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Orchestrating Physical Internet-Led Urban Logistics through Comprehensive Planning and Implementation Guidance from Meta Model Suite

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Introduction

Urban freight is becoming increasingly important for the European economy, but also more challenging for cities. The transport sector includes 1.3 million enterprises, employs 10.2 million people, and contributes around 5% to EU GDP, while freight transport demand and e-commerce growth continue to intensify pressure on urban logistics systems (Directorate-General for Mobility and Transport, 2024; Eurostat, 2024, 2025; Sarkar, 2023). In particular, last-mile delivery remains highly emission- and cost-intensive, accounting for up to 50% of delivery-related CO_2 emissions and 40–50% of delivery costs (Sarkar, 2023).

The **Physical Internet (PI)** offers a promising response through shared, modular and interconnected logistics networks that can improve resource utilization, reduce costs and lower emissions (ALICE, 2020; Ballot et al., 2012; Barbarino, 2018; Naganawa et al., 2024). However, cities still lack practical tools to assess readiness, select suitable PI-driven innovations and support implementation in a structured way. To address this gap, this paper presents the **Meta Model Suite (MMS)**, developed in the HE DISCO project as an orchestration tool that combines readiness assessment, innovation selection and adaptive implementation guidance for sustainable urban logistics.

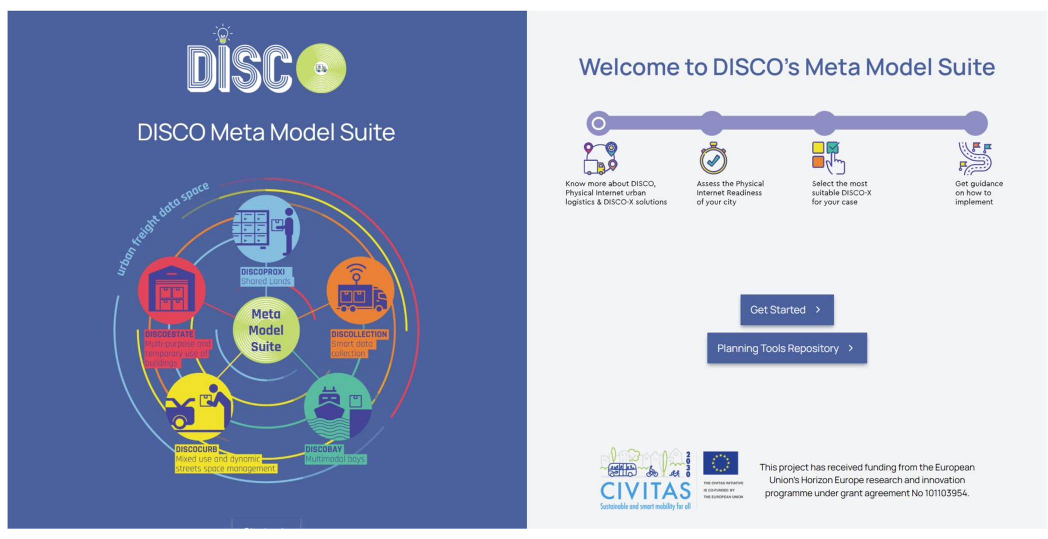

Figure 1: The DISCO Meta-Model Suite

The DISCO Concept

DISCO aims to accelerate the transition toward decarbonized and digital urban logistics through PI-led planning and deployable innovations. The five DISCO-X solutions are: **DISCOBAY** (multimodal consolidation at peripheral gateways); **DISCOESTATE** (warehouse marketplace in midtown districts); **DISCOPROXI** (neighborhood micro-hubs and parcel lockers); **DISCOCURB** (dynamic curbside logistics); and **DISCOLLECTION** (federated data backbone).

Figure 2: The DISCO-X meta-models definition

MMS Architecture

The Meta Model Suite (MMS) is a modular, service-oriented decision-support platform for PI-led urban logistics. It combines city vision, infrastructure, policy and digital maturity inputs with AI- and rule-based processing to recommend tailored DISCO-X packages and generate implementation blueprints.

