon, D., Meier, A.: Identification and quantification of principal-agent problems affecting energy efficiency investments and use decisions in the trucking industry. Energy Policy **49**, 266–273 (2012)
10. Shepherd, S.P.: A review of system dynamics models applied in transportation. Transportmetrica B: Transport Dynamics **2**(2), 83–105 (2014)
11. Ghisolfi, V., Tavasszy, L.A., Correia, G.H.D.A., Chaves, G.D.L.D., Ribeiro, G.M.: Freight transport decarbonization: a systematic literature review of system dynamics models. Sustainability **14**(6), 3625 (2022). https://doi.org/10.3390/su14063625
12. Santarius, T.: Investigating meso-economic rebound effects: production-side effects and feedback loops between the micro and macro level. J. Clean. Prod. **134**, 406–413 (2016)
13. Observatorio del Mercado del Transporte de Mercancías por Carretera. MITMA. https://www.mitma.gob.es/recursos_mfom/32observatoriomercadomarzo2023v1.pdf. Accessed 10 Apr 2023
14. Wang, Z., Lu, M.: An empirical study of direct rebound effect for road freight transport in China. Appl. Energy **133**, 274–281 (2014)
15. Rodney, S.: Road transport energy demand in Australia. Energy Economics **17**, 329–339 (1995)
16. Khan, M.Z., Khan, F.N.: Estimating the demand for rail freight transport in Pakistan: a time series analysis. J. Rail Transport Planning & Manage. **14**, 100176 (2020)

17. Granger, C.W., Weiss, A.A.: Time series analysis of error-correction models. In: Studies in Econometrics, Time Series, and Multivariate Statistics, pp. 255–278. Academic Press (1983)

Implementing Sustainable Micro-Logistics Hubs for Innovative Physical Internet Urban Delivery Methods: The Bologna Case

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Abstract. Within the HORIZON EUROPE project URBANE, the Bologna Living Lab is implementing a measure listed in the Sustainable Urban Mobility Plan (SUMP): Nearby Delivery Area (NDAs), combined with a collaborative approach among logistics operators and the utilization of zero-emission vehicles. The NDA serves as a micro consolidation centre for the transhipment of goods from conventional vans to cargo bikes and/or light electric vehicles. The ultimate goal of this pilot project is to define guidelines for implementing low-impact and sustainable micro-logistics hubs for urban deliveries.

The paper provides an update on the ongoing implementation, with a description of the current state of the art and the incoming data from the deliveries operations.

Keywords: Sustainable urban logistics · Micro-logistics hubs · Nearby Delivery Area · physical internet · Collaborative logistics · Freight as a Service (FaaS)

1 Introduction

Microhubs play a crucial role in re-designing the last-mile delivery chains and enabling the use of light electric vehicles. These vehicles, while having shorter travel ranges compared to traditional diesel and petrol trucks, are well-suited for circulating in high-density city centres with narrow streets and limited space for loading and unloading activities [1]. Many pilot projects indicate that urban cycle logistics and microhubs concepts can be successfully implemented. These initiatives seems to offer a more viable alternative to Urban Consolidation Centres, but they might still face similar issues like low profitability and high dependence on public subsidies [2, 3].

As part of the HORIZON EUROPE project URBANE, the Bologna Living Lab is working towards implementing a measure outlined in the Sustainable Urban Mobility Plan (SUMP). This measure involves the establishment of Nearby Delivery Areas (NDAs) combined with a collaborative approach among logistics operators and the deployment of zero-emission vehicles. The primary objective is to create a low-impact solution that restructures last-mile deliveries by integrating the use of electric cargo tricycles and lockers as microhubs.

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The ultimate goal of this pilot case is to define guidelines for implementing sustainable, low-impact, and innovative micro-logistics hubs for urban delivery methods. These guidelines have the potential for significant replicability in other contexts due to the modular approach that allows for the activation of various services as needed.

This paper aims at the implementation of the pilot project in order to contribute to the lack of specific knowledge about the diversity of functions and special features of cycle logistics and related transshipment hubs, extensive urban planning regulations, and scaling of cycle logistics systems beyond pilot status.

2 Methodology

The pilot project in Bologna is analyzed as a case study, with two main phases. The first phase of the pilot deals with designing and planning the implementation. It has been running from December 2022 until January 2024.

