Flexible framework for sustainable and efficient last mile logistics

ADRIÁN HORVÁTH[1]

Abstract
Today, consumer habits are undergoing a profound transformation. E-commerce and on-demand economy is growing exponentially, which is accompanied by an increase in home delivery tasks. This places a heavy burden on last mile and home delivery companies. The effective use of vehicles and drivers is a growing problem. Increasing vehicle traffic also has many negative effects on the lives of citizens and municipalities. A digital twin framework provides an opportunity to analyse negative impacts and provides a basis for strategic decisions to address them effectively. The paper presents a framework what is able to offer solution for an outlined problem.

Keywords: last mile, home delivery, digital twin, e-commerce

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INTRODUCTION

The rise of on-demand logistics puts serious strain on last mile delivery systems. Consumers require responsive logistics systems that deliver customized products at low cost. The industry promises instant delivery and personalized products manufacturing. The last mile delivery market is developing fast through both large and small-scale consumer platforms, however economic incentives to create sustainable systems are weak. Cities, therefore, are confronted with the possible negative consequences of this changes. As there is much uncertainty about the actual market developments and course taken by leading companies, such as parcel network integrators and major retailers, one cannot reliably predict the most likely developments for the next 20 years and propose feasible policies on that basis. Urban planners, city authorities and business stakeholders need a new adaptive approach to help them predict possible consequences of market driven developments, evaluate fast response green strategies, and introduce incremental changes by adopting innovative business models that promote public-private cooperation.

Cities have already been evolving in this direction in the recent years, with an increasing number of living labs, complementing the 'predict and provide' paradigm. Highlight development goal is to create a complex solution that supports connected and shared last mile delivery with low environmental impact. To reach this goal the approach is based on adaptability and digital twin solutions. For this, data-driven models need to work in parallel with real-life experiments to reproduce findings and predict results of response actions. The Digital Twin based on the real city logistics value cases, supports all decisions from operational to strategic level (Marcucci et al., 2020).

[1] senior lecturer, Széchenyi István University Department of Logistics and Forwarding, E-mail: hadrian@sze.hu

1. ADAPTIVE SOLUTIONS FOR LAST MILE LOGISTICS

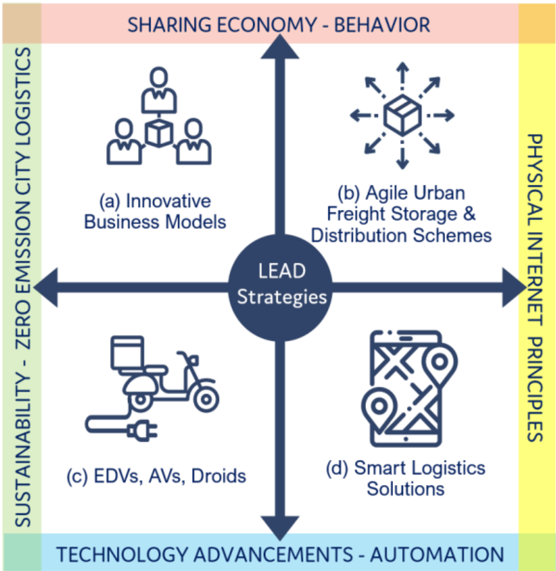
The project will examine the city logistics network in six prominent locations with the help of Digital Twin. This provides a way to support decision making in last mile distribution focused on public-private integration. This approach based on special value case scenarios in connection with on-demand economy. This creates value for all partners (Marcucci et al., 2021).

Each version examines unique specialties and circumstances (Figure 1):

- flexible freight delivery solutions with particular regard to on-demand delivery,
- use of alternative drive vehicles,
- smart data-driven logistics solutions.

Balanced city measures will most likely have combinations of these strategies in place to covers the problem area of city logistics in its full depth.

Figure 1 LEAD Strategies and Innovation Drivers



Source: Empresa Municipal de Transportes de Madrid SA (2019)

Low emission, connected and shared logistics is the core of value cases based on special innovation incentives:

- Sustainability - Zero Emission Logistics,
- Sharing Economy,
- Technology Advancements,
- PI paradigm.

PI concepts applied to urban logistics, integrating low-emission, connected delivery vehicles with special storage facilities. This helps to determine the location and functionality of Physical Internet hubs with automate scheduling and routing. Whit this it is able to satisfy the special demands of consumers (Marcucci et al., 2021).

Behavior and changes related to the environment, costs and operations will be closely monitored in six intervention areas - from here onwards referred to as Living Labs - with different Logistics Profiles, aimed at reaching a good representation of European cities. The strategic goal of LEAD is to establish a framework for intelligent urban distribution that deals with six locations Digital Twin, the setup of comprehensive Digital Twin of cities based on this.