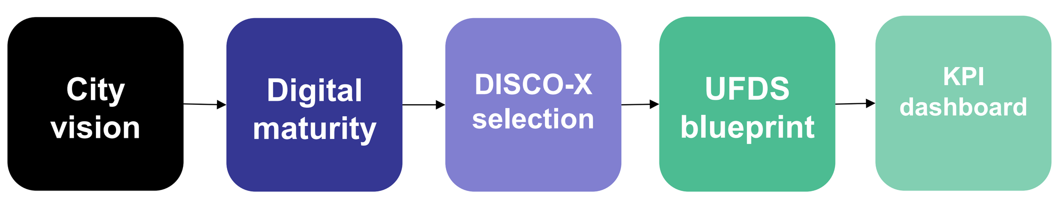

Figure 3: The user path of the DISCO Meta-Model Suite

The user path summarizes the main workflow of the MMS, from defining city vision and assessing digital maturity to selecting DISCO-X solutions, developing the UFDS blueprint and monitoring outcomes through KPIs. The architecture below shows how these functions are operationalized through planning, innovation-selection, tools-library and data-space modules, together with links to **DISCOLLECTION** and the **ALICE Knowledge Hub.**

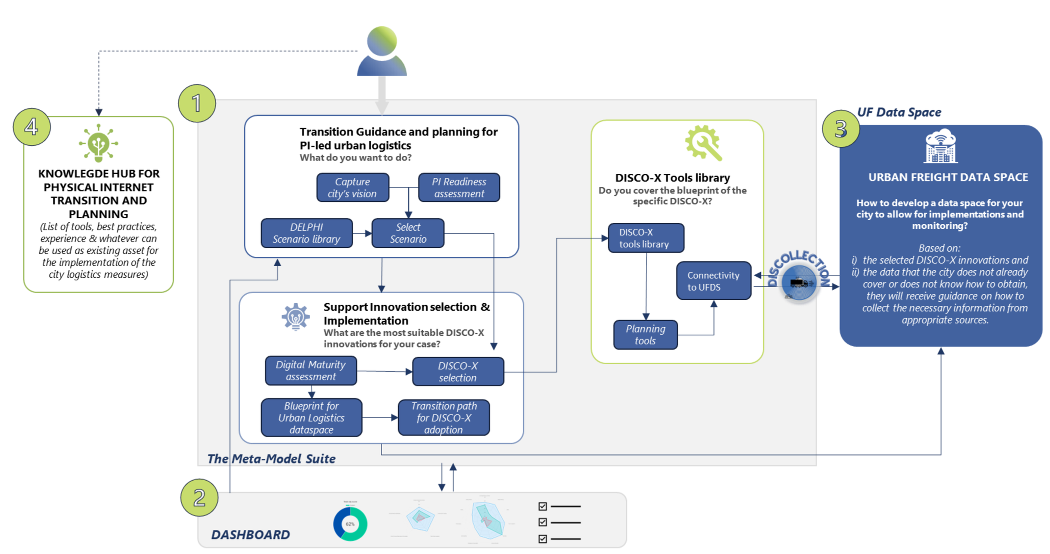

Figure 4: The overarching Architecture of Meta Model Suite

MMS Use Cases

The Meta Model Suite (MMS) supports four core use cases that guide cities through the successive phases of Physical Internet (PI) adoption, from foundational learning to implementation. Through modular services, embedded AI and federated data integration, the MMS helps stakeholders build a common understanding of PI, define a city-specific transition vision, identify the most suitable DISCO-X innovations, and move from strategy to practical deployment.

