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The URBANE Innovation Transferability Platform: Learnings for Decarbonising Last-Mile Delivery Networks

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Abstract. Logistics plays a crucial role in modern society, particularly in densely populated urban areas, facilitating the transportation of goods. Last-mile e-commerce deliveries are emissions-intensive, contributing significantly to CO₂ levels and traffic congestion. Addressing this challenge requires systemic changes in last-mile delivery ecosystems. Based on this observation, in alignment with the EU decarbonisation goals, the URBANE project (GA101069782) aims to promote the adoption of sustainable and environmentally friendly last-mile delivery solutions by introducing a collaborative layered “Platform as a Service” (PaaS) paradigm. The initiative focuses on establishing Physical Internet (PI) inspired interventions combined with **the implementation of** innovative tools, such as agent-based and AI models, **employing** a Digital Twin platform addressing the operational and strategic planning challenges of city logistics networks. A multi-factorial impact assessment radar further enhances the evaluation of the PI interventions’ effectiveness. The platform fosters collaboration among urban logistics stakeholders governed through “green” smart contracts, addressing security and privacy concerns **by using a** blockchain infrastructure and digital IDs, **creating a trustworthy system for collaboration.**

The paper showcases the applicability of the URBANE Innovation Transferability Platform in designing, measuring, testing, and validating targeted logistics interventions in Lighthouse Living Labs. Cities and logistic operators receive suggestions for informed data-driven decision-making coupled with integrated and

transferable applications that can be standardised and structured, aligned with the targets set in a city's Sustainable Urban Logistics Plan (SULP).

Keywords: Last mile logistics · decarbonisation · collaboration · Physical Internet

1 Introduction

In response to the urgent calls of the Paris Agreement, governments, associations, and businesses worldwide are stepping up their commitments to ambitious climate targets. Within this global context, the European Union has set an ambitious goal through its European Green Deal: to transform into the first climate-neutral continent by 2050. To that end, CO₂ emissions must be significantly reduced, with targets aiming for a 50% reduction, if not 55%, by the year 2030. However, the current pace of transitioning to greener freight vehicles and low-emission energy solutions may not be sufficient to meet these formidable targets.

Given the urgency of the situation, there is a growing emphasis on optimizing logistics efficiency as a crucial component of the transition. This involves leveraging idle transport and storage assets and streamlining logistics flows to enhance overall industry efficiency. Furthermore, the implementation of open and interconnected logistics networks, inspired by innovative approaches such as Platform as a Service (PaaS) derived from the principles of the Physical Internet (PI), holds promise in maximizing capacity utilization to address both present and future demands. By prioritizing efficiency-driven value creation, the aim is to accelerate the transition to greener operations, contributing significantly to the collective effort in combating climate change.

The remaining of this paper is organized as follows: Sect. 2 presents the Physical Internet (PI) inspired interventions employed in URBANE's Living Labs, detailing the innovative approaches and their initial outcomes in various European cities. Section 3 describes the URBANE Innovation Transferability Platform, emphasizing its technological underpinnings and the operational benefits it offers to urban logistics. This section also explores the collaborative governance and security measures implemented to foster trustworthy partnerships. Section 4, reflects on the successes and challenges of the URBANE project, discussing the potential for scalability and replication of the PI approach across different urban environments. The paper concludes with an analysis of the impact of these innovations on urban logistics, supported by data-driven evaluations from the project's interventions. Throughout, the paper highlights the significance of collaborative efforts in achieving sustainable urban logistics, aligning with broader European sustainability targets.

2 Utilization of Physical Internet (PI) Inspired Interventions in URBANE LLS

In urban logistics, modular approaches involve dissecting intricate logistics networks into smaller, adaptable units to better suit urban requirements. This approach aims to optimize urban logistics by introducing eco-friendly and economically viable solutions.

The key advantage lies in its flexibility, allowing for tailored logistics solutions to address specific urban challenges. However, challenges include integrating new models into urban environments and planning for shorter delivery distances. The introduction of the Physical Internet paradigm and connected technological advancements are driving a shift towards integrated multi-modal delivery networks enhancing supply chain efficiency driven by real-time data.

