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Developing a holistic decision support framework: From production logistics to sustainable freight transport in an urban environment

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ABSTRACT

In recent years, policy makers as well as urban logistics and transport research have investigated how to reduce environmental impact from transportation in urban areas. Therefore, many new frameworks that can help a specific actor in its decision making process at a certain decision making level (i.e., business or policy level) have been implemented and published. However, the first screening of existing literature did not reveal frameworks that can be used across different decision making levels. This limits the possibility for actors using the same infrastructure but not necessarily co-operate to discuss how the actions and needs of each actor of different decision making levels mutually influence each other. This paper first presents an outcome of a literature review and analysis of existing research project results before. It combines these to a multi-layer framework that can enhance collaborative decision-making and seamless aggregation of performance measures such as environmental impact from multiple transportation activities in and around urban areas. For this multi-layer framework, factors are identified, and possible relationships across the various layers are indicated. The field of application is the area near urban manufacturing sites and specifically addressing all actors that share on regulate infrastructure relevant to last mile inbound logistics. The source of data is project databases as well as for the literature review research databases. The methodology applied is a combination of a literature review based on database entries and a snowball approach. The article also presents how the framework can be prototypically implemented in participatory simulations using a simplified example. Potential usage for establishing holistic urban mobility structures is also discussed.

1. Introduction

More than 75% of the European population lives in and around cities (Eurostat, 2016). Logistics plays an essential role in the quality of life of the growing urban population. A considerable proportion of CO_2 emissions and other environmental pollutants comes from transport-related production activities within an urban area (Hai et al., 2020; Meppar-ambath et al., 2021). To increase the quality of life, reduce greenhouse gases, and ensure high service quality to all citizens, cities worldwide have implemented different strategies for reducing noise and GHG emissions, often including a sustainable urban mobility plan (SUMP) that shall support the long term achievement of the set goals (Kaur and Singh, 2017; Krishankumar et al., 2021). Such plans and strategies directly impact how to deliver and distribute material and goods to and from production sites within an urban area, since such activities influence heavy truck transport schedules and routes, night-time deliveries, noise pollution from productions sites at night time, etc. (Gupta et al., 2017) that can be perceived as a limitation to the flexibility of operation of manufacturing plants in an urban area since such plans have a direct impact on possible deliverable schedules (Gupta et al., 2017). We are focusing on the area from the last waiting slot for trucks till the delivery in the inbound goods inspections, as well as all the material and part movements on the production site. This is in line with the part of supply chains often termed production logistics (BVL, 2019). In order to have an efficient organisation of goods and material handling, most large production sites operate with very short delivery windows with costly fines for those who do not manage to deliver within the slot (Gnap et al., 2017). The consequence of this is the increase of idle waiting time at different parking lots nearby but outside the production site. Consequently, this might have a negative impact on the

Abbreviations: GHG, Greenhouse gas; SUMP, Sustainable urban mobility plan.

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overall contribution of GHG, noise, and also land usage, but also on the efficiency of material supply (Doi and Kii, 2012).

The decision on whether to keep manufacturing capacities in an urban area at the end is a company decision at the microeconomic level. This process is heavily influenced by decisions taken at the macroeconomic level – i.e., legislative and regulatory decisions. While the decision-makers at the company level focus on the company's needs and its employees, the city authorities often have a broader view. They need to take the requirements of different groups (citizens, businesses, etc.) into account. Bringing these often conflicting needs into a shared vision is often a challenge. Therefore, it needs to be interactions with the decision-makers acting at different levels during the decision-making process. As a part of investigating how to reduce the negative effect of such behaviour, it was our intention to develop simulation models allowing multi-criteria optimisation of inbound and outbound material and goods flow, taking the SUMP and local strategies into account as system boundaries while taking the all traffic movements as system inputs. The proposed solutions should support a seamless information flow and interaction across different varying levels of decisions by various actors and offer a possibility to align different actors' priorities. This is in addition to the lack of possibilities to exchange and update the information to be used as input for multi-actor decision making (Brusselaers et al., 2021). Such multi-actor, multi-criteria simulation should contain the relevant variables. In the first search of suitable frameworks to use as a basis for such simulations, we identified several decision-making frameworks for transportation and logistics in an urban area. Still, they did not cover trust and data exchange barriers in collaborative settings, and most did not support multi-actor decision making. Of those considered, multi-actor decision-making focused on the aggregation of decisions based on pre-set conditions and tools, providing limited possibilities to support collaborative decision making. Collaborative decision support frameworks need to be flexible, upscalable, and replicable based on prevailing decision levels and context (Brusselaers et al., 2021). Looking at what exists of collaborative models, there are models for global supply chain operators and others for reverse logistics, but these focus on collaboration across the whole supply chain and not on the interaction of actors not necessarily collaborating but using the same infrastructure. This is in line with the challenges identified in the ETP-ALICE (2015) roadmap on Urban Freight. Since we did not find one single framework that we could use for the described purpose, we decided to make a more systematic search on the existing framework and combine these in a way that would support different types of users of infrastructure for fostering the communication between actors with different needs and interest. Therefore, this research explores the possibilities for complementing existing multi-actor decision-making approaches with a mechanism for iterative interaction that facilitates the information and long-term proactive engagements towards sustainable urban area production and freight logistics. We intend that the envisaged framework will contribute to assessing the impact of policy regulations at different levels (ETP-ALICE, 2015, p. 22)

The study aims to address some challenges related to decision-making in urban production logistics, thereby proposing a holistic multi-layer model that can be input for decision-makers beyond the scope of just manufacturing enterprises. It aspires to provide support for collaborative decision-making towards more sustainable urban and *peri*-urban transportation.

To guide the process towards achieving the aim of the study, the following research questions have been set forth:

RQ1. How can existing frameworks and earlier projects in the domain of transportation in and around cities be re-used and combined to support collaborative decision making at multiple layers?

RQ2. How can we relate existing frameworks to each other to enable seamless information exchange between different decision levels?

The paper is structured as follows. Section two describes the methodology (a literature review). In contrast, section three analyses these results and comprises a description of the implications of different stakeholders' roles and goal conflicts at another layer and summarises the outcome of the existing research project. In section four, the multi-layer framework is presented. In section five, we discuss how the framework can be implemented in the specific case using a simplified example based on an analysis of existing works and simulation models. This is followed by the conclusion and the next step in section six.

2. Methodology

The overall approach followed in this study can be described as a series and iteration of three steps. It started with a literature review; then came the review of reports from recently concluded urban mobility projects; the third and iterative step involved proposing a multi-layer framework bringing in elements from the first two steps together.

The study aspires to explore existing frameworks in the area of logistics and transportation in and around cities with the intent of proposing a holistic decision making structure. With this in mind, a structured literature review has been the primary methodology. A systematic search of paper has been used to identify and learn from frameworks proposed in earlier studies in the broad domain of transportation and logistics in an urban area context. We have started by identifying key literature in the discourse that helped us fix search queries. The search query used for guiding the systematic literature review is provided in Table 1. The search is done using Scopus® as a database.

Then the search query along with the exclusion criteria have been used to iteratively reach a shortlist of papers that are used for detailed review. The initial list of 310 publications has been arranged to fulfill the search query in descending order of relevance. Below is a simplified representation of the procedure followed to reach a final shortlist of publications for detailed review. A simplified representation of the literature review process is presented in Fig. 1.

Finally, 40 papers were included in the detailed analysis. The shortlisted articles covered the years 2000–2021, with the peak appearing in 2018 (9 titles), followed by 2017 (8 titles), and next 2020 and 2021 (6 titles each). The final review has several aspects: (1) identification of the application focus areas of frameworks in reviewed literature; (2) identification of hierarchies and possible mechanisms collaborative mechanisms for multi-actor decision making; (3) identification of initial parameters of interest for stakeholders involved in urban area logistics and transportation.

To ensure that the initial use of keywords was close enough for what was intended to be covered, we have checked author keywords from the final list of papers. The list shown in Appendix A has been identified, indicating the relevance of the review process in a broader sense.

Following the review of selected academic publications, an initial list of relevant framework elements has been prepared for further analysis. The focus of the to-be-proposed framework was to support multi-layer decision-making for sustainable urban logistics and transportation. Therefore, a review of findings from earlier research projects has been conducted as well. The reviewed projects were mainly sustainable urban

Table 1
Literature search query.