To describe the main characteristics for the phase 1, the framework proposed by Katsela et al. in 2022 [2] is adopted. This framework focuses on microhubs typologies, and their distinctive features. It includes the following seven elements:

1. Microhub definition
2. Infrastructure and location
3. Last-Mile Fleet Composition
4. Operational Typology- focus on Shared Infrastructure
5. Stakeholder Partnerships
6. Public Support
7. Key and Value-Added Activities

2.1 Data Source

The second phase, focused the actual test of the microhubs and final deliveries, will run from February 2024 until August 2024 and it will provide a dataset with information such as the details of routes for deliveries, trip distances, and the use of the lockers. These data are not presented in the paper, however a presentation of the preliminary data will be available for the conference.

3 The Pilot Project in Bologna, Italy

The Living Lab will be implemented in the historical centre of the municipality of Bologna, with an area of about 4 km^2. The coordinates of the most important square (Piazza Maggiore) are 44.493889°, 11.342778°.

Bologna (387,842 inhabitants) is the regional capital of Emilia-Romagna region, located north-central Italy. The city is one of the main nodes of national and international transportation networks. Indeed, it has a direct access with the main motorways (A1 Milan-Naples, A14 Bologna-Bari, A13 Bologna-Padua) and with the regional and national rail networks (including high-speed one). The Bologna International Airport

(Marconi) and the railroad terminal (Bologna Freight Village, that is located in the territory of Bologna Metropolitan City) are classified as Core Nodes of three European Transport Corridors (Baltic Adriatic, Scandinavian Mediterranean, Mediterranean).

The municipality of Bologna has 387,842 inhabitants, of which 53,737 residents in the historical centre, namely the oldest part of the city that is included in the ring road system. Almost the entire road traffic in the historical centre is regulated by limited traffic areas. In the municipality of Bologna there are 6,866 active commercial businesses. Almost the 40% of the total amount of these businesses (2,656) are in the historical centre and 2.312 are included in the limited traffic areas.

The city aims to promote Freight as a Service (FaaS) and the physical internet approach in urban freight distribution, utilizing cargo bikes and vehicles with modular units to facilitate flexible, fast, and sustainable transhipment. For this pilot test, the city of Bologna adopts an omnichannel approach, enabling the flexible, shared, and optimized use of infrastructures primarily located in public spaces.

City planners are exploring the introduction of physical internet delivery methods and the potential future application of crowd shipping. The URBANE Project also supports the development of a Digital Twin of the micro-logistics hub network, using real-time data, which will aid in planning for public administrations and enable resilient and sustainable deliveries for operators.

The following subsections describe the pilot case based on the seven elements identified by Katsela et al. [2].

3.1 Microhub Definition

The microhubs are identified as part of the NDAs, where installing an automated parcel locker, remotely managed and monitored. Each locker has 45 slots, 135 in total for the three lockers.

3.2 Infrastructure and Location

The municipality has conducted the difficult task of identifying suitable locations considering the spatial constraints in dense urban environments. The medieval city's morphology posed limitations for logistics operations, characterized by limited curb space and a lack of available parking and loading facilities.

In determining the chosen locations, factors such as the site for loading/unloading and transhipment activities, whether at the curb, in public or private parking lots, had to be taken into account. These selected locations needed to allocate the required space while also ensuring minimal conflicts with nearby residents, institutions and shops, and adhering to efficiency criteria for optimizing last-mile operations.

As a result, three NDAs have been identified, indicated by a blue star is the microhub, for deliveries within the historic centre (Fig. 1).

3.3 Last Mile Fleet Composition

The final deliveries are carried out with electric pedal-assisted cargo tricycles, a 90 cm wide rear-wheeled tricycle with a carrying capacity of 90 kilos, a maximum battery