Following these trends, URBANE introduced several innovations in the first four (4) Living Labs (LLs) including shared infrastructure (e.g., lockers and urban consolidation centers) and new delivery models and services through shared resources and networks. These innovations were a result of a co-development phase initiated at the start of the project that has led to the formulation of several use cases aimed at addressing multifaceted city challenges, as follows:

- Bologna LL tests micro hub networks and light EDVs to define a guideline on how to implement sustainable, low-impact and innovative micro-logistics hubs to be used for innovative delivery methods in urban areas. The guidelines would have a great impact in terms of replicability in other contexts, thanks to the modular approach which allows to activate several services or only some of them. The tested Use Case has the ambition to promote the Freight as a Service (FaaS) and the physical internet approach in the urban freight distribution, thanks to the use of vehicles with modular units able to make the transshipment flexible, fast and sustainable.
- Helsinki LL introduces Autonomous Delivery Vehicles (ADVs) into the last mile delivery. Its objectives include piloting diverse delivery methods, testing deliveries for businesses and consumers across various goods and areas, and experimenting with consolidation micro hubs to optimize efficiency. By collecting valuable data and embracing multimodal solutions, the LL aspires to reshape urban logistics for a greener, more efficient future in Helsinki.
- Thessaloniki LL implements a strategic initiative integrating a Hub & Spoke delivery model with last-mile delivery services through micro-fulfilment centers. These centers, located on the historical center, will optimize operational efficiency and enhance customer satisfaction by reducing vehicle usage and improving load factors. The ultimate goal is to create a scalable ecosystem facilitating the transition towards climate-neutral last-mile logistics and finalizing the Regional Sustainable Urban Logistics Plan (SULP).
- Valladolid LL seeks to enhance the efficiency of loading and unloading areas to improve urban goods distribution sustainability, organization, and effectiveness. It also encourages the use of fully electric vehicles for transporting small goods. Furthermore, the city targets to enhance pedestrian safety by integrating intelligent systems into various delivery vehicles, contributing to a safer urban environment.

The interventions mentioned above are undergoing thorough evaluation to assess their social, environmental and efficiency impact on the urban landscape. This assessment will serve as valuable input for the upcoming phases of Living Lab initiatives in Karlsruhe and Barcelona. These cities, using the Innovation Transferability Platform toolset as presented in the following sections, will examine the potential transferability of these interventions, tailoring them to address their unique challenges and requirements. By scrutinizing interventions' effectiveness in diverse urban contexts, the URBANE project

aims to assist cities on EU level to refine and adapt strategies to optimize their last-mile delivery networks. This iterative process ensures that lessons learned, and successes achieved in one city can inform and inspire innovations in others, fostering a collaborative approach to urban logistics that prioritizes sustainability, efficiency, and adaptability.

3 URBANE Innovation Transferability Platform

The URBANE Innovation Transferability Platform (ITP) offers last-mile delivery solutions to a plethora of communities and actors – i.e., logistics industry actors, city stakeholders, policy makers, and scientific experts - through a cloud-based infrastructure that utilizes state-of-the-art technologies such as Distributed Ledgers and Digital Twins (DT). The developed solution follows the Platform as a Service (PaaS) paradigm, thereby offering practical as well as economic benefits to the beneficiaries through the elimination of important obligations, such as infrastructure deployment, maintenance, and licensing [ref. 9].

Figure 1 presents the container diagram of the ITP. The diagram depicts the internal components or containers that make up the Platform and highlights their relationships, interactions, and dependencies. The most central component of the ITP is the URBANE Digital Twin (DT), which interacts with all other components, namely: (i) the domain-specific DT Applications, (ii) the Blockchain Service, (iii) the Data-Driven Impact Assessment Radar, and finally the modelling containers, i.e., (iv) the ABM models and the (v) AI driven and linear optimization models. The diagram also illustrates how different user roles interact with these services.

The DT is a domain-agnostic platform that consists of two key components. First, a Big Data Infrastructure that enables the ingestion, processing and storage of both real-time and batch data employing various streaming and processing technologies – such as Apache Kafka, Spark and so on- and acts as the integration point with the Block-chain Service. Secondly, a Model Execution Engine, powered by Apache Airflow, that offers scheduling, execution, and monitoring of digital models in a standalone manner but also as sequences of models - a.k.a., model workflows.

A dedicated DT Portal that can be accessed via a web browser provides users, especially modelers, with advanced configuration functionalities, such as the dynamic creation of model workflows, allowing them to create their own “*what-if*” scenarios through the custom configuration and execution of models integrated and available in the DT.