Inclusion keywords combinations	Other filters
*Search in titles: (logistics OR "urban logistics" OR "city logistics" OR "urban mobility" OR "freight logistics" OR "production logistics" OR "urban freight" OR "third party logistics" OR "logistics outsourcing" OR "third party logistics" OR 3PL OR 4PL) AND (*framework*)* *Exclude: humanitarian logistics; technology focus in logistics (e.g., RFID or Artificial Intelligence), logistics service design as product; other research topics beyond the scope of the current study such as humanities*	Only articles or book chapters; published in English, 2000 or later

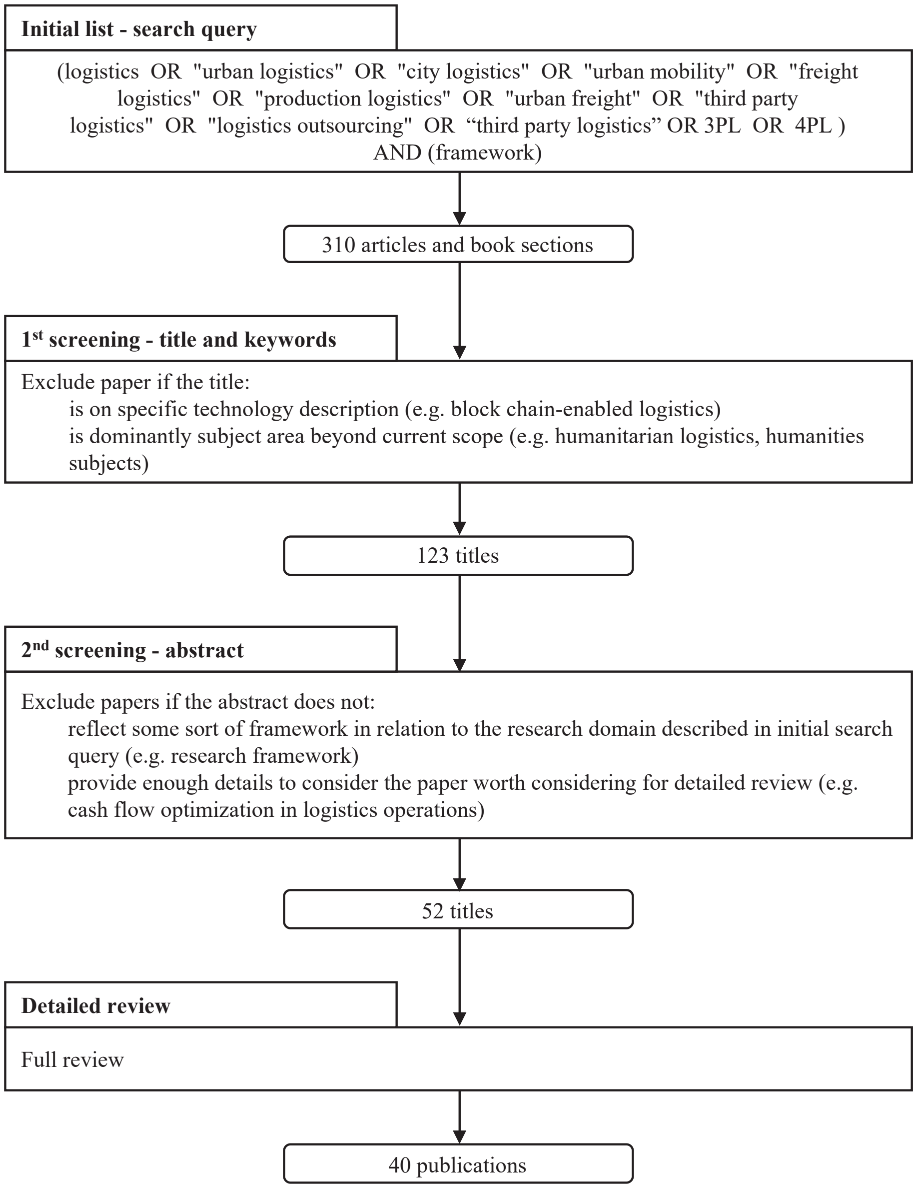

Fig. 1. Simplified representation of the literature review process.

mobility planning (SUMP) related ones within the scope of the European Union or a sub-region within it.

To get a systematic overview of how the identified parameters influence the decision model, we took advantage of a well-known process modelling tool, integration definition for functional modelling (IDEF0). IDEF0 modelling was chosen for its comprehensive nature in modelling systems. Besides the possibility to be easily modified and its modifiability to handle varying details of a system of interest are added benefits. IDEF0 model can subsequently be adjusted, making it applicable starting with the provision of an initial baseline to planning, managing, and implementing change on the system of interest.

IDEF0 is a systematic functional modelling methodology for describing, analyzing, and design of systems of interest. It was initially developed by an integrated computer-aided manufacturing program of the .S.U.S. Air Force in the 1980s (Ang et al., 1994). The method is schematically represented as an activity box (which means an activity of a system to be studied) with three arrows (inputs, controls, mechanisms) pointing into the box and one arrow (outputs) pointing out of it. Using a function model, it is possible to identify and map different activities, processes, operations, etc., with depictions of the concepts: inputs (I), outputs (O), mechanisms-resources (M), and controls or settings (C). These four are called concepts and are together abbreviated to represent ICOM.

The methodology follows a top-down breakdown approach that can analyse and improve an existing system or propose a new one. In the current study, the IDEF0 model for establishing a holistic mobility and urban production logistics framework is illustrated in section four.

3. On frameworks about logistics and freight transportation

Since there is no precise definition of the framework, we here understand that a framework can be thought of as a representation to conceptually and visually depict elements, mechanisms or methods, and their relationships in a system of concern such as city logistics (e.g., Lagorio et al., 2017). Constituent elements of a system and parameters, issues of integration among sub-system elements, and possible reciprocal influences on performance measures are used in conceptual frameworks representing complex systems such as logistics for smart cities (e.g., Kaur and Singh, 2017). Frameworks could be used to depict, discuss and assess fundamental aspects in undertaking processes or tasks such as selection of methodology for data acquisition and modelling, identification of stakeholders, and possibly competing for objectives, as well as for comparative analyses (Anand et al., 2015; Golini and Gualandris, 2018).

Framework focus areas

The lack of a precise definition of a framework is reflected in the initial survey of the literature. That is why we used framework application focus areas to structure the synthesis. The survey reveals that the application areas of logistics frameworks proposed in the literature can be classified into four types. These are (i) frameworks for collaboration and integration purposes (COL), (ii) frameworks for policy and decision-making (POL), (iii) frameworks for analysis and performance measurement (ANL), and (iv) frameworks for design, planning, and implementation of initiatives (DSP). Several papers may address one or more of the above application areas.

Table 2 summarises the count of publications touching upon the different framework application areas as synthesised through literature review. Out of the reviewed 40 articles and book chapters, 15 have specifically mentioned a framework or some form of decision-making tool. Only 8 have an explicit discussion on collaboration as a decision enabler or collaborative decision-making mechanisms. The other papers provided frameworks or methods of analysis that could be employed in business decision-making, policy setting, planning, or design.

The number of reviewed publications addressing frameworks towards ANL and POL for logistics and mobility seems to be relatively higher compared to the other two categories, COL and DSP. It appears that only a few frameworks picked up integrated or multi-level multi-actor decision-making aspects in the context of urban transport and production logistics. The contributions discussed so far seem to be quite limited compared to the complexity of the matter. On the other hand, such studies pave the way for understanding and exploring further different dimensions, decision elements, targets, and multiple stakeholders' perceptions and are therefore considered vital input for other developments.

Table 3 depicts a sample of the reviewed publications with a short description of the frameworks they discussed. For example, Audy et al. (2012) propose a framework for enhancing collaboration in logistics activities focusing on information and benefit-sharing. Therefore, their framework can be considered under the collaboration and integration category. Frameworks such as those discussed in Buldeo Rai et al. (2018) can be regarded as dominant policy-focused. In an attempt to address integration challenges between multiple perspectives of environmental initiatives by logistics service providers, Centobelli et al. (2017) propose a collaboration framework. The development of a common taxonomy for green initiatives also contributes to application in the analysis and measurement area. An example of a paper discussing logistics framework for design, planning, and implementation is by Lagorio et al. (2017). Articles classified under ANL and DSP tend to provide more analytical and quantitative-based frameworks than the other two categories.

With a few exceptions, most of the papers we reviewed have discussed logistics and mobility frameworks as applicable in just one decision hierarchy. This limits the possibility of incorporating relevant information from other hierarchies influencing the decision-making processes. Those few that discussed collaboration frameworks have discussed some form of horizontal or vertical collaboration issues among logistics mobility actors (Centobelli et al., 2017; Feng et al., 2017; Liu et al., 2021; Martin et al., 2018).

Table 2
Description of the reviewed publication.

Framework application areas	COL	POL	ANL	DSP
Publication count	10	19	21	6
Percentage (of 40 papers)	25%	48%	53%	15%

Note: COL = Collaboration and integration; POL = Policy and decision-making; ANL = Analysis and performance measurement; DSP = Design, planning and implementation.

Seamless information flow among actors is frequently mentioned as a vital issue for a collaborative decision involving multiple actors (e.g., Audy et al., 2012; Zhang et al., 2020). It becomes even more critical when actors from multiple hierarchies -or layers, as referred to in our study here- are involved (see Fig. 2). Further supporting the line of argument is that several analytical frameworks discussed in the reviewed literature have multi-layer decision implications even though it may not have been a primary objective in those studies (Lewis, 2016). The stakeholders making decisions at different hierarchy layers often have other priorities and possibly conflicting goals concerning different performance targets, including multiple sustainability dimensions.

We learn from the literature review that the different framework application focus areas (shown in Table 3) could be perceived as if they each apply to a particular hierarchy. While this could be intuitively thought so, the logistics framework application areas could be each utilised at multiple layers, as we have proposed in Fig. 2. For example, a collaboration and integration framework for logistics activities at layer one could direct horizontal relations between business organisations. In contrast, collaboration and integration at the society layer may require actors from business, public and other sectors to create information exchange to achieve broader goals. Analytical frameworks could be utilised to cascade societal requirements down to individual businesses connected to logistics in an urban setting while aggregation of performance measures into common and consistent evaluation dimensions relevant at each layer.