The Digital Twin will feed with contextual data, real-time sensor information and other operational data, so can the solution facilitate (Marcucci et al., 2021):

- understanding the dynamics of distribution structures in urban areas and the role of introducing specific innovations,
- the design and evaluation of sustainable and economically viable strategies through simulation,
- the complex organization and implementation of deliveries in cities and metropolitan areas.

Key to this undertaking is scalability - small-scale models need to feed into cumulative city-scale Digital Twins. The LEAD project will develop, test and validate the first building blocks of this framework in six cities and will provide tools and guidelines for wide adoption and up-scale.

2. MODELLING OF LOGISTICS PROFILES

Logistics profile is a structured way of characterizing a city's challenges and understanding the relevant characteristics of stakeholders, the organizational arrangements among agents and the transportation of goods. In theory, the logistics profile can assist in systematizing the knowledge concerning the specific urban freight characteristics, logistics needs and stakeholder interactions, thus enabling better informed decisions and the implementation of better intervention policies (van den Bossche et al., 2017). In practice however, the logistics profile of an arbitrary urban area is dynamically evolving, therefore operational or policy planning for green last mile logistics in an intrinsically complex environment is challenging.

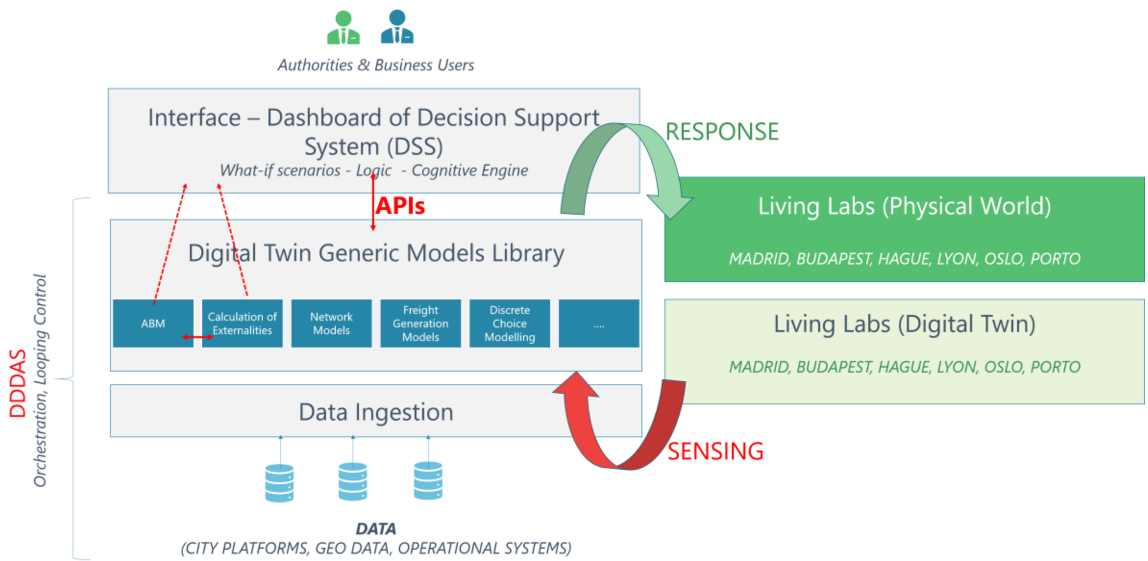
Related to it the project applies Digital Twin which comes from the industry for supporting decision making in the field of urban distribution. An urban network is a sensitive system and Digital Twin is able to simulate this and the effects of new policies, the behaviour of logistics operators, etc. The Digital Twin feeds on the city, real-time data ensure the twin nature of reality between real life city and the model. So the model will update constantly. The dynamic nature of the system is given by Dynamic Data-Driven Application System which is a sensing-response loop (Figure 4) (Hinestra, 2018; Knyazkov et al., 2014). This allows:

- Analysis and optimization, supports decision making with visualization for users in city logistics (Madni et al., 2019).
- To make more efficient city logistics processes.
- Visibility, flow and quick response in all sub-processes.
- Create and operate new business models.
- To improve life quality with lower emission of logistics processes.

While Digital Twins have not yet achieved widespread application in logistics, the key enabling technologies are already in place (Dohrmann et al., 2019). The main goal of using Digital Twins in urban distribution is to develop the efficiency of processes, decrease costs, forecasting the expected consumer needs. The technology of Digital Twins is has matured for modeling and examination of future scenarios with the use of historical data bases and real-time data of urban freight systems (Damjanovic-Behrendt–Behrendt, 2019).

The LEAD system will be built as a modular platform-as-a-service type cloud-based system, utilizing open-source scalable big-data middleware to establish a secure, reproducible computational environment. At the lowest level of the LEAD architecture is a scalable modular data ingestion solution that will be interfaced with the LLs. The data ingestion system will be tied either directly into the physical sensor networks or to existing smart city management and other database platforms. Through these systems, access to data such as traffic, satellite imagery, weather, pollution will be continuously ingested for use within the models that make up the Digital Twin.