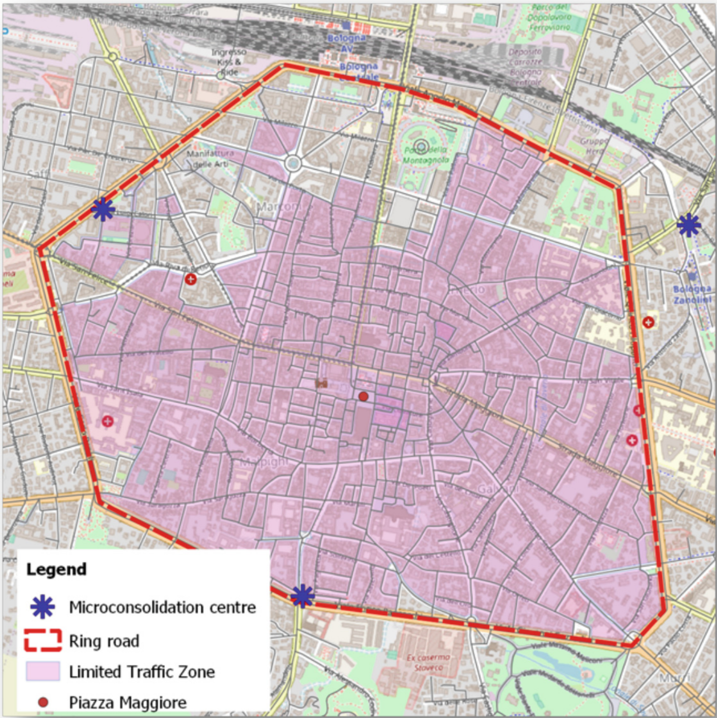

Fig. 1. Bologna's three microhubs. Image courtesy of the Horizon Europe project URBANE (grant no 101069782), reproduced with permission.

operating range of 100 kms, and the maximum speed for pedal assistance capped at 32 km/h. The vehicle provides real time tracking.

3.4 Operational Typology- Focus on Shared Infrastructure

The city of Bologna opted for a shared infrastructure for logistics operations. For the pilot project, the local authority has started the lease for three lockers, accessible to the three carriers involved in the test. The lockers are located in public land. The public authority has contracted private transport providers via tender for the final deliveries.

3.5 Stakeholder Partnerships

The strategy at city and metropolitan levels includes various stakeholders from the public, private sector, and civil society. In practice retailers, transport providers, society, residents, and end-receivers have been involved in the process of urban planning over the years. The SULP of Bologna already identified a permanent table for the development of the freight activities which is the Freight Quality Partnership (FQP). This working group is led by the City of Bologna and all the trade associations for shops and transport operators are members.

The partners involved For the pilot project, selected stakeholders have been involved, including the Institute for Transport and Logistics (ITL) to coordinate the technical activities; and Gel Proximity, the facilitator of data exchange between lockers (or delivery points). Its task is to provide the access to the NDA to the different transport operators and to the different last milers. This is done by using API which allows to connect different services to an open network of logistics deliveries. The transport operators involved are TYP and 2 Torri.

The partnership includes the Emilia-Romagna Region, OPEN ENLoCC, Trade associations, AICAI (Italian Air freight forwarders associations), DHL, FedEX, UPS, Etc., the Metropolitan City of Bologna, Enel X for the potential use of NDAs as recharging stations for electric vehicles. Moreover links to other cities of the region (e.g.: Ravenna, Piacenza, Modena, Reggio Emilia, Rimini) are established.

3.6 Public Support

The pilot project receives public financial support for operations at the startup phase, with the intention of phasing out subsidies as the centre generates enough market volume to create self-sustaining operations.

Moreover the city of Bologna has designed restricted access areas and emissions-based restrictions, with deliveries time windows.

3.7 Key and Value-Added Activities

The key activity linked to the pilot project is the opportunity to digitalize the NDAs use and to implement a booking system for the transhipment activities, which could be linked to the routing system to optimize trips. Moreover real time information on flows and quantity of freight will be available, combined with geolocalization of vehicles. This information is particularly important for the city in order to take decisions on the time windows of the Limited Traffic Zone and for the implementation of other urban freight related measures (e.g. night deliveries). The digitalization process must be accompanied by a relevant and detailed study on GDPR.

The identification of these areas and the use of EGNSS systems will also allow a more optimal use of the infrastructures, passing over the traditional booking system and using more innovative IT tools based on artificial intelligence.