There are various kinds of stakeholders in this framework, as shown in Fig. 2. Each stakeholder has its own needs, goals, and applications. For example, citizens and tourists, who are higher-level stakeholders, are the users who use the services provided by this framework. They can use traffic or public transportation schedule service for urban areas. Also, they can get information about the noise levels and environmental effects. These services can be provided within the scope defined by the policy making level, and stakeholders such as city administrations establish and implement policies and guidelines necessary for urban areas. In the mobility integration and management layer, stakeholders related to freight transportation behavior in urban areas are included. They can utilize this framework when making plans for transportation and supply chain management. The stakeholders in the individual business entity are the main actors performing urban logistics and freight transportation. They can obtain the information necessary to improve the efficiency of logistics flow through this framework.

Two aspects of multi-layer framework design are vital to consider in the context of this study. The first is the identification of relevant parameters of interest in different decision layers. The second is establishing a working proposal for a functional model representing the decision layers and flow of information across layers. The first issue is addressed by identifying performance parameters from literature and recent SUMP projects that discuss some performance items in connection with logistics and around urban areas. A combination of the two reveals common parameters of interest applicable at multiple decision layers. Congruency between academic and practitioner interests on urban logistics performance metrics has been displayed, while divergence areas can also be noted as depicted using the last columns of Table 4. The second aspect relates to the modelling of urban (production) logistics using the IDEF0 approach. A working model has been proposed considering the identified performance items and the diverse goals of multiple stakeholders in an integrative manner. More explanation on that comes in the subsequent paragraphs.

Integration and involvement of stakeholders are then essential to enhance potential ecological, socio-cultural, and economic value derived from goods and services in a logistics ecosystem (Janjevic et al., 2019; Lagorio et al., 2017). Decisions need to reflect some form of cost-

Table 3
Sample literature discussing different urban logistics modelling framework application areas.

Reference	Short description	COL	POL	ANL	DSP
Andersson and Forslund (2018)	Framework for measuring sustainable logistics innovation in retail business			X	X
Audy et al. (2012)	Explains how to build and manage inter-firm relationships efficiently. It proposes five coordination mechanisms that contribute to ensuring information sharing, the coordination of logistics activities, and the sharing of benefits.	X			
Baruffaldi et al. (2020)	Framework for managing and improvement of warehouse operations in a 3PL setting		X		
Bottani et al. (2015)	A framework was developed to support an integrated logistics channel design, starting from independent companies belonging to an industrial food district.		X		
Brusselaers et al. (2021)	Proposes a framework to facilitate collaboration among stakeholders for construction logistics in urban areas	X	X		
Buldeo Rai et al. (2017)	Policy assessment framework		X		
Carter and Jennings (2002)	A framework of logistics social responsibility is introduced with the goals of helping managers resolve social responsibility issues and providing a guide for future research efforts			X	
Centobelli et al. (2017)	The framework addresses collaboration issues by developing a taxonomy of green initiatives in logistics service providers. Paper argues that integration among different perspectives has been lacking	X		X	
Doi and Kii (2012)	a cross-assessment model that supports both vision-led and consensus-led approaches is proposed as an analytical tool for developing sustainable urban transport and land use strategies for a low-carbon society		X	X	
Feng et al. (2017)	Present a leader–follower based collaboration model among stakeholders in (port-logistics operation) covering vertical and horizontal collaboration dimensions; collaborative framework of an intelligent agent system	X			X
Fontoura et al. (2020)	Presents a decision support model using system dynamics as a modelling and simulation tool to evaluate the impacts of sustainable urban mobility plan implementation		X	X	
Golini et al. (2018)	Framework to support collective decision-making	X			
Gonzalez-Feliu (2018)	Propose a systemic vision of literature on sustainable urban logistics assessment and evaluation.			X	X
Golroudbary et al., (2019)	Hybrid framework (with simulation) for decision-making in delivery management to compare the outcomes of logistics processes and dynamic risk effects		X	X	
Gupta et al. (2021)	Decision making framework based on analytical approach of sustainable service quality for LSPs		X	X	
Gupta et al. (2017)	Present a multi-objective shortest path evolutionary algorithm for comprehensive solutions to real-world manifestations of the classical vehicle routing problem.			X	
Hribernik et al. (2020)	Decision framework for horizontal collaboration among actors in urban delivery context	X			
Irfani et al. (2019)	Logistics performance management system framework for multiple role companies			X	
Janjevic et al. (2019)	Urban logistics policymaking characterised using complex adaptive systems theory in which three decision stages and corresponding actions are described		X		
Kaur and Singh (2017)	An analytical framework for low carbon logistics network of manufacturing located in cities			X	
Kengpol and Tuammee (2016)	Decision support framework for multimodel green logistics		X		
Krishankumar et al. (2021)	Integrated analytical decision framework for sustainable urban mobility		X		
Lagorio et al. (2017)	A generic urban logistics framework comprised of planning and management, stakeholder involvement, values and functions in an ecosystem has been presented				X
Lewis (2016)	A harmonised methodology framework for calculating environmental impacts forms only one part of the decision-making process, alongside cost, promptness, reliability, safety, etc.			X	
Liu et al. (2021)	It proposes an analytical framework depicting possible relationships of influencing factors (information sharing level and empowerment capabilities) for collaboration in logistics chains	X			
Jabbour et al. (2020)	Framework for low carbon production and logistics	X	X		
Marchet et al. (2018)	Framework for classifying logistics variables and strategic options for logistics operators		X	X	
May et al. (2017)	Develops recommendations that would enable national governments to support individual cities in creating sustainable urban mobility plans.		X		
Martin et al. (2018)	A stage-based decision framework for the development and management of horizontal logistics alliances; to support logistics service providers with horizontal collaboration and analysis of the decision process underlying horizontal logistics alliances	X	X		
Mirhedayatian and Yan (2018)	Framework to evaluate policy options in EV adoption I urban freight transport		X		
Moufad and Jawab (2019)	Provide a performance assessment framework for the urban management department explaining the impact of factors on the urban freight transport performance		X	X	
Mubarak and Zainal (2018)	A framework that helps companies to calculate CO_2 emissions from freight logistics and which gauges the level of such emissions generated by companies			X	X
Paraskevadakis et al. (2021)	services operations performance measurement framework		X	X	
Perboli et al. (2018)	A simulation optimisation framework for city logistics		X	X	
Pomponi et al. (2015)	Framework for collaborative decision based on trust and cooperation level	X			
Rose et al. (2017)	Framework for simulating the impact of logistics operations in an urban area traffic network				X
Simoni and Claudel (2018)	A traffic simulation framework to reproduce urban freight movements, particularly concerning double-parked delivery operations			X	
Suryani et al. (2021)	Modelling of urban mobility for reduced congestion impact based on a selected strategic approach			X	
Lewandowska and Golinska-Dawson (2021)	Model to assess the maturity of sustainable logistics management maturity level			X	
Zhang et al. (2020)	The study implies that factors influencing green logistics need to be priorities and these factors exist at different levels, implying the need for information exchange across levels to make use of the prioritised factors for analysis			X	

Note: COL = Collaboration and integration; POL = Policy and decision-making; ANL = Analysis and performance measurement; DSP = Design, planning and implementation.

benefit comparison on such values. Identifying relevant parameters in relation to what is perceived as value by the different stakeholders is a challenging but important aspect to develop a multi-actor multi-layer framework. Even seemingly, common concepts like "efficient use of resources" or "efficient flow" could mean different things depending on the specific role a stakeholder has in the logistics ecosystem under question.

One way to address such complexities and possible misalignment of stakeholders, given the aim of this study, is to consider a function modelling to represent the different (sub-) systems in urban logistics and mobility parent systems. Parameters and attributes of interest are identified under one of the four concepts (ICOM) using IDEF0 at a particular aggregation layer. The modelling can be done at multiple layers so that relationships and integration needs can be better perceived. A working set of aggregation layers for this study is set (from lowest to highest) as (layer 1) individual business entity, (layer 2) mobility integration and management layer, (layer 3) broader policy-making layer, and (layer 4) society layer (see Fig. 2). These layers are proposed based on the system boundaries relevant to different stakeholders and decision-making bodies.

As mentioned earlier, different stakeholders involved in urban logistics activities have goals that might be conflicting or at different aggregation layers. The proposed four-layer framework attempts to create a basis upon which sustainable urban logistics and mobility planning discussions can be held. Each stakeholder can identify their goals and interests at a layer relevant to them. The proposed framework then can capture local layer intents without losing sight of parameters of interest at another layer.

The potential for reducing negative environmental impact from transportation in and around cities can be considerable (Brusselaers et al., 2021). One way to enhance possibilities for impact reduction is by creating decision support frameworks that traverse multiple decision layers and many decision-makers. Creating collaborative settings is essential for this to take effect.

In a multi-actor, multi-criteria analysis (e.g., Macharis et al., 2009), priorities from multiple stakeholders about specific criteria are estimated as relative weights that, in conjunction with measurement methods, provide an aggregate unified result. In the multi-actor decision framework proposed in this study, essential additions are proposed:

1. Actors at higher decision layers can employ priority rules on aggregate measures that result from estimation at a lower layer;
2. Priorities set at higher decision layer can be used to inform cascaded decisions at a lower decision layer flexibly and independently;
3. Mechanisms can be established to use interaction and data exchange among layers for iteratively adjusting the accuracy of decision elements;

Decision-makers at any layer could expand the decision framework to establish alternative scenarios based on which forecasts and future planning efforts can be made.