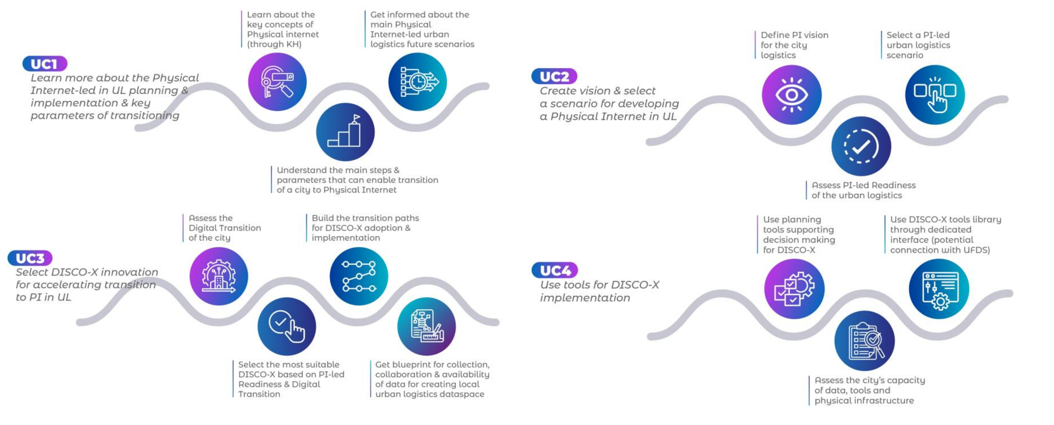

Figure 5: Description and main functionalities of MMS Use cases.

Education — Builds a common PI vocabulary and conceptual understanding among stakeholders.

Strategic Visioning — Translates city goals and baseline conditions into a tailored transition roadmap.

Innovation Selection — Assesses readiness and recommends the most suitable DISCO-X package.

Practical Implementation — Links cities to tools, data and infrastructure requirements for deployment.

DISCO-X Selection & Requirements Guidance

The MMS supports evidence-based selection of the most suitable DISCO-X innovations by classifying cities into typologies based on two baseline assessments: PI-led Innovation Readiness and Digital Maturity. Using a logistic regression model trained on data from the four DISCO Living Labs, the platform generates context-specific recommendations and then translates them into implementation requirements through a structured readiness-guidance process.

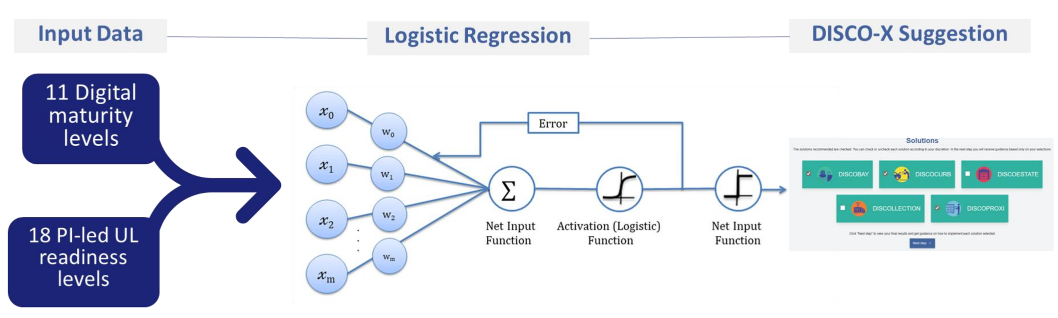

Figure 6: The DISCO-X Selection background calculation

Following DISCO-X selection, the MMS guides cities through a requirements assessment to determine whether the recommended innovation can be deployed in practice. This step translates the recommendation into an actionable implementation pathway covering data, tools, infrastructure, governance and regulatory needs.

Table 1: Predictor variables and data sources used for DISCO-X selection

Variable Category (predictors)	Description & Scoring Logic	Primary Data Sources
PI-led Innovation Readiness	18 indicators weighted via AHP: Smart Actors (23%), Smart Governance (19%), Resources & Infra (19%), Networks (19%), Safety & Security (19%).	City stakeholder surveys, logistics baseline analyses.
Digital Maturity	11 indicators assessed via 5-point Likert scale across: Security, Interoperability, Commercial/Societal Support, and Environmental Impact.	Municipal IT, policy, and operations questionnaires.
Target Variable (Label)	City Typology classification leading to a specific DISCO-X recommendation.	Living Lab baseline classifications.