The digitalization of the service can be done by using the digital solutions like as Blockchain technology or APIs: Indeed, considering that most deliveries are expected to be done through a cargo bike, it is important to consider also the social situation of riders. Bologna is the first EU city which implemented the "Carta dei diritti fondamentali dei lavoratori digitali nel contesto urbano" (Chart of the fundamental rights of digital urban workers, signed by the city of Bologna on gig economy) to which some web platform already joined. In this perspective, the aim is to protect the riders right by using digital registers which preserve the information and log all the pick ups and drop off from the NDA. This digital solution will also allow the unattended deliveries and pick ups to and from the NDA.

4 Final Remarks

Consolidation centers have typically encountered challenges such as low profitability and a strong reliance on government subsidies due to stringent regulations. The emerging trend of transitioning towards smaller hubs, like microhubs, represents an attempt to address these issues. This ongoing pilot project in Bologna aligns with the current trends and it has the goal to test a low-impact solution combining NDAs with automated lockers and light electric vehicles.

Various challenges are faced including the development and establishment of a business model for innovative delivery methods in urban areas [2]. In similar initiatives in European cities, players of the last mile deliveries have experienced the greatest levels of disruption and might have not financially benefitted from additional and costly transshipment operations in the urban core. Therefore it is even more crucial to foster collaboration among various logistics operators, including potential competitors in the sector, as promoted in Bologna.

Moreover reducing the distance travelled by traditional vehicles is crucial to mitigate negative externalities such as road congestion, noise, CO2, and pollutant emissions. This approach will enhance road safety and improve the quality of urban spaces. Furthermore,

References

1. Katsela, K., Güneş, Ş, Fried, T., Goodchild, A., Browne, M.: Defining urban freight microhubs: a case study analysis. Sustainability **14**(1), 532 (2022). https://doi.org/10.3390/su14010532
2. Janjevic, K., Ndiaye, A.B.: Development and application of a transferability framework for micro-consolidation schemes in urban freight transport. Procedia-Soc. Behav. Sci. **125**, 284–296 (2014)
3. Assmann, T., Müller, F., Bobeth, S., Baum, L.: Planning of Cargo Bike Hubs: A Guide for Municipalities and Industry for the Planning of Transshipment Hubs for New Urban Logistics Concepts; Otto von Guericke Universität Magdeburg: Magdeburg, Germany (2019)

Freight Demand Modeling for Green and Digital Logistics

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Abstract. Freight transport demand modelling (FTDM) from dispatch logs and partial observations play a key role in providing realistic expectations of freight transport needs and in assessing the environmental impacts of new policies. Shaping freight transport to answer the current challenges of green logistics – decarbonization, energy consumption optimization, intelligent and sustainable management – requires a continuous assessment and adaptation of the whole logistic system. Demand-centric models may support these ends. Understanding advances in freight modelling is thus crucial to overcoming FTDM challenges, including data scarcity. This paper provides two major contributions: i) a review of the state-of-the-art models on freight transport demand modelling, and ii) an integrated overview of how these models can support decision-making aligned with sustainability goals towards green (zero emissions) and digital logistics.

Keywords: Freight demand modeling · Green logistics · Digital logistics

1 Introduction

Freight demand models aim to provide a representation of how vehicles, goods, commodities (or other units of reference) move within a spatial network. Understanding these patterns involves the development of models that simulate the demand and supply for various transportation services, such as road, rail, air or sea. In the literature, two types of freight demand modelling are prevalent: Origin-destination and tour-based models [1, 2]. Origin-destination (OD) models aim to represent the flow between an origin and the final destination, while tour-based models estimate trip chains starting and ending at the same location (e.g., a single truck departs from a warehouse, distributes goods to a number of sites, and then heads back to the same warehouse). Regardless of the unit trip formulation, these approaches are a specialized aspect of transportation planning and analysis, crucial for providing valuable insights into the movement of vehicles/goods (e.g., supplier to consumer or supplier to warehouse), optimizing supply chains, and making informed decisions related to freight operations, logistics, and transportation policy. This paper aims to contribute with: i) a review of state-of-the-art freight demand models ii) their applications in aiding decision-making that aligns with sustainability objectives (Sect. 2) and discussion of future challenges associated with demand modelling in the context of decarbonization and digitalization (Sect. 3).