Business entities often establish collaborations for reasons of better competitiveness, market opportunities, or addressing operational constraints (Audy et al., 2012). Most collaborations are motivated by economic gains. But collaborations could also provide additional value to address multiple dimensions of sustainability. Collaboration for decision making towards better environmental and social sustainability often entails the integration of decisions from multiple decision layers.

Once the scheme of the function model has been drafted, we then proceed towards building the framework by mapping identified concepts from reviewed literature on the function model. Since the aim of our study is closely related to the theme of sustainable urban logistics and mobility, we have considered that reviewing earlier SUMP results that could feed to a potential future framework would be helpful. These points are discussed in the next section and synthesis of key findings from recent SUMP-related projects in Europe.

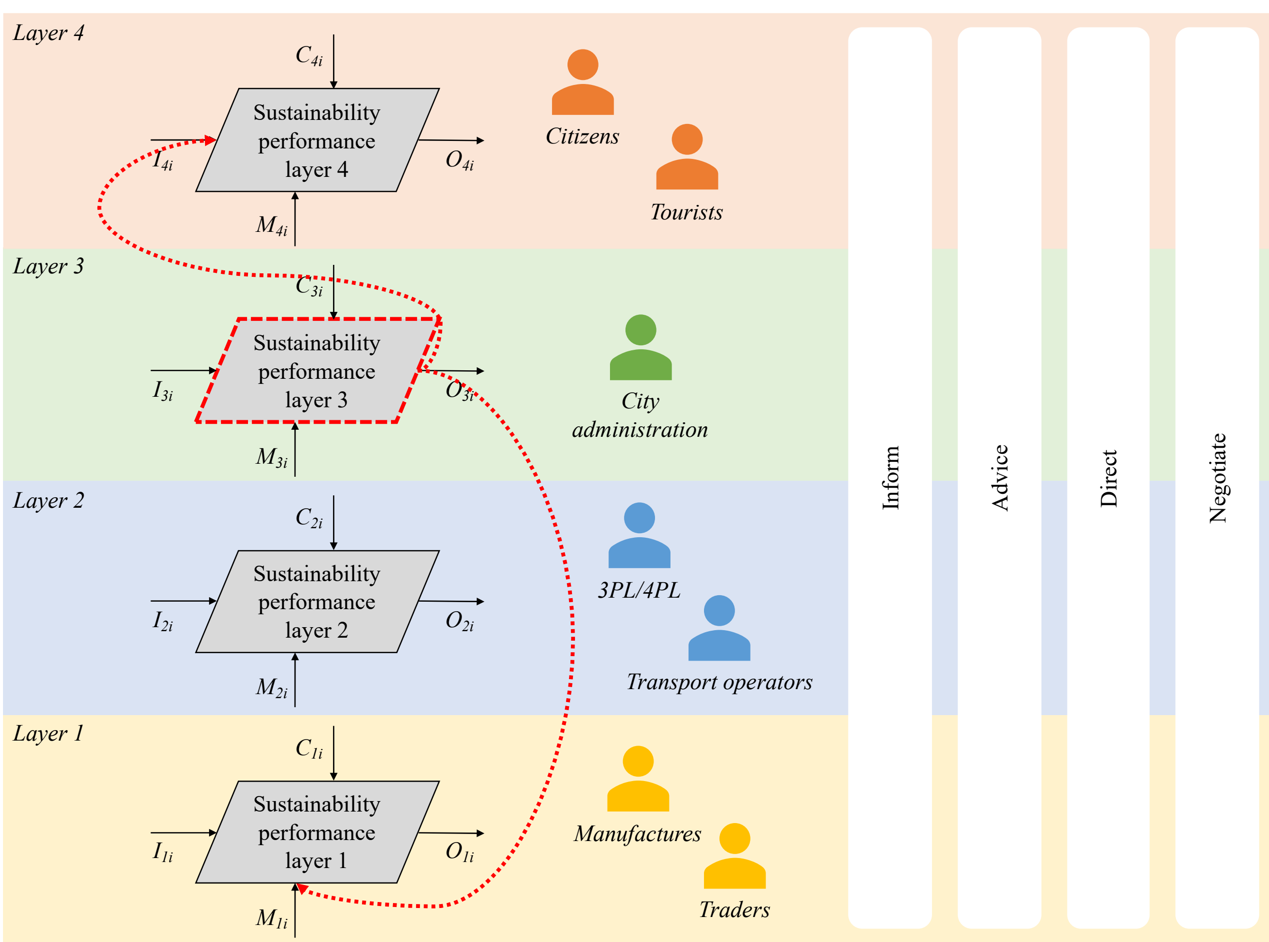

Fig. 2. Scheme of a function model with layers representing decision hierarchies.

Table 4
Mapping of parameters on multi-layer frameworks.

Relevant parameters (possible measurement items)	Layer 1				Layer 2				Layer 3				Layer 4				Reference	
	I	C	O	M	I	C	O	M	I	C	O	M	I	C	O	M	Literature	SUMP reports
Demand (trend) for mobility and freight transportation	1				1				1				1					x
Modes of transport available and compositions	1				1				1				1					x
Distance travelled	1																x	
Traffic data [(dis-)aggregated movements)					1				1				1					x
Economic profit(-ability) of business activity*			5				5										x	x
Emission levels [for aggregation, e.g., CO_2 equivalent]			6						6								x	x
Air pollution level- [for aggregation]							6		6		6				6		x	x
Air pollution levels (per # of vehicles and travel distance)			6												6		x	
Local establishments data					2				2				2					x
Inhabitants (demographics)									2				2					x
Urban zones, routes, and restrictions		2				2				2							x	x
Forecasts and scenario conditions (with breakdown)	3				3				3				3					x
Road occupancy (by running and parking vehicles)									3								x	x
Inter-Intra organisation freight consolidation arrangements								3									x	
National/regional mobility guidelines, customisations, and support				3				3				3				3		x
Urban regulations and restrictions on vehicle types used in an urban area		3				3				3				3			x	x
Restriction of access on time and routes (e.g., Off-hour delivery policy)										3							x	
Emission standards and targets		3				3				3				3			x	
Traffic congestion	7				7						7		7				x	x
Accident related fatalities											7		7				x	x
Service levels (agreed or achieved)		7				7											x	
Noise pollution level -nuisance (per # of vehicles and travel distance)			7								7				7		x	
Accident risk levels (per # of vehicles and travel distance)			7												7		x	
Delivery quality			7				7										x	x
Acceptability (by user, public & political decision-makers)		7				7				7							x	x
Employee satisfaction			7				7										x	
Mobility accessibility for citizens															7		x	x
Inhabitants' satisfaction rates															7		x	
City attractiveness											7				7		x	x
Traffic Safety and security											7				7		x	x
Loading factor	4				4												x	
Costs related to transportation	4																x	
Energy intensity [fuel per ton-km]	4								4								x	
Freight transport intensity [ton-km]									4				4				x	
Mobility resource (e.g., vehicle types) capacities available				4				4									x	

Note: 1 = basic mobility data; 2 = geo-demographics data; 3 = regulatory issues/conditions; 4 = technical parameters; 5 = economic indicator; 6 = environmental indicator; 7 = social indicator.
I = input; C = control; O = output; M = mechanism.

Stakeholders analysis

Individuals and groups that affect or are affected by processes and activities undertaken to achieve organisational objectives can be regarded as stakeholders. Understanding and creating an act of balance for apparently conflicting stakeholder goals is an essential element of stakeholder management. Some studies (e.g., Katsela and Pålsson, 2019) propose a multi-criteria decision model with an analytical hierarchy process to identify and incorporate relative weights of influence from multiple stakeholders towards the sustainability of urban logistics.

Several modelling (and simulation) approaches targeted at one decision hierarchy inevitably consider or assume information input from other layers. For instance, modelling traffic congestion in an urban area implies some mobility data is aggregated from public and private transportation and other sources from different levels. One can see such an example in Suryani et al. (2021).

The current study takes an alternative view such that each stakeholder can have an application of a holistic framework at their decision hierarchy layer, and at the same time, look at how their decisions relate to decisions by other stakeholders. This way, the model can be dynamically updated to reflect changes, emerging trends, and new information. The model also allows stakeholders to focus on the accuracy of input data as they will have the interest to utilise subsequent analytics for their organisational benefits. Information sharing is critical for logistics collaboration, especially in intelligent logistics (Liu et al., 2021).

Different stakeholders in urban logistics areas might have conflicting interests and focus, even though all might consider some sustainability goals (e.g., Anand et al., 2012; Katsela and Pålsson, 2019). For example, public authorities tend to focus on improving city attractiveness (e.g., Buldeo Rai et al., 2017; Janjevic et al., 2019) while business companies look primarily for offering their business offerings at reduced operational costs possible (e.g., Browne et al., 2012).

In Table 4, we have identified different parameters at different aggregation layers and identified them as an input, control, monitoring, or output mechanism according to the IDEF0 terminology. These parameters may have other influences at the different aggregation layers. Therefore, they will also affect the stakeholders' decision-making in various ways since stakeholders' roles and goals may differ (e.g., Anand et al., 2015) depending on the aggregation layer. This can be illustrated in an example of considering the parameter "urban zone and routes designations and restrictions," which, according to Table 4, has a control function on the individual business and broader policymaking layers.