Figure 2 LEAD Conceptual Architecture Overview



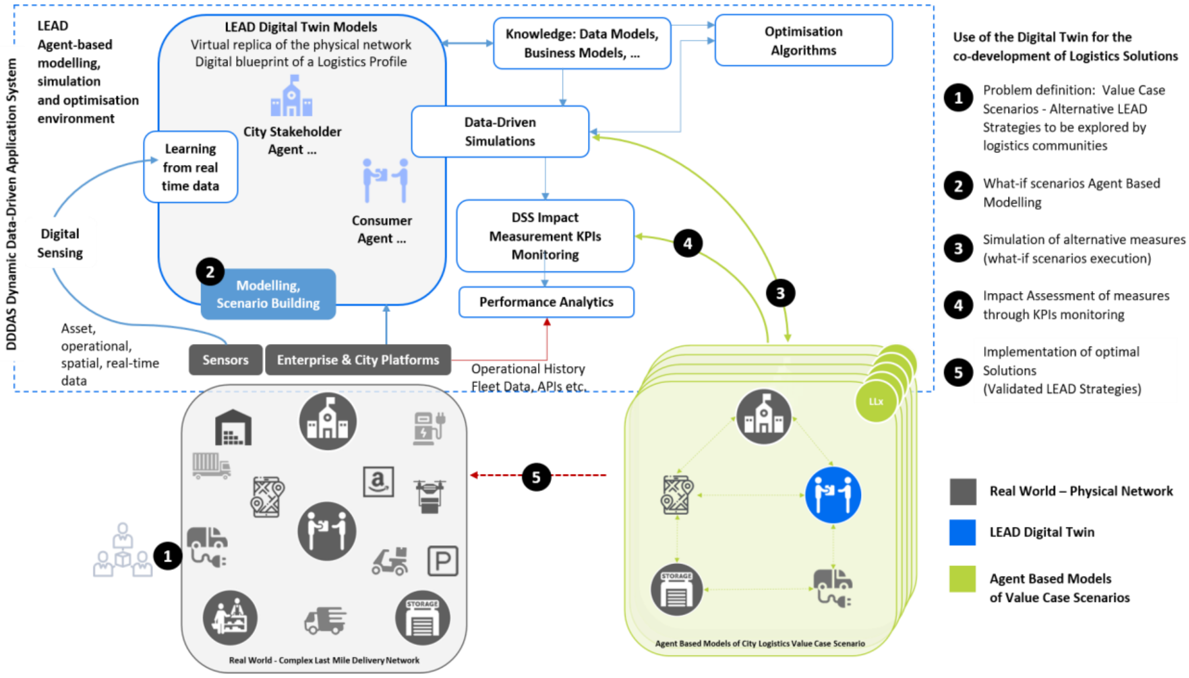
Source: Empresa Municipal de Transportes de Madrid SA (2019)

Within the platform the next layer of the architecture includes the models that make up the Digital Twin. As part of the development of the LEAD project, the Digital Twin Generic Models Library will include models that best represent physical sub-systems within the project's LLs. All models will be designed with re-applicability in mind. The project envisions the development of several models that will be specific to a particular LL but reusable in different contexts. Consequently, to achieve simulation composability and interoperability, the project will specify a meta-model, linking established proprietary and non-propriety systems-modelling approaches, sufficient for abstracting an understanding for a last mile logistics network and its stakeholders. The interdependency types (Varun, 2015), modelled through the meta-model, will be physical, informational, geospatial, policy, procedural and societal.
The models to be considered as a baseline include:

- Network models forming the core of the re-usable cross LL representation tools. These models will include transport systems, known or inferred supply chains, social activities and participants. Coupled with freight generation and freight trip generation models, a holistic approach can be taken to represent the LL environment.
- Models that can be applied effectively for analysing network capacity and traffic conditions, hubs capacity and performance. "What-if" and "Before-After" scenarios will be interrogated via these models in a cost-effective way to provide LEAD KPIs and other relevant insights, for example, on research questions such as the impact of service reliability.
- Impact assessment models for appraising the sustainability of the measures adopted (Bueno et al., 2015).

The simulation element of the modelling layer will not only include parameter sweeping but will also incorporate advanced agent-based simulation. ABM is a valuable approach for both the analysis of human decisions as well as complex, adaptive systems (Achter et al., 2017). Both cognitive and ANN models will be utilized to represent actors and their behaviour as agents. Agent-based modelling will be used to better understand real-world logistics systems, where the representation of many diverse stakeholders and their interactions is important. Agents are self-contained computer programs that interact with their environment and with one another. Agents can be designed and implemented to describe rule-based behaviours and simulate interaction effects of real-life decision makers and other actors. Uniting complex and heterogeneous processes and operations requires a flexible modelling environment, capable of connecting different modelling methods.