To support this process, the MMS applies the MoSCoW prioritization method, distinguishing between "Must Have" requirements essential for core functionality and "Nice to Have" elements that enhance performance. Through a structured self-assessment, city planners evaluate their existing capacities and identify critical gaps. The platform then generates a readiness verdict and directs users to the DISCO-X Tools Library and the Urban Freight Dataspace (UFDS) blueprint for targeted remediation.

Thessaloniki Living Lab Implementation

Thessaloniki applied the MMS selection methodology and achieved 50% PI-led Innovation Readiness, indicating moderate baseline preparedness. Based on this profile, the MMS recommended a four-pillar package combining **DISCOBAY, DISCOESTATE, DISCOLLECTION and DISCOPROXI** to support multimodal consolidation, warehouse sharing, data federation and shared parcel-locker deployment.

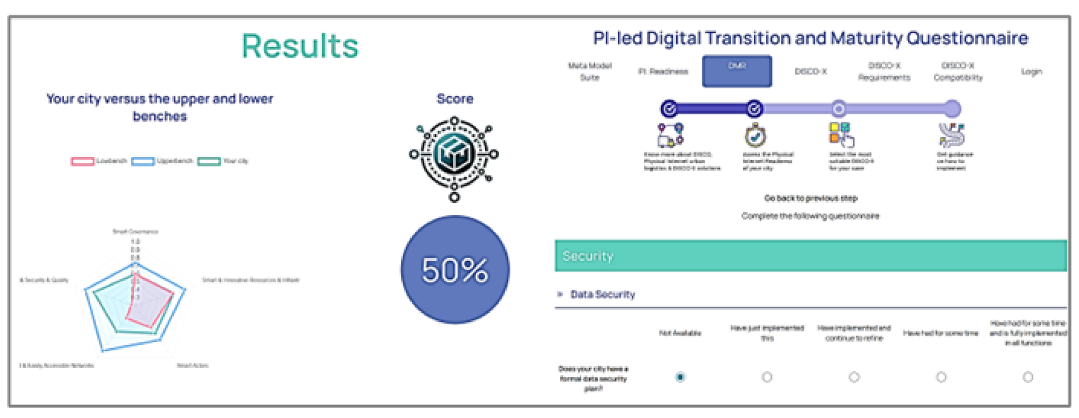

Figure 7: The Physical Internet-led urban logistics readiness and the digital maturity readiness results.

For **DISCOPROXI**, the city validated all Must Have requirements, including data from 1,000+ stakeholders, municipal GIS open data and five smart lockers, leading to a "can be deployed" verdict. Preliminary pilot results showed **26% locker utilisation**, **82% first-time delivery success** and an average **cost of €1.20 per parcel**. A key lesson was that technical readiness alone was not enough: active municipal mediation was needed to overcome data-sharing hesitancy among competing operators.

↑85% utilization | ↓54% CO_2 | ↓26% costs

Conclusions, Limitations & Future Research

The paper introduced the Meta Model Suite as a comprehensive orchestration tool designed to accelerate the adoption of PI principles in urban logistics. By bridging analytical readiness assessments with the automated generation of prescriptive, gap-remediation blueprints, the Meta Model Suite provides city authorities with actionable transition pathways. As demonstrated in the Thessaloniki use case, these data-driven blueprints directly inform and calibrate local Sustainable Urban Logistics Plans, ensuring that logistics interventions align strategically with the broader sustain-ability objectives of the UN Agenda 2030 (specifically SDGs 9, 11, and 13). Further-more, the reliance on standardized PI-readiness and digital maturity indicators ensures that the MMS methodology remains highly replicable across diverse European urban contexts.

However, several practical and methodological limitations must be acknowledged. Practically, the seamless integration of federated dataspaces is frequently hindered by legacy, fragmented municipal IT infrastructures and varying data governance standards. Methodologically, the logistic regression model currently relies on self-reported survey data from local stakeholders to establish baselines, which inherently carries a risk of subjective bias. Finally, while technical integration barriers are addressable, overcoming the competitive hesitancy of private stakeholders to share operational data remains a significant risk to true PI deployment. Future research will focus on integrating automated data-ingestion APIs to reduce reliance on surveys and developing formalized trust frameworks to incentivize public-private data shar-ing.

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