In URBANE, the scenarios utilize the ABM and AI models developed in the project and serve as the *Model Library* of the ITP. Models are integrated in the DT and included in the Model Library following a methodical integration process – either as open-source components or available via API, which in turn makes them applicable in the Wave 1 Living Labs but also transferable to a variety of logistics use cases.

The DT empowers users with data-driven decision making by simulating complex last-mile scenarios in an urban setting. This is particularly enhanced through the utilization of domain-specific and ready-to-use applications that are developed on top of the DT. These web-based applications support the design of scenarios tailored to specific use cases through intuitive configuration capabilities. The applications enable decision

Container Diagram for URBANE WP3
The container diagram for the URBANE Innovation Transferability Platform

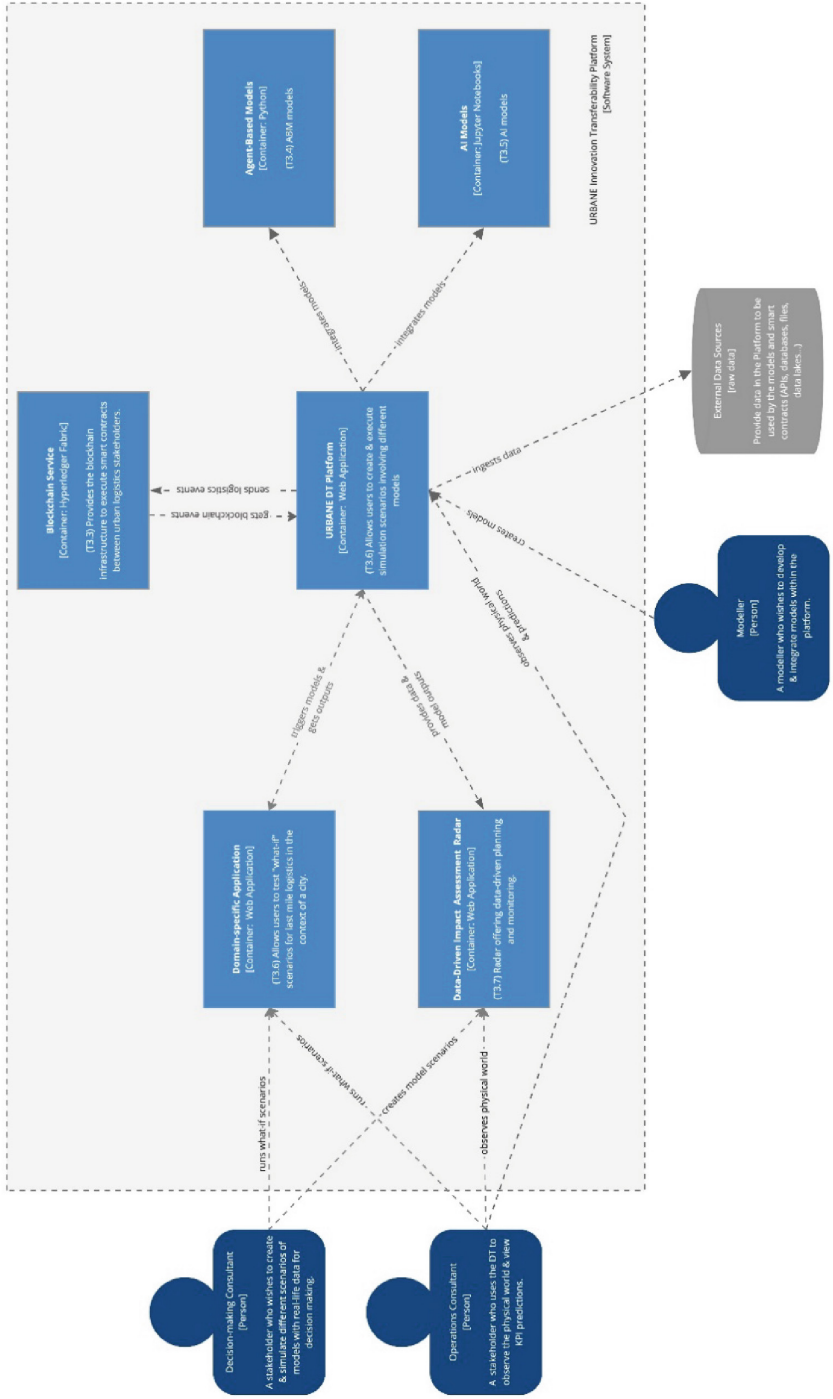


Fig. 1. Container Diagram of URBANE Innovation Transferability Platform.

makers to explore different “*what-if*” scenarios in each use case, which in turn empowers them to understand the impact of potential interventions in the short term but also in the long run.