Figure 3 Digital Twin as a city logistics modelling, simulation and decision support tool



Source: Empresa Municipal de Transportes de Madrid SA (2019)

Each experimental iteration will incorporate econometric models, such as discrete choice models to predict and estimate the behaviour of agents and to calculate the externalities produced. This method of performing iterative simulations through ABM's enables policy makers -and stakeholders in general- to consider and account for the unpredictability of the market through what-if analysis and optimization procedures (Figure 3). What-if scenarios are described with ABMs, based on actual preference elicitation techniques such as Stated and Revealed Preferences. For example, the simulation can be configured to identify the network conditions if in a given area (at a given time of day) one performs 60% eco-friendly deliveries and 40% urgent ones. Alternatively, it can be configured with different types of last mile solutions. Each configuration represents a value case and the simulation output of these value-case scenarios helps build a knowledge base that can be verified by the real-time 'ground truth' being ingested into the system, so that it may be used by a Learning and Decision support unit as predictable outcomes.

The DDDAS, based on the two layers (ingestion and modelling) and the ground-truth collection process, orchestrates the sets of descriptive and executable models (Boschert et al., 2018). Using the continuous sensor and data input, the DDDAS system first initializes the digital models with representative starting conditions and then provides the simulation needed to determine optimal outcomes. Based on different models, simulation, and urgency, this orchestration is either near real-time or is executed in a micro-batch to batch modality. The DDDAS is the mechanism that links data and models in real-time, thus ensuring that the twin always represents the state of the network in real-time. Data fed into the model guarantee the model is an accurate representation of the real world at any given point in time. Outputs from the model (produced faster than real-time) can be fed back into the real system to optimize its functioning.

Through a set of APIs, the DDDAS provides input to the User Interface and Decision Support System (DSS). A drag-and-drop visual interface enables operators and stakeholders to design the what-if scenarios by selecting the models and linking them to data sources. Dashboards provide KPI metrics for both the physical and digital world. For the latter, the dashboard will show alignment of the simulations to actual ground conditions, as well as progress towards value scenario goals. This will enable monitoring of flows, KPIs or individual processes to identify low-running processes with discrepancies or structural fault. Since last mile logistics processes are quite dynamic, with many changes occurring in terms of technologies, restrictions in cities, product mix and customer behaviour, the dashboards will be customizable without requiring reprogramming or additional investments. Using a Cognitive Engine (Griffiths et al., 2006), the DSS will provide recommendations by evaluating the various outcomes emerging from the ABMs, the calculation of externality models, and the learning modules with validated ground truths. These outputs and recommendations will be shown on the dashboard and will be used for closing the loop with the Digital Twins. Depending on the LL environment, the Digital Twin will manipulate physical systems to make adjustments to help achieve outcomes. While this will not include manipulating traffic or such citizen centred services, it will suggest changes for cargo and freight routing – retaining the option for operator override.

3. EXPECTED IMPACTS

Last mile urban logistics is a prominent growth sector. Continued strong growth is expected until 2030 as on-demand imperatives see increased significance across markets. The changing consumer habits and their expectations for same or next day deliveries put pressure on last mile logistics networks, carriers and supply chain stakeholders to replace legacy and conventional business models and achieve faster delivery services, offering real-time transparency throughout the fulfilment process. LEAD will contribute to the European consensus and direction to balance the 'on demand economies' and shared, connected and low-emission logistics operations, and will provide practical tools and tested solutions to enable last mile communities make steady progress in reaching zero emissions by 2030. Specifically, LEAD will provide significant and measurable impact at two principal levels:

- Increase knowledge in relation to sustainable urban logistics strategies and plans.
- Quantify, on the basis of a common framework, the sustainability impact of the specific strategies implemented at the local level for each of the LEAD LLs.

The impacts will be measured by the LEAD project using impact assessment indicators. A set of KPIs will be monitored:

- via simulation before the interventions,
- during the project’s period in LL settings,
- estimated via projections in 2030.

The KPIs can be used for understanding the current condition of a target city based on historical changes and comparing with KPIs of other cities. This implies better understanding and accommodating the changes in the role of cities and regions in providing transport services, systems and infrastructure, and properly framing the expanding role of the private sector and other third parties.

4. CONCLUSIONS

The field of last mile distribution faces many challenges imposes negative impacts to the environment and the counter-interest of the actors is high. The consumer demand is growing dynamically therefor these problems will also increase. The aim of the paper was to present a framework that able to explore effectively the counter-interest and helps to find an effective solution. Top operate and maintain sustainable and efficient last mile logistics solutions necessary to apply frameworks as shown. This is the only way to achieve constant monitoring and fine-tuning of last mile logistics solutions with zero emission and with minimalized negative social impacts.

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