Taking the municipality as a stakeholder, it may act as an entrepreneur at one layer by offering mobility solutions to its citizen and companies with production sites within the area. In this function, the municipality would seek to fulfill its customer needs- i.e., the travel needs of its citizen and the companies' need for delivery and supply of goods. Naturally, it would try to comfort and support services that fit the demand (i.e., busses late at night in the living area, the prices of service, truck deliveries serving the need of the production or operating hours, etc.). Still, on the other hand, it would also need to entertain the citizens' need of low noise during night time, reduction of the pollution, etc., which might increase the fair price, due to restriction on vehicles, and limitation in routes to operate. At the policy-making layer, the same municipality has the function to place guidelines and regulations for collective social, environmental, and economic targets achievements. Having this in mind when analysing the articles related to sustainable urban mobility plans shows an awareness of conflicting goals among the stakeholders in an urban area.

We have illustrated in Table 3 that frameworks proposed in extant literature often focus on one of the possible application areas. This might lead to an inconsistency in the decision-making process due to the often lacking visibility of decision-making processes among the different layers and application areas. This implies that the needs of the stakeholders that are reflected in the frameworks on collaboration and integrations are not necessarily reflected with the design, planning, and implementation or in the policy application area. Likewise, stakeholders' objectives and performance goals at different layers, as shown in Fig. 2, could be other. As an example, this can lead to a stakeholder like a manufacturer in a city area, and its suppliers and transport service providers are not adequately involved in the planning process of new urban measures for fulfilling a SUMP plan or decreasing environmental pollution and noise. Steps for improving this are, for example, not allow heavy transport during night times, delivery zones, etc. Suppose this is not coordinated with the needs of the companies. In that case, it might induce a negative impact since the window for delivery may clash with the main commuting hours or that there are not sufficient parking lots in and around cities, etc.

The following section will describe our proposed framework that combines the different findings extracted in our analysis (section three and four) that may allow a more holistic view. It first details the methodological approach before applying the outcome of the investigation (outcome presented in sections three and four) by constructing the specific layers for our multi-layer urban logistics framework.

Synthesis from earlier SUMP projects in Europe

Research findings from SUMP projects in Europe have been published in the form of reports or academic articles. The SUMP projects have different application scopes and diverse stakeholders involved. Therefore, they provide a way of validating if parameters identified from the literature are relevant for some stakeholders or decision layers. Using the SUMP reports, a few additional performance items not identified from the literature have been added. This can be seen from Table 4 last column, as it depicts whether parameters were determined from literature, SUMP report, or both.

The synthesis is organised as follows. First, the project reports are reviewed to identify if any form of framework or guideline idea has been proposed. Those considered relevant for the current study have been identified and summarised in terms of application area, proposed and applied methodology, identified stakeholders, and parameters of interest. This synthesis has identified parameters of interest for different stakeholders, compared with parameters reported in the literature, and mapping of these parameters on the proposed multi-layer framework.

Extant literature in urban logistics provides a large set of sustainability indicators as applied at one decision-making level. Bringing that together would have limited benefit without consideration of different decision-making levels. On the other hand, the reviewed reports from multiple SUMP projects in Europe show that many of them propose (and in some cases demonstrate) practical solutions towards integrating better sustainability related to urban mobility. The challenge is that these reports often provide very generic descriptions of goals and stakeholders, mostly without distinguishing which parameters of interest are relevant to which stakeholders and at what level. Some of the conceptually discussed "indicators" of sustainability dimensions are not easy to measure or estimate. One such example is city attractiveness.

There are many indicators for logistics performance, many of which can be directly mapped to sustainability performance. Prioritisation and understanding of the factors and the more applicable hierarchies are essential in logistics research (e.g., Zhang et al., 2020).

Table 4 shows the mapping of identified parameters on the proposed multi-layer framework. It combines findings from literature and SUMP reports. Parameters of interest are mapped at multiple layers into IDEF0 function concepts (categories). We try to demonstrate how the parameters identified from literature and SUMP projects appeared to be related to the ICOM (I = input, C = control, O = output, and M = mechanism) model such that we can establish possible relation among the decision layer.

The idea of Table 4 is not to have an exhaustive list of parameters. It is instead to exemplify some parameters of interest and how they relate to decision-making at different layers. Another form of relation could be noted among the layers concerning parameters. Some have an aggregation/disaggregation relationship. For example, CO_2 emission equivalents from multiple business organisations at layer one can be aggregated to estimate total emission levels at policy or society layers. Others could be used as feedback to adjust the next iteration or collaboration relationships; for example, traffic congestion level is an input for decision at layer one. It could be treated as an output value at layer three that can be fed back to layer 1 for the next computation rounds. Others could be accumulated to form a more comprehensive performance dimension that might not have been captured in other (e.g., lower) layers; an example is city attractiveness that individual logistics companies do not target. As we mentioned before, stakeholders have varying goals, and this can be reflected in the mapping of performance parameters at different layers. Using multi-layer modelling, a better perception of how stakeholders at other layers are doing can be gained for better-informed decision-making.

4. Towards a collaborative urban logistics framework

Modelling using IDEF0

Combining the multi-layer framework scheme and the identified parameters as applicable at multiple levels, this study results in an IDEF0 model that can be used to represent the relationship among parameters.

As outlined in section two, the modelling follows the input-control-output-mechanism definition. The whole framework follows the same pattern at multiple layers. However, the specific parameters in each category may be different. The value of similar parameters may also change due to aggregation/disaggregation and other influencing inputs relevant at a particular layer. We think that a better understanding of the proposed framework can be established by presenting a simplified representation of the IDEF0 diagrams representing the four-layer, as shown in. Generic IDEF0 modelling representation. The representation in this figure is generic despite layer (i = 1, 2, 3, 4).

These diagrams shall be iterative by switching from one level to the other following interconnected parameters of interest. The iterations also depend on the interdependence of stakeholders' goals in a participatory planning/decision-making setting.

The generic IDEF0 model of Fig. 3 is decomposed into a more detailed representation, as shown in Fig. 4. The figure shows a generalised representation of processes and relationships applicable within the generic IDEF0 model. It is possible to observe, for example, that eight processes (numbered 1–8) are shown in the diagram that represents steps from identification of hierarchies for aggregation to the estimation of local, sustainable performance to passing arguments to other aggregation or decision layers.

Fig. 5 shows a different level of decomposition example. It represents details of process 7 (local optimisation) from Fig. 4. Using Fig. 5 as an example, we illustrate how the IDEF0 model can be broken down to a required level of detail for each process (and subsequent sub-process) specified in a higher-level model using indicators identified in the articles in Table 3 and the ICOM classification of the SUMP projects in Table 4. Furthermore, the sub-process specification may be applied either as generic to all decision (aggregation) layers or specific to a particular layer.

Figs. 6 and 7 represent the generic IDEF0 at layer 1 (business entity) and layer 2 (service integration and management), respectively. In these two figures, one can note that some parameters are related to data from other layers. The relation represents information and data being transferred from one layer with availability to another, including aggregation or disaggregation transformations.

Operationalisation of the proposed framework in urban logistics problems

The proposed framework is based on a combination of existing frameworks found in the literature. It aims to be a tool that will support the communication and visualise the needs, restrictions, and resources the various stakeholders have at the different decision levels (compare Fig. 2). Figs. 6 and 7 illustrate a generic specification at two different decision layers. Applying the framework with a bottom-up approach would mean that the output 'logistics flow,' 'social impact,' and 'environmental impact' and at layer one would be used as input for layer 2 (demand for mobility and freight). However, the output at layer 1 is dependent on the vehicle type. At layer 2, where we also have the 3 and 4 PL and the transport operator, the vehicle type can be modified to stay within the restriction' urban area regulations* or the 'SUMP.' This is illustrated in Fig. 8.

Using a top-down approach for the same two levels could mean that a specific set of congestion levels or max allowed emissions contributions would serve as a restriction on layer 1. In this case, again, we can either change the vehicle type or adapt the company plans and schedules. At a theoretical discussion level, this is quite a straightforward exercise. However, bearing in mind that one challenge, according to the ETP-ALICE roadmap on Urban Freight, is to create awareness and understanding, there is a need for more practical implementation of the framework that can generate sufficient data for different solutions also taking into account that there is a lot of uncertainties. Operationalising the inputs, outputs, and constraints as boundaries in a simulation model will offer experts a possibility to discuss the different effects at each layer and create a more holistic understanding of how a decision in one layer affects decisions at another layer. Next section will explain this approach in more detail.

5. Discussion on framework execution

The framework proposed in this research addresses the urban logistics problems considering sustainability aspects at one hand and the challenge of decision-making in multi-stakeholder, multiple layers or hierarchies in which the different stakeholders may have different needs, requirements, and above all, goals. In this section, we discuss the possibilities for its implementation.

Proposed framework as a decision support tool

Urban logistics problems are classified by transportation, network and infrastructure problems, vehicle routing problems, urban consolidation, and mutualisation problems, inter-modality problems, and electro-mobility problems according to the characteristics of the issues (Jlassi et al. (2017). As a decision-making support tool, our framework is applicable as a guideline. For example, as Nuzzolo and Comi (2014) suggested, a simulation system based on the framework is useful for urban freight transport to support decision-makers before planning. Also, Simoni and Claudel (2018) proposed a method and model as a decision-making support tool that considers the interaction between freight movement and traffic.

Practical operational application of the framework implies that smooth and preferably automated information exchange among stakeholders or feeding to a central platform would facilitate further identification of decision options. An example of how such an interoperable information system application could work in an urban logistics setting can be found in Jacobsson et al. (2020).