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2 Freight Transport Demand Models Applications: Insights from the Literature Review

2.1 Freight Origin-Destination Models

In the context of aggregate freight demand analysis, the four-step approach is still largely used for freight OD demand modelling [1, 4]. Due to the challenges in acquiring disaggregated trip data, including the fact that individual trip data is private, this method is still used in research [4]. By combining input assumptions and aggregated data (e.g. Direct survey of demand and supply), this model generates a set of trip tables that describe the major flows within a study area (by zone). Conventionally, the model is iteratively refined along the following four stages: i) trip generation, ii) trip distribution, iii) mode choice and, iv) trip assignment. The trip generation model estimates trips generated in each zone using socio-economic and land use variables as its first step [1–3]. Having attraction and production volumes, the trip distribution model disaggregates the data by assigning trips (or another reference unit) for zone-to-zone links. To this end, gravity models are a prevalent approach [1, 4, 6]. This model establishes trip frequency between i and j as proportional to the product of attraction in zone i and generation in zone j, adjusted by the distance or impedance function. For instance, Kalahasthi et al., (2022) include the weight of cargo transported from zones i to zone j. The mode choice model aims to distribute the trip flows between modes (e.g., private car, truck, rail), considering for instance market shares and shipment level [1, 3]. Holguín-Veras et al., (2021) provide qualitative insights by interviewing industry experts and found that freight rates and reliability are the primary determinants for mode choice. Although road mode was preferred, those interviewed were willing to switch to more sustainable modes. Furthermore, the research emphasizes the importance of using precise commodity information in the mode choice model. Consistent with this idea, Jensen et al. (2019) introduce a discrete model designed to estimate how freight transport chains are chosen in Europe, considering a multimodal transport chain (rail, sea and road) and different commodity groups (dry bulk, liquid bulk, containers and general cargo). Finally, the trip assignment model aims to assign the flows on each road or transit route based on the mode choice and trip distribution results. OD models can be also applied for commodity flow estimation. In this context, Kalahasthi et al., (2022) highlight that due to network asymmetry in commodity flow distribution, estimating empty trips is necessary. The commonly used approach for this estimation is the Noortman and van es' empty trips model [8].

2.2 Freight Tour-Based Models

In the context of freight transport and logistics, a tour-based model is a type of modelling approach that focuses on the representation and simulation of the movement of goods, shipments or vehicles in the form of "tours" [9]. Freight tour-based modelling is especially applied to urban freight transport systems where the vehicle needs to perform a sequence of activities and stops (e.g., last-mile delivery). Research has increasingly adopted tour-based modelling in transportation and logistics due to its ability to better simulate real-world scenarios [10–13]. By accounting for the complexities of multi-stop and multimodal trips, this shift allows researchers and decision-makers to effectively provide optimal planning (e.g., optimize routes, minimize cost, and reduce environmental impacts). To this end, GPS traces are collected and combined with survey data with activity information. For instance, Alho et al., (2019) and Venkadavarahan et al., (2020) acquired activity data through driver surveys, encompassing information like stop purpose, location, duration, and the amount of cargo handled. Indeed, tour-based models require higher data and computational capacity. However, as technology, sensorization initiatives, and data integration protocols advance, the advantages of employing tour-based models surpass these obstacles. Despite the limited data, advanced approaches have been proposed with the aim of effectively and comprehensively representing tour demand by considering several factors [10–13]. Venkadavarahan et al., (2020) focus on understanding and modelling complex tour-based freight movements of vehicles. It identifies driver and vehicle characteristics, estimates tour numbers and employs non-linear and soft computing models for predictions. Amongst these, neural networks outperform the peer machine learning models, offering valuable insights for transport planners and researchers. Moreno-Palacio et al., (2023) improve freight tour synthesis with fuzzy logic, addressing the variability of human behaviour that is overlooked in traditional entropy-based models. Fuzzy logic allows for a more flexible modelling approach, accommodating variations while nearing expected values. Alho et al., (2019) assess different model specifications for urban freight simulation, focusing on trip- and tour-based models for converting shipments into vehicle flows, using Singapore's vehicle operations data. Comi et al., (2021) provide a framework for simulating delivery tours, to demonstrate its effectiveness in generating freight distribution O-D matrices. The authors calibrated the model using GPS trajectory data from light goods vehicles in Italy. Within tour-based models, agent-based models have gained presence offering advantages when compared to the analytical demand models mentioned earlier [14]. Shippers, carriers, receivers and other actors in the freight transport and logistics ecosystem are modelled as agents that interact with each other, enabling them to simulate movements or actions in alternative policy scenarios. Besides the ability of each agent to learn and adapt, it is possible to evaluate spatio-temporal dynamics [15].