3.1 Model Library: Agent-Based and AI Models

Last-mile logistics systems, comprising diverse interconnected actors, involve complex interactions and interdependencies. Despite the shared goal of delivering goods efficiently, conflicts of interest might emerge among stakeholders as each actor prioritises individual interests over overall system efficiency (Anand, 2015; Robenek, Maknoon, Azadeh, Chen, & Bierlaire, 2016). In response, organisations within the URBANE ecosystem are exploring innovative solutions, ranging from drone deliveries to autonomous vehicles and novel logistics platforms, aiming to optimise efficiency and meet evolving consumer demand. However, the interconnected roles of stakeholders, at times in competition, pose challenges to the long-term economic and financial sustainability of such initiatives (Zenezini, van Duin, Tavasszy, & De Marco, 2018).

While existing studies have explored various modelling techniques to understand the economic feasibility and the overall impact of last mile delivery (LMD) services, they generally emphasise business perspectives rather than user acceptance of a service. Agent-based Modelling (ABM) presents a distinctive approach that holds promise in addressing various challenges in LMD systems, surpassing the limitations of traditional methodologies (Comi, Donnelly, & Russo, 2014; Macal, 2016). This approach is particularly relevant in addressing challenges such as traffic congestion, rising operational costs, and environmental concerns associated with last-mile deliveries. To this end, we developed an organization-centric agent-based modelling approach to model the individual interactions of human (user of the services) agents and logistics components of the LMD. By introducing generic agents and associated roles, we aim to generalise the modelling of LMD systems. Our generic approach can facilitate the structure of stakeholders—in other words, agents—making the roles of the agents transferable to other LMD use cases.

Beyond the agent-based model implemented in URBANE, the project also implemented AI driven and linear optimization models to reduce emissions and congestion associated with last mile deliveries. These models are a Collaborative Delivery Model (CDM), a Dynamic Parcel Reshuffling Model (DPRM), and a Parking Zone Monitoring System (PZMS). Firstly, as collaboration is a key feature of the PI (Franklin, 2023), the CDM was developed to coordinate the actions of several non-cooperative agents. This results in a coordinated flow of parcels from multiple first mile Delivery Service Providers (DSPs) to micro-hubs, from micro-hubs to last mile DSPs, and from the last mile DSPs to the recipients. The results of this approach show a reduction in total last mile emissions, compared to the non-coordinated case. Secondly, in last mile deliveries, uncertainty in travel times is observed due to road congestion, parking availability, the recipient’s presence at delivery, and other factors. Depending on the conditions encountered during the delivery round, last mile operators frequently need to dynamically redesign delivery rounds to alleviate delivery delays. The DPRM can serve as a smart decision support tool for last mile operators that automates and optimizes this dynamic delivery in a live setting. Finally, the PZMS uses a computer vision algorithm to monitor parking spaces

in real time and routes delivery vehicles to available spaces. This will reduce the time a delivery vehicle spends looking for an appropriate parking location and will reduce the chance of a delivery vehicle parking illegally and blocking other traffic. These models have been designed to be flexible and scalable, and their integration into the Innovation Transferability Platform ensures that they can be deployed in multiple cities to aid in decarbonizing last mile logistics.

3.2 Collaborative Governance and Security Measures: Towards the PI Adoption

Collaborative logistics has been demonstrated to be a much more efficient model of logistics operations than traditional competitive models (Zheng et al., 2019; Briand et al., 2022). Unfortunately, there are few large commercial examples of where logistics service providers willingly collaborate (Basso et al., 2018). While a number of factors act as obstacles to collaboration, a primary reason found in all studies of collaboration is that the partners lack trust in one another (Vangen & Huxam, 2003). To build a foundation for trust, which is a necessary condition for collaborative logistics, requires building a system worthy of trust. Such a system must address the issues of security, privacy, equity, transparency, and usability in an open and fair manner. Within the URBANE project the problem of building a trustworthy system for encouraging logistics service providers to collaborate was addressed by building a set of services on top of a blockchain infrastructure. A blockchain infrastructure based on the open source Hyperledger Fabric blockchain was selected due to blockchain's ability to provide non-repudiation services for events that are tracked through the platform. Hyperledger Fabric was selected because of its broad use and support, and because it provides services that enable the security and privacy necessary for building a trustworthy system. Security and privacy within the URBANE system are managed through the use of state-of-the-art digital identification and authorization processes employing industry standard Decentralized Identifiers, Verifiable Credentials, and Open Authorization that control access to the services of the platform.