In addition, Karakikes and Nathanail (2017) investigated how to analyse the effectiveness of smart logistics solutions on urban logistics and the impact of the sustainability perspective. Our framework covers the sustainability perspectives as well as this paper. Also, the framework can be applied in smart logistics solutions to urban logistics problems.

Proposed framework as input for modeling, simulation

A model is a representation of a system, and a simulation is the operation of the model, according to Jlassi et al. (2017). The framework that we proposed in this paper can be executed for modleing and simulation in urban production logistics, and the utility of the framework can be justified from the researches in this area. For example, the multi-layer model for pedestrian dynamics problem (Gaud et al., 2008), urban goods transports (Gonzalez-Feliu et al., 2012), improvement of traffic congestion (Suryani et al., 2021), and large-scale problems in the automotive industry (Straka et al., 2018) was suggested to model the complex system.

Since various models existed for urban logistics simulation, we also found essential to use existing models to build scenarios that fit the requirements and evaluate the simulation results. For example, Ambrosini et al. (2013) defined the policy-based scenario's key elements and analysed the inputs and outputs from the pre-defined urban logistics simulation model, the FRETURB model. This approach is in line with the output items of the framework we suggested.

The discussed simulation research show how simulations based on specific models related to logistics problems (sufficiently mapping the real world's processes, but still simplified, in our case, the IDEF0 models) can be used to understand a system behaviour better and thereby to create new knowledge keeping more control on the system's boundaries and variables. Therefore, the next section will outline an implementation plan that will make it possible to transfer our theoretical and generic models into a simulation of a specific area of investigation.

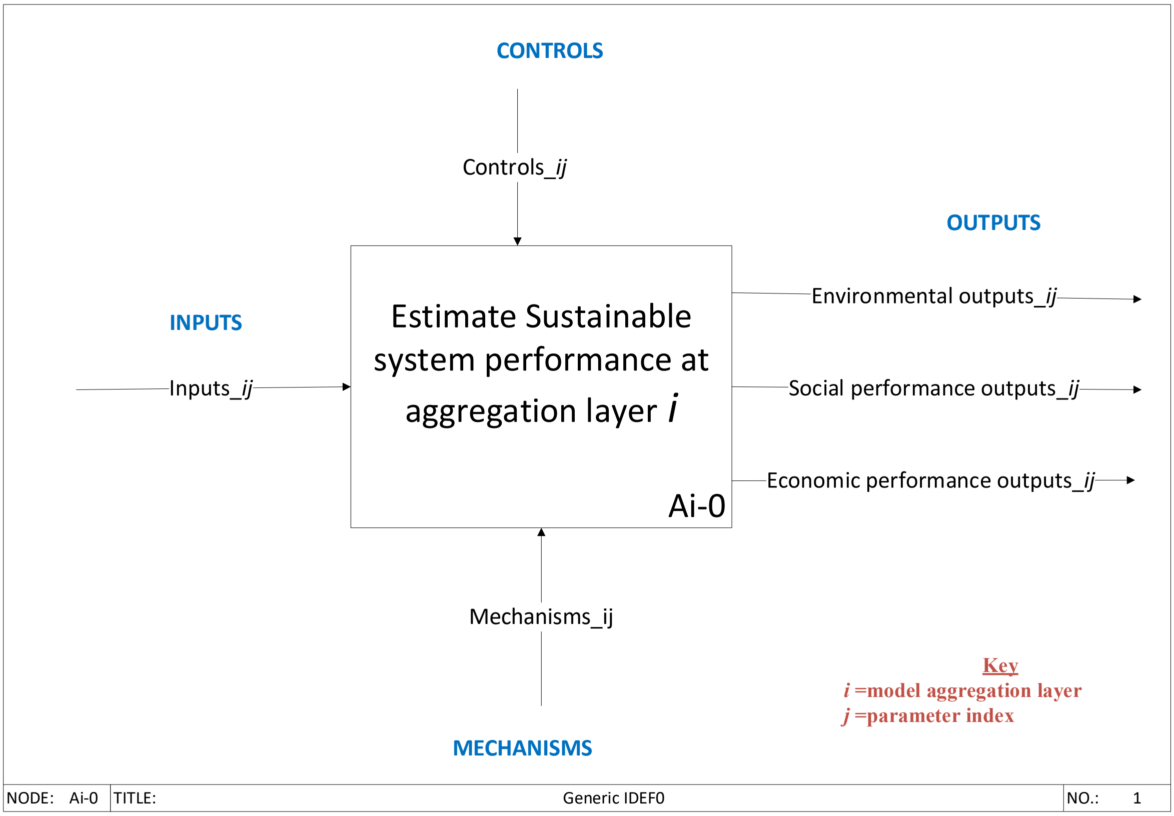

Fig. 3. Generic IDEF0 modelling representation.

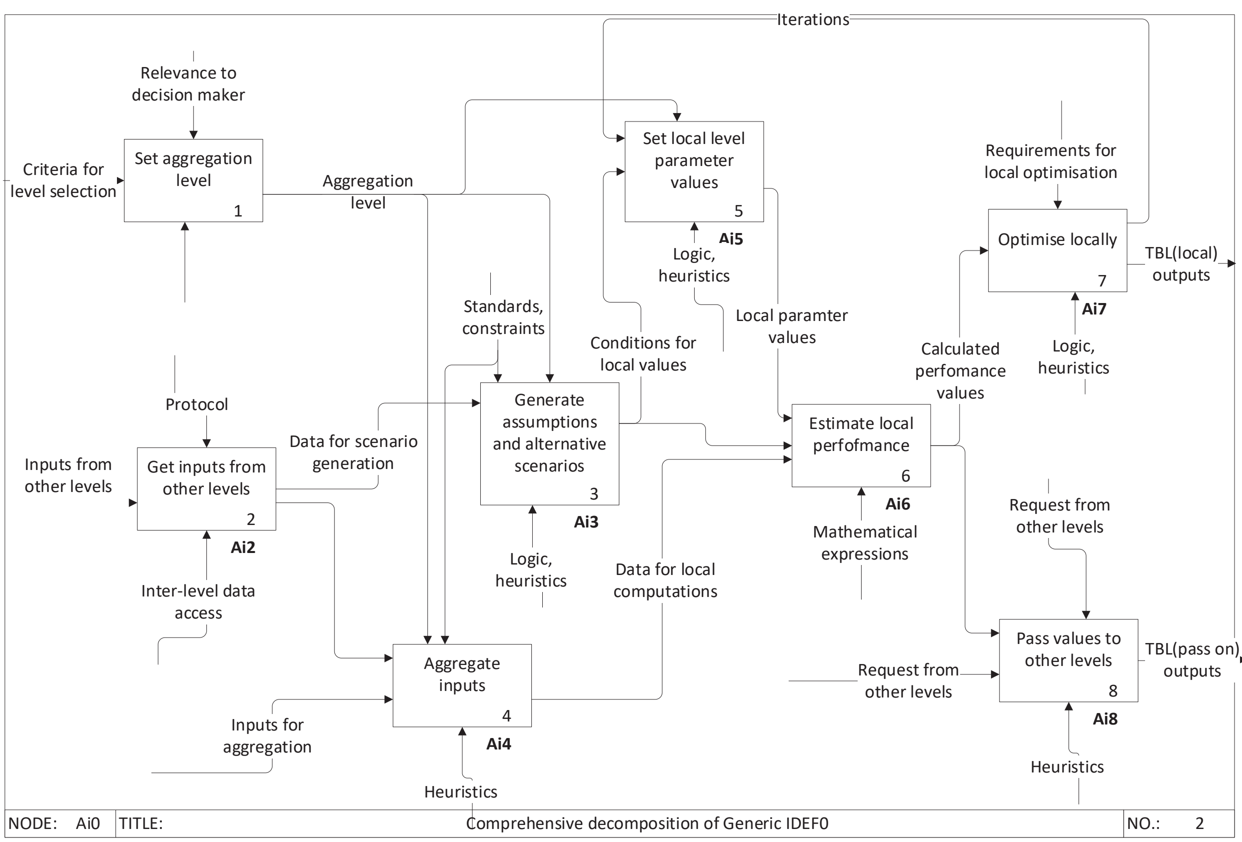

Fig. 4. Detailed decomposition of the generic IDEF0.