2.3 Transport Modeling for Green and Digital Logistics

OD models or tour-based models are indispensable tools that provide and guide decision-making processes for achieving environmentally responsible and technologically advanced supply chains [15–20]. In this context, we now provide a view of recent research that hinges on demand modelling and contributes towards green and digital logistics. Homayouni et al. (2022) introduce a sustainable logistics model that considers vehicle types and emissions in commodity transportation, favouring cap-and trade policies over carbon tax policies for more effective emissions reduction. Given the uncertainty of product demand, the previously mentioned authors provide a probabilistic approach that considers pessimistic, expected and optimal scenarios, along with assumptions such as a fixed carbon capacity and price during the time horizon. In a more dynamic spatial and temporal approach, Anand et al. (2021) simulate the delivery cap and price policy using an agent-based model, showcasing its potential to reduce vehicle travel and generate revenue for municipalities. Recent studies have focused on optimizing modal shift, route planning, and capacity allocation while considering sustainability goals. For example, Guo et al., (2022) calculate the carbon emission estimation considering the Well-to-Wheel and the Tank-to-Wheel perspectives for the hinterland-based container intermodal network (roads, inland waterways, railways, and sea). Two models are employed, i) an energy computation model that considers vehicle features during transportation and transfers, ii) a freight flow model that uses the gravity approach but assumes shortest routes and does not consider traffic congestion. Among the practical insights, Guo et al. (2022) advise optimizing container capacity, considering the cargo and multimodal network constraints. In this scope, effective commodity-based models are vital since they allow for the ahead planning of cargo combinations, reducing transportation resources and consequently, minimizing environmental impact and providing cost reductions. The vehicle routing problem (VRP) has been extensively studied, and emerging research is now integrating environmental considerations, advanced vehicles such as drones and autonomous robots, and multimodal options [17]. Another application of VRP appears in reverse logistics (RL) operations. In the scope of e-commerce, Lamba et al., (2019) identify the uncertainty of demand as one of the three topmost barriers for RL. Sar et al., (2023) emphasize the need for future research to integrate VRP with Industry 4.0 tools to mitigate demand uncertainty. With the introduction of greener fuel energy (e.g., electric, hydrogen, biofuel), freight demand modelling becomes pivotal, along with route optimization, infrastructure planning and energy provision. In the scope of electric vehicles, Vazifeh et al., (2019) contribute a novel data-driven approach to optimize the placement of EV charging stations in urban areas. The demand model estimates vehicle flows using “Call Detail Records” over 4 months. Spatiotemporal demand dynamics are crucial for strategically siting hubs for smart electric charging (or other green energy sources), accounting for freight vehicle constraints and power grid limitations.

3 Digital and Decarbonization Challenges

Table 1 serves as an overview of the referenced works, assessing their contributions to two key aspects: i) digitalization, which involves enhancing organizational and network efficiency and productivity through the integration of technology, and ii) addressing sustainability goals, particularly decarbonization [5]. In this literature review, we utilize the review by Kalahasthi et al. (2022) as a key reference while also incorporating the most noteworthy studies from the past three years (2019–2023) in the field. “Partial” category means that the work touches upon these topics but primarily suggests them as areas for future research. In the context of this analysis, ensuring the quality and availability of data emerges as a crucial concern [1–4, 6–8]. This entails the acquisition or estimation of crucial data points, such as trip details, energy consumption, and transportation modes used between attraction and generation zones. Efforts have been made to overcome the data limitations by developing algorithms that seamlessly integrate various data sources. The second significant challenge pertains to demand uncertainty. There is a need for dynamic demand modelling to accommodate both spatial and temporal variability. Despite the complexity of the freight transport and logistics ecosystems, agent-based modelling shows to be a promising approach in capturing complex interactions among stakeholders and dynamic variables in transportation systems [9, 10, 15]. Table 1 seems to indicate the need for multimodal models to accommodate interactions of stakeholders in transport markets while accounting for fuel emissions and other externalities across the whole supply chain, which will require collaborative approaches in logistics. As environmental-related concerns and policies evolve, freight demand models need to be adaptable and open to new socioeconomic dynamics. Several studies outline the need to tackle challenges related to green vehicle routing, reverse logistics, and optimizing supply chains in line with sustainability goals [18–20]. Further research is being conducted within the EU funded project ADMIRAL to assess needs of companies/stakeholders for greener approaches to logistics with enhanced models to support decision making.