While security and privacy are key considerations for building a trustworthy system, logistics service providers are commercial entities, and they require the ability to ensure that service level commitments are met whether they deliver the service, or a third party performs the service on their behalf. To provide secure, non-repudiable verification of services conducted by partners, the URBANE platform implements dynamically configurable smart contracts that allow partners to observe delivery activities and determine service level performance. Because the smart contract service posts all activities to the blockchain, service performance is verifiable and non-repudiable. This capability of the URBANE platform provides users with the ability to “trust but verify,” a necessary condition for a system designed to be used in the dynamic environment of urban logistics.

The architecture employed for the URBANE blockchain infrastructure is shown in Fig. 2. This architecture employs a Kubernetes cluster to house the blockchain services. This cluster is connected via an application programming interface to the URBANE platform and receives event information through the platform's Kafka real-time event ingestion system. Users configure the smart contracts they wish to employ through a user interface that also serves as an event monitoring interface for deployed smart contracts. The platform uses a dynamic smart contract configurator that structures smart contracts

based on high level user inputs, abstracting the actual configuration and deployment of the smart contracts away from the user.

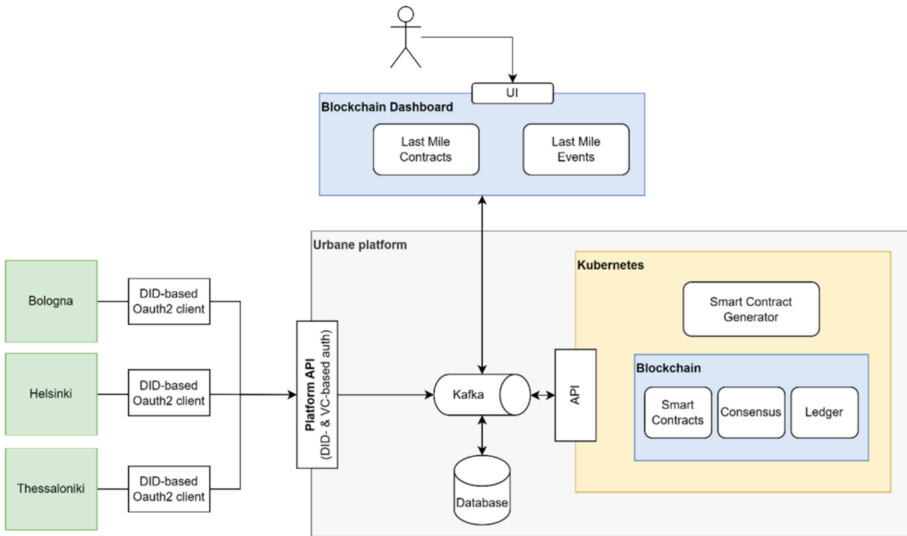


Fig. 2. URBANE Platform blockchain architecture

Figure 3 shows the high-level digital identification-based authorization process used for accessing services on the URBANE platform. This process uses tokens to identify approved users and the platform services they are allowed to use. The digital identifier and the resources accessed by the user are tracked and posted to the blockchain to ensure that should any breach in security occur, a history of how the breach occurred can be clearly defined.

Creating a trustworthy system is a necessary condition for facilitating collaboration among traditionally competitive service providers. However, while necessary, it is not sufficient. Addressing the complex collective action problem of building trust between commercial, governmental, and societal players takes time and more than a trustworthy system. However, the blockchain infrastructure developed for the URBANE platform provides a starting point for the more difficult task of establishing the strong trust relationships needed for next generation collaborative urban logistics.