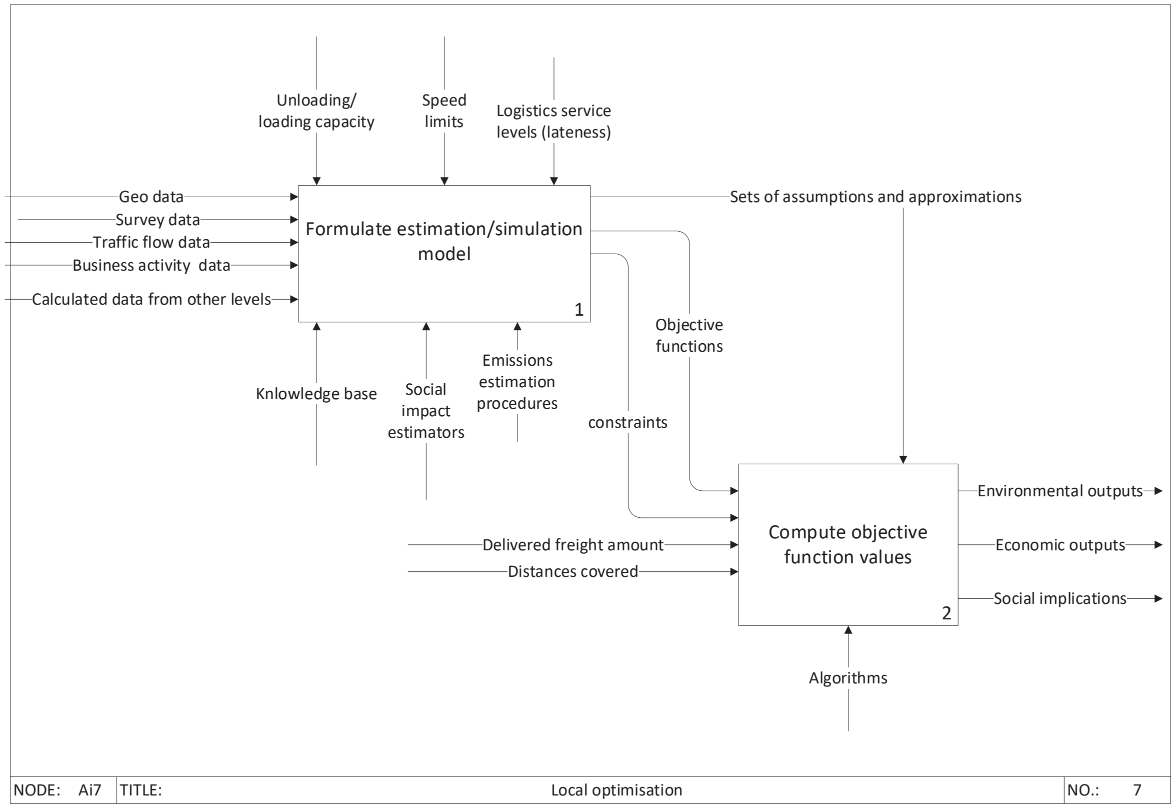

Fig. 5. Decomposition of local optimisation sub-process from the generic IDEF0.

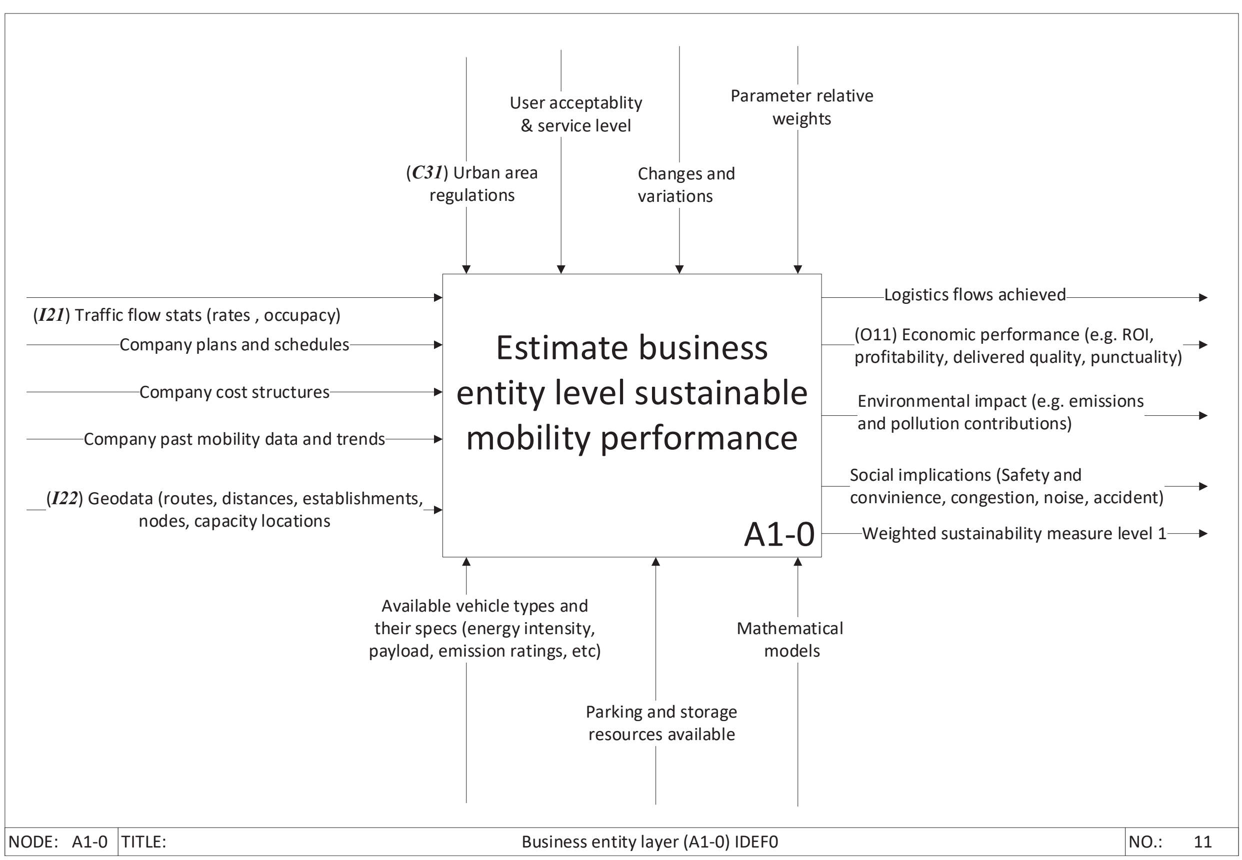

Fig. 6. IDEF0 generic specification for aggregation layer 1.

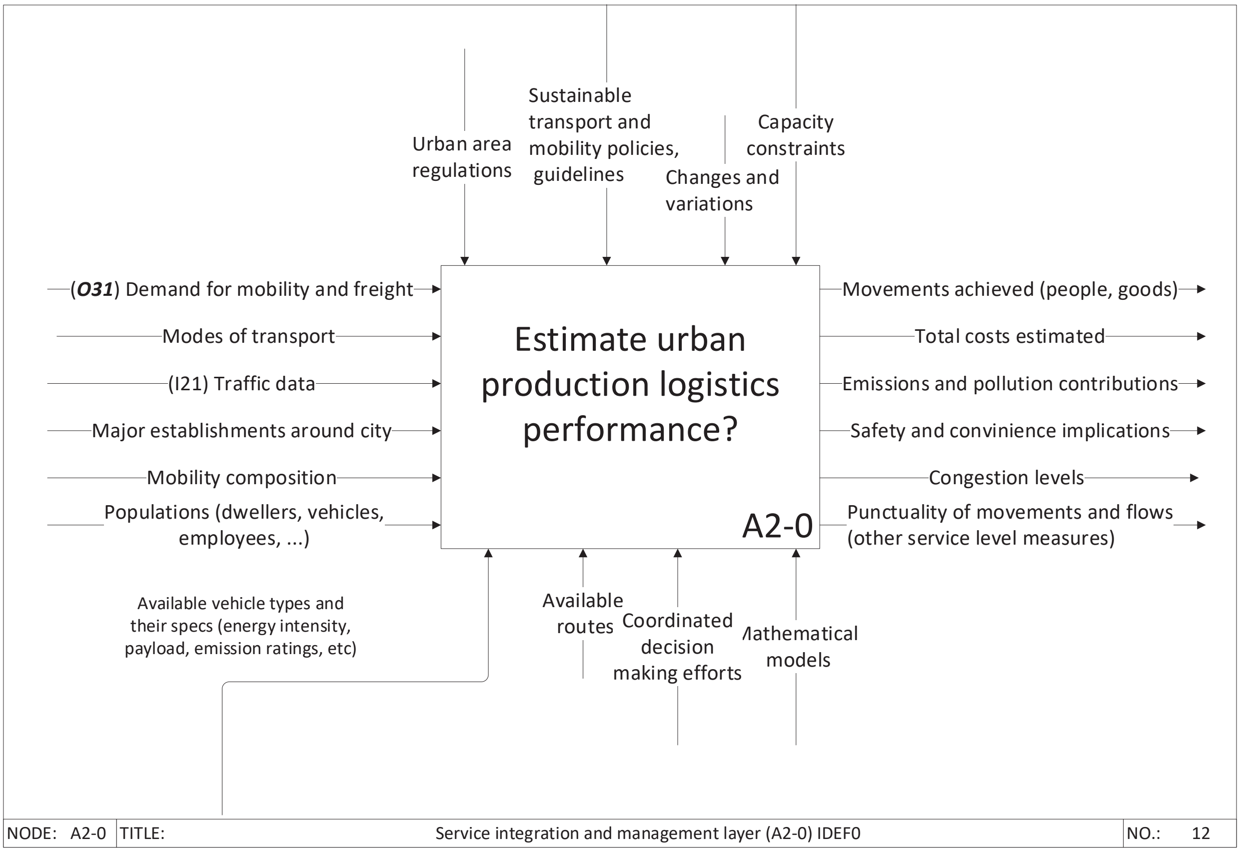

Fig. 7. IDEF0 generic specification for aggregation layer 2.

Implementation plan

The proposed framework in this paper can be applied for building a simulation model of urban production logistics problems from heavy industry, shipbuilding industry, and large construction projects such as high-rise building construction with large and complex production sites, since such cases generally have to consider various stakeholders and different levels of detailed information.