Table 1. Reviewed studies: decarbonisation and digital logistics issues addressed (yes/no).

Studies	Freight transport mode (road/rail/maritime)	Model or Problem type	Digital logistics Yes/No/Partial	Decarbonisation Yes/No/Partial
[18]	Road	VRP	Partial	Yes
[1]	Road/Rail	GM and DC	No	No
[6]	Road/Rail/Sea	GM	Yes	Yes
[4]	Road	GM	Yes	Partial
[16]	Road	OP	Yes	Yes
[3]	Road/Rail	DCM	Yes	Yes
[8]	Road	ETM	Partial	Partial
[15]	Road	ABM	Yes	Yes
[11]	Road	SCM	Partial	No
[20]	Road	OP	Yes	Yes
[10]	Road	ABM	Partial	No
[7]	Road/Rail/Sea	DCM	No	No
[2]	Road	EMM	Partial	No
[9]	Road	ABM	No	No

VRP: Vehicle Routing Problem; GM: Gravity model; DCM: Discrete-choice Model; EMM: Entropy maximization model; SCM: Soft computing models; OP: Optimization Problem; ETM: Empty trips model; ABM: Agent-based model; SCM: Soft computing models.

4 Conclusion

This work explores advances in freight OD models and freight tour-based models (FTDM) and their alignment with sustainability goals in decision-making. Among the advancements in demand modeling, agent-based models are promising, as they may integrate real-world data, support sustainability and simulate interactions between agents (e.g. suppliers, carriers). With the integration of Industry 5.0, demand models can be enhanced and integrated with social and environmental sustainability aspects (e.g., low/zero emissions) and promote self-adaptive and collaborative logistics, while optimising supply chains. Algorithms to reduce demand uncertainty will prospect future research on current challenges related to sustainability in freight logistics.

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References

1. Kalahasthi, L., Holguín-Veras, J., Yushimito, W.F.: A freight origin-destination synthesis model with mode choice. Transportation Research Part E: Logistics and Transportation Review **157**, 102595 (2022)
2. Sánchez-Díaz, I., Holguín-Veras, J., Ban, X.J.: A time-dependent freight tour synthesis model. Transportation Research Part B: Methodological **78**, 144–168 (2015)
3. Holguín-Veras, J., Kalahasthi, L., Campbell, S., Gonzalez-Calderon, C.A., Wang, X.C.: Freight mode choice: results from a nationwide qualitative and quantitative research effort. Transportation Research Part A: Policy and Practice **143**, 78–120 (2021)
4. Malik, L., Tiwari, G., Biswas, U., Woxenius, J.: Estimating urban freight flow using limited data: The case of Delhi, India. Transportation Research Part E: Logistics and Transportation Review **149**, 102316 (2021)
5. Raza, Z., Woxenius, J., Vural, C.A., Lind, M.: Digital transformation of maritime logistics: exploring trends in the liner shipping segment. Computers in Industry **145**, 103811 (2023)
6. Guo, X., He, J., Lan, M., Yu, H., Yan, W.: Modeling carbon emission estimation for hinterland-based container intermodal network. J. Clean. Prod. **378**, 134593 (2022)
7. Jensen, A.F., et al.: A disaggregate freight transport chain choice model for Europe. Transportation Research Part E: Logistics and Transportation Review **121**, 43–62 (2019)
8. Gonzalez-Calderon, C.A., Holguín-Veras, J., Amaya, J., Sánchez-Díaz, I., Sarmiento, I.: Generalized noortman and van es' empty trips model. Transportation Research Part A: Policy and Practice **145**, 260–268 (2021)
9. Hunt, J.D., Stefan, K.J.: Tour-based microsimulation of urban commercial movements. Transportation Research Part B: Methodological **41**(9), 981–1013 (2007)
10. Romano Alho, A., Sakai, T., Chua, M.H., Jeong, K., Jing, P., Ben-Akiva, M.: Exploring algorithms for revealing freight vehicle tours, tour-types, and tour-chain-types from GPS vehicle traces and stop activity data. J. Big Data Analytics in Transportation **1**(2–3), 175–190 (2019)
11. Venkadavarahan, M., Raj, C.T., Marisamynathan, S.: Development of freight travel demand model with characteristics of vehicle tour activities. Transportation Research Interdisciplinary Perspectives **8**, 100241 (2020)
12. Moreno-Palacio, D.P., Gonzalez-Calderon, C.A., López-Ospina, H., Gil-Marin, J.K., Posada-Henao, J.J.: Freight tour synthesis based on entropy maximization with fuzzy logic constraints. Transportation, pp. 1–35 (2023)
13. Comi, A., Nuzzolo, A., Polimeni, A.: Aggregate delivery tour modeling through AVM data: experimental evidence for light goods vehicles. Transportation Letters **13**(3), 201–208 (2021)
14. Anda, C., Erath, A., Fourie, P.J.: Transport modelling in the age of big data. Int. J. Urban Sci. **21**(sup1), 19–42 (2017)
15. Anand, N., van Duin, R., Tavasszy, L.: Carbon credits and urban freight consolidation: an experiment using agent based simulation. Res. Transp. Econ. **85**, 100797 (2021)