3.3 Consolidated Evaluation Framework: Impact Assessment Radar

Multi-Factorial Impact Assessment

The Impact Assessment Radar serves as a platform that facilitates data informed decision making, planning and monitoring of innovative urban logistics business models. It acts as an access point for private companies and public authorities offering valuable tools and insights to support the effective design, implementation or expansion of innovative urban logistics business models. In more detail, the toolkit includes three levels of analysis:

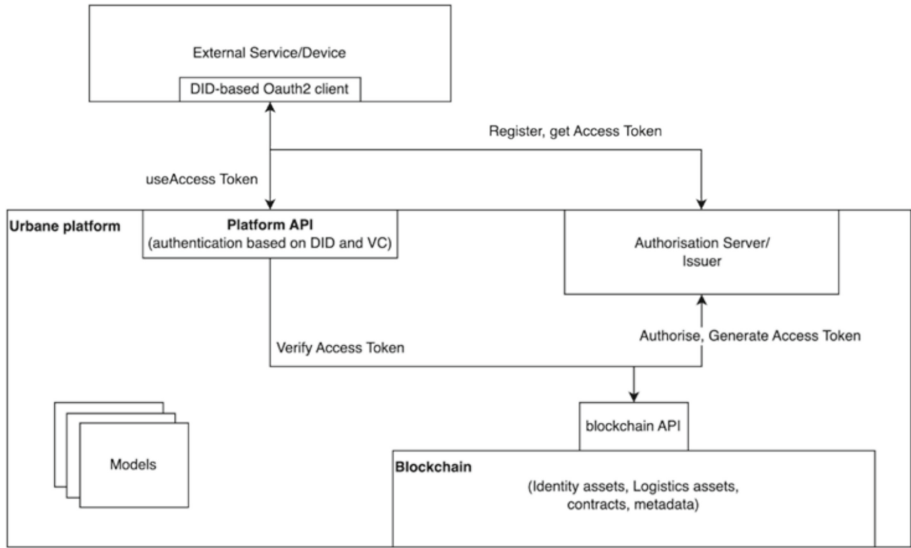


Fig. 3. Digital Identity authorization process

- **Strategic Level:** This level provides guided planning for innovation. It assists city officials (planners and decision makers) in shaping the urban logistics environment. Specifically, it evaluates a city's readiness for urban logistics innovation and pinpoints areas that require enhancement. The assessment investigates a city's readiness to adopt innovations in city logistics through aspects such as governance, sustainability, infrastructure, stakeholders, accessibility and safety. The main objective is to advise and steer cities on enhancing areas to develop Sustainable Urban Logistics Planning (SULP). This analysis stage involves a survey comprising 22 questions with a 3-point descriptive scale; users choose the response that best depicts their city's urban logistics system.
- **Tactical Level:** This level provides arguments-driven network design. It supports logistics service providers and municipal authorities in designing infrastructure and services for cutting edge urban logistics solutions inspired by the Physical Internet (PI). Within this phase, the Impact Assessment Radar provides tools to enhance the effectiveness of the chosen solution, such as determining the quantity of parcel lockers and urban consolidation centers (UCCs). The objective of this analysis level is to address the challenge posed by data availability in city logistics and guide cities on designing based on their objectives. The results, at this stage consist of Key Performance Indicators (KPIs) depicting the projected operational and externality costs of each scenario for both private and collaborative innovative urban logistics solutions.
- **Operational Level:** This level provides fact-driven assessment. At this level companies and cities can assess facts to measure and track the impact of their activities. The use of Digital Twin tools enables the analysis of scenarios for impact assessment. Different

technologies like Artificial Intelligence (AI), Agent Based Modelling (ABM), Optimal Routing (OR), optimal facility location and fleet composition tools are employed to simulate urban logistics solutions. The goal is to utilize simulation outcomes to calculate Key Performance Indicators (KPIs) chosen by each city for regular progress monitoring.

The architecture of the Impact Assessment Radar allows users to access the three levels of analysis through a single-entry point (Fig. 4).