For a better understanding of the proposed framework, this section define an example to illustrate: a virtual company, X. Company X is a large-scale manufacturer of heavy construction equipment, trucks, and buses, and it is located in city Y. In this city Y, there are several production sites of company X, each production site is located within a short distance, but public roads connect them. Company X has suppliers in other cities as well. Fig. 9 represents the layout of production sites of company X in city Y.

A simulation model of the single unit factory (e.g., assembly factory, machining factory, and logistics center) can be built based on the proposed framework. Operational regulations and restrictions are required as constraints, and input data based on forecast scenarios or product demands using historical data is necessary for simulation model building. It is possible to analyse production logistics occurring inside the factory and evaluate logistics facilities' travelling distance through this model. In addition, the simulation could be conducted with the aim of low-carbon and low-emission to minimise the environmental impact at the factory level.

There are inter-factory logistics in the large-scale production site with multiple unit factories. Therefore, a simulation model is required from a broader perspective, such as the management level of the production site, to analyse logistics flows between the factories. The regulation at the enterprise level and the unit department and unit factory is required in this case. Since company X is located in the city Y and they use the public roads between the production sites, the various regulations necessary for the public road and local traffic data from the city Y should be used as input data to construct the integrated simulation model. For example, the logistics flow to the Assembly 1 factory in Fig. 9 must pass through the public road. It is necessary to establish a logistics plan in accordance with the regulations required by city Y and also consider the traffic of public roads.

It can be expanded to a broader point of view, and it is possible to have a perspective from suppliers located outside of the city Y. In this case, public transportation traffic and individual traffic flow should also be considered. In addition, since those logistics flow through the city, it is necessary to consider regulation from society's perspective, such as environmental impact analysis and noise level. Then the same framework could be used to develop simulation models in line with the local policy decision layer.

We can also consider the commuting simulation model of city Y citizens employed by company X. In this scenario, not only the public transportation schedule and traffic flow estimation information but also the shift schedule information of each employee are used as simulation input data. As such, the framework proposed in this study helps to link the information defined in different layers and use them for various purposes.

6. Conclusion

While modal shifts in city mobility are one excellent way to reduce congestion and subsequent negative impact of unsustainable transport around cities (e.g., Schliwa et al., 2015), it does not contribute to overcoming all challenges that derive from steadily increasing traffic, limited access to infrastructure and little goal congruence. The lack of common "language" and integrated multi-layer decisions for sustainable logistics is also a considerable challenge. This paper aimed to contribute

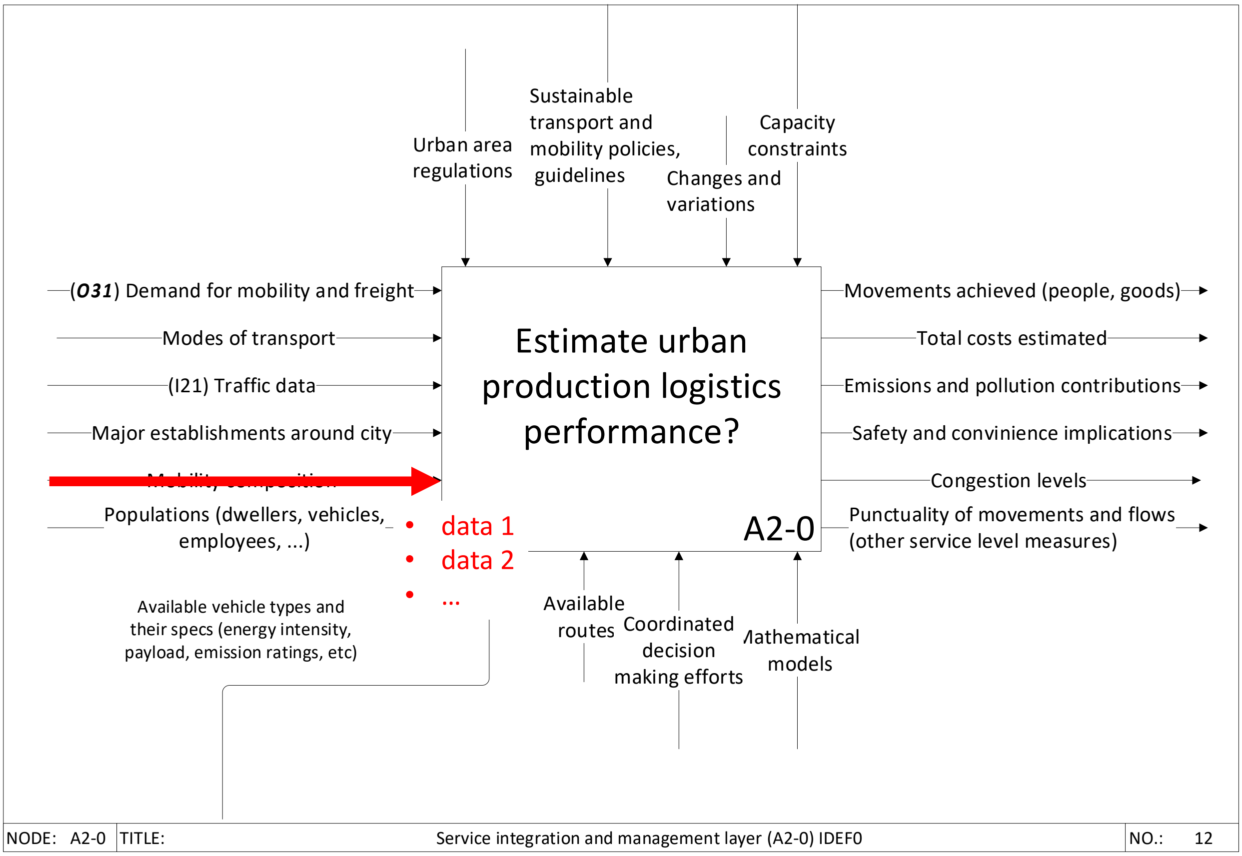

Fig. 8. Operational example of the proposed example.

in a direction that supports mutual understanding of these challenges while showing how decisions at different levels influence decisions and stakeholders at other hierarchy levels. The outcome of this research that is based both on a literature review and analysis of previous research projects on urban mobility, is a multi-layer framework to model and understand the complex nature of participatory decision-making for sustainable urban logistics. The framework consists of a hierarchical function model with four layers (Fig. 1) consisting of a set of IDEF0 models (see section four). The proposed framework intends to visualise the link between the different layers and the interrelation between the decisions. The usage of the IDEF0 methodology with its process focus helps in showing how an input at one layer can serve as a control mechanism on a different layer. Based on the literature review, we have derived several different indicators (partly independent factors, partly functions) relevant to the stakeholders' goal achievement and thus influence the decision-making process. These also allow us to model parameters and relationships at four different levels. The framework also depicts parameters of interest at each level.

There are some limitations in our study as well as in the developed multi-layer framework

a. The literature review has tried to capture a broad research discourse in an attempt to be comprehensive. This in itself makes detailed analysis difficult, and that broader perspective creates a challenge to integrate diverse views into a common theme.
b. A part of the analysis relies on previous project results. The main challenge is in the identification of relevant projects. We have mostly used the EU research database Cordis, references to project found in other EU publications like ETP ALICE, or research articles. It might therefore be possible that relevant project results have been overseen
c. In the conceptualization of the framework, we have focused on processes relevant to production logistics. Since the basis of the framework IDEF0- a function diagram- describing the interaction between input variables, control, and mechanism forming the output. The interaction, as well as what is defined as an input, control, and mechanism, are specifically mapped for this part of supply chains and is not without further analysis transferable to distribution logistics. The model is unlikely to be applicable for full reverse logistics or the supply chains since the controls as well as the mechanism differ.

Furthermore, we still need to investigate in more detail any limitations we identify in the operationalisation and make them more usable for a potential user group. In this paper, we have analysed the possibility of transferring the framework into simulation models based on previous work. This seems suitable for the next step. Based on our experience, we believe that the proposed framework could further facilitate the participatory design of urban logistics systems in which the diversified interests of stakeholders can be simultaneously viewed.

Currently, the framework is made explicitly for production logistics, but it might be transferred and applicable for other areas of mobility due to its generic scope. Thus, in the next steps of the research avenue, we envisage developing simulation models with which the framework can be validated for different urban mobility solutions.

CRediT authorship contribution statement

Jannicke Baalsrud Hauge: Conceptualization, Writing – original draft, Supervision, Project administration. **Seyoum Eshetu Birkie:** Methodology, Writing – original draft, Validation, Data curation. **Yongkuk Jeong:** Writing – original draft, Writing – review & editing, Visualization, Investigation, Resources.

Fig. 9. Production sites and surroundings of company X in city Y.

Declaration of Competing Interest

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

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Appendix A:. Author keywords from shortlisted papers

- Sustainable logistics
- City logistics
- Collaborative planning
- Collaboration platform
- Collaborative logistics
- Coordination mechanisms
- Decision (support) framework
- Decision making
- Enterprise collaborations
- Freight transport
- Horizontal cooperation (collaboration)
- Land use and transport
- Logistics and transportation
- Logistics service
- Multi-Actor * Analysis
- Reverse logistics
- Stakeholder involvement
- Third-party logistics (3PL)
- Urban ecosystem
- Urban freight policy
- Urban freight transport
- Urban logistics
- Urban mobility
- Stakeholder engagement
- Organisational collaboration transport infrastructure
- Reverse collaboration
- Forward and backward logistics
- Fourth party logistics
- Logistics 4.0
- Production logistics

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