16. Homayouni, Z., Pishvaee, M.S., Jahani, H., Ivanov, D.: A robust-heuristic optimization approach to a green supply chain design with consideration of assorted vehicle types and carbon policies under uncertainty. Annals of Operations Research, pp. 1–41 (2021)
17. Taniguchi, E., Thompson, R.G., Qureshi, A.G.: Modelling city logistics using recent innovative technologies. Transportation Research Procedia **46**, 3–12 (2020)
18. Sar, K., Ghadimi, P.: A systematic literature review of the vehicle routing problem in reverse logistics operations. Computers & Industrial Engineering, 109011 (2023)
19. Lamba, D., Yadav, D.K., Barve, A., Panda, G.: Prioritizing barriers in reverse logistics of E-commerce supply chain using fuzzy-analytic hierarchy process. Electron. Commer. Res. **20**, 381–403 (2020)
20. Vazifeh, M.M., Zhang, H., Santi, P., Ratti, C.: Optimizing the deployment of electric vehicle charging stations using pervasive mobility data. Transportation Research Part A: Policy and Practice **121**, 75–91 (2019)

Road Freight Electrification: Digital Model for Fleet Depot Electric HGV Charging Infrastructure

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Abstract. Charging infrastructure is a significant investment on top of the purchase cost of electric HGVs, therefore decisions to minimise the charging infrastructure requirements, meanwhile future proofing options for maturing technology, need to be informed by computer simulation that will build confidence and facilitate the evaluation of various options.

This paper describes the investment challenges and use of a new digital model for computer simulation of fleet depot based electric HGV charging infrastructure. This enables the evaluation of fleet and infrastructure technical options, provides costs for investment decisions, and guides operational planning.

Keywords: Sustainable freight and logistics · Electric HGV · Charging infrastructure · Depot operations · TCO · Digital model · Simulation

1 Background

1.1 Challenging Business Case

The environmental imperative for HGV electrification is established, with European governments moving to ban the sale of new non-zero emission goods vehicles [e.g., 1, 2]. However, there is unclear economic and operational viability making the business case for HGV electrification particularly challenging for fleet operators.

Electric HGVs are approximately three times the cost of equivalent diesel vehicles. Meanwhile, fleet operators also need to plan electric HGV recharging facilities at depots, adding significant infrastructure investment cost.

1.2 Prior TCO Research

Prior total cost of ownership (TCO) studies suggest electric HGVs can reach parity with diesel HGVs by end of life, but recharging infrastructure costs are often skipped.

Ledna et al. [3] explored long-term scenarios for total cost of driving (TCD), on the basis that public access recharging infrastructure will develop to meet demand. Wang, Z. et al. [4] addressed vehicle rather than recharging infrastructure cost. Wang, G. et al. [5] also studied TCD, introducing penalty costs for dwell time lost to recharging.

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