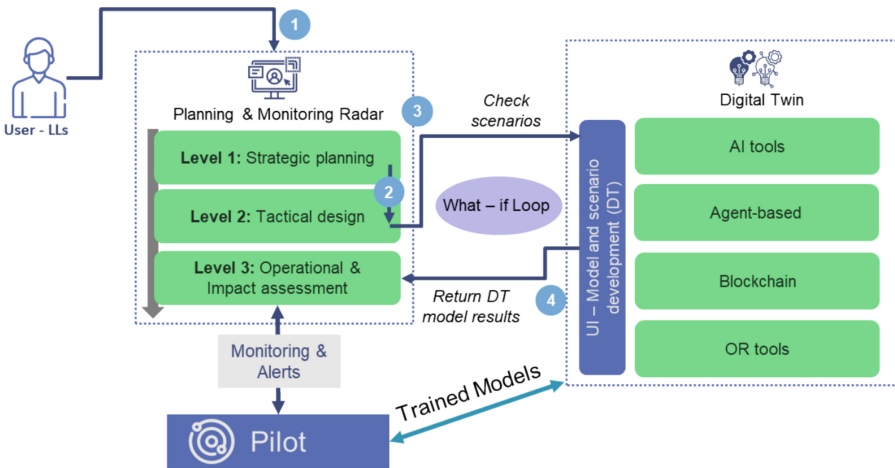


Fig. 4. The architecture of the Impact Assessment Radar.

Level 1 serves as a tool that assists city authorities in understanding their ecosystem. By leveraging city capacity data users can move on to Level 2 where they can create design scenarios with limited data. Subsequently based on Level 2 results users can further evaluate the impact of innovative urban logistics solutions through simulation in Level 3. Through Level 3 setup users can gain insights into the anticipated (outcomes of operations, within the city.

Effectiveness Evaluation of Intervention

The selection of Key Performance Indicators (KPIs) within the URBANE Innovation Transferability Platform follows a strategic approach based on established KPIs and methodologies familiar from prior EU projects on Urban Logistics and the CIVITAS methodology. This approach ensures that the KPIs are not only relevant and robust but also standardized across similar initiatives, allowing for consistency and comparability in the assessment of interventions. By relying on well-known methodologies, the platform enhances the validity of its evaluations and ensures that the insights generated are grounded in proven frameworks. This alignment with established practices facilitates effective benchmarking and sharing of best practices within the broader community engaged in urban logistics and sustainable city planning.

The assessment structure used for the URBANE Innovation Transferability Platform follows a data focused method positioned within the third tier of the Impact Assessment

Radar. This operational stage concentrates on evaluating the efficiency of innovative urban logistics solutions. Initially, each Use Case of each city is related to specific Key Performance Indicators (KPIs), that are computed by the beginning of the pilot as a baseline (ex-ante). After the implementation of the innovative solutions, the same KPIs are recalculated in the implementation phase to enable a direct comparison of performance pre and post interventions. This comparison allows for an analysis of the impact of each innovation to the operational, effectiveness and environmental sustainability of the urban logistics system. By utilizing this approach, the assessment structure offers a mechanism for evaluating the effectiveness of innovative logistics solutions guiding future improvements and ensuring ongoing progress in urban logistics practices.

4 Discussions and Conclusions

The Innovation Transferability Platform (ITP) toolset is not merely a static solution, but a dynamic resource designed to empower urban logistics communities. Its core aim is to offer a readily adaptable last-mile solution infused with the principles of the Physical Internet (PI) approach, ensuring its successful application across diverse contexts, including collaborative logistics scenarios leveraging shared assets or capacity. Every component of the ITP has been meticulously crafted with replicability and transferability in mind, expediting the replication and adoption of tailored solutions. For example, the models within the Decision Tool (DT) showcase the benefits of collaborative last-mile logistics and can be readily repurposed and expanded beyond the confines of the URBANE project. Similarly, the smart contracts generator facilitates collaboration governance among stakeholders across various logistical settings. Furthermore, the Impact Assessment Radar, serving as a comprehensive planning and monitoring tool, holds promise for widespread adoption throughout European cities, exemplifying the ITP's commitment to fostering scalable, impactful solutions for urban logistics challenges.

In this context, URBANE provides real life evidence of the advantages of using new methods to meet increasing demand and enhance resource efficiency for the transportation, storage, and physical handling of freight. It should be noted that the exploration and implementation of such innovation transferability enablers represent a pivotal advancement in urban logistics, positioned to significantly enhance the adoption and dissemination of innovative last-mile delivery solutions throughout European cities. By leveraging these enablers, cities can effectively bridge the gap between pioneering solutions developed in one context and their applicability in diverse urban landscapes. This not only accelerates the uptake of cutting-edge technologies and methodologies but also fosters collaboration and knowledge-sharing among EU cities, ultimately fostering a more sustainable and efficient urban logistics ecosystem.

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