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The integration of passenger and freight transport for first-last mile operations

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\section*{A B S T R A C T}

The “First-Last Mile” problem (FLM) is a relevant transport issue. According to the Green Paper on Urban Mobility, the combination of passenger and freight flows may be a valid approach to promote sustainable, efficient and socially desirable FLM transport. This paper proposes a set of key performance indicators to evaluate potential improvements in operational, environmental and social performances of integrated passenger and freight flows, compared to the current transport schemes. The two case studies of the Northern lagoon of Venice in Italy and the Slovenian Municipality of Velenje indicate that the model may be particularly effective in those cases where reduced freight volumes, limited freight pickup/delivery locations and a lower elasticity of the travel demand reduce the constraints to the adoption of this integrated scheme. Results call for a reduction both in distances travelled and in externalities produced, and hence a good potential in FLM terms. Beside these technical aspects, one of the main issues is the need for innovation in the normative/regulatory context: a prerequisite in order to apply this solution to real-life contexts.

\section*{1. Introduction}

Passengers and freight mobility are facing growing challenges, such as urbanization trends, the increasing complexity of stakeholder scene, e-commerce and rising fragmentation of freight transport. All these changes have negative impacts on congestion, safety, environment and quality of life in general (EC, 2019). The First-Last-Mile problem (FLM), involving the first/last leg of each transport movement, is one of the most challenging aspects because of its high costs and generated impacts on both the environment and the communities of the concerned areas (Macioszek, 2018). Authorities and decision-makers have so far produced uncoordinated policies and regulations to tackle such issues, often resulting in minor or even counter-productive effects (Nocera et al., 2020).

Referring to FLM, mobility and logistics deal with relevant issues in both dense urban cores and in rural or peri-urban areas with lower densities. Pursued uncoordinated, hurried measures have generally brought no or few positive results. This paper will analyze the potential of the integration of passengers and freight transport, as a possible solution to those issues. For mobility integration, such effort is in accordance with the 2007 “Green Paper on Urban Mobility” (EC, 2007): the document suggests how strong inter-modal and inter-sectorial passenger and freight integration could improve mobility and logistics efficiency as well as sustainability, while at the same time promoting a socially acceptable approach, responding to authorities’ needs and indications. Even if the definition was introduced more than a decade ago, this integration has been analysed by scientific literature only in a limited amount of cases: in their recent literature review, Van Duin et al. (2019) were able to find only four papers dealing with this issue. A few more recent contributions focus on the potential of the integration, identifying a list of challenges (Tavasszy, 2020), discussing an urban case study in Bratislava (Galkin et al., 2019) and a rural implementation in the Netherlands (Van Duin et al., 2019).

This paper discusses in further details the potential to serve first-last mile operations by combining passenger and freight transport, particularly highlighting the consequences in addressing FLM issues. The focus is on the analysis of achievable operational, environmental and socioeconomic benefits and improvements, as well as on regulatory and operational constraints that currently interfere with the promotion of the mobility system as a whole. The paper is structured as follows: after the definition of the FLM problem (section 2), section 3 discusses a possible integration of freight and passenger transport, defined as IPFL

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problems may be attributed to reasons related to growing freight volumes, increasing fragmentation of orders and deliveries, and a wide and interactive range of users, resulting in numerous and dynamic but scattered exchanges, which is business-to-consumer and business-to-business and even consumer-to-consumer oriented. These problems occur much more seriously in highly developed and e-commerce-oriented countries. In fact, traditional retail patterns become more complex and fragmented due to the diffusion of online shopping. Two main elements are responsible for FLM-related issues: passenger mobility (both public and private transport) and freight transport. These two components generate high traffic volumes and costs, especially in dense urban areas where several uncoordinated operators and carriers follow different routes with low load factors.

High costs related to the FLM are also due to the dominant separation between freight and passenger transport. For passenger mobility, the FLM suffers from similar issues, as it involves a considerable amount of disutility for passengers. Indeed, conventional transport modes can be rather slow, inflexible and unreliable at this stage of the trip and might not provide a direct or reliable connection for all passengers, thus favoring the use of private transport modes. These reasons make it difficult for transport and mobility operators to provide an efficient service, i.e. managing to get the right product at the right time and at the right place, at sustainable costs for both operators and society. It is often not possible to invest resources to obtain a higher capacity, either because of possible lack of space for expansion or because of the prohibitive costs that this change would imply (Savelsbergh and Van Woensel, 2016). A coordination in flows is therefore needed, together with consolidation of freight volumes, and multi-organizational cooperation. It is necessary to promote innovative concepts at all levels: design, planning, execution, remembering that no pre-designed theoretical model can fit to real-life city logistics (Savelsbergh and Van Woensel, 2016). A cooperation between public intervention and company-driven efforts, a locally based strategy and a mix of technical/technological solutions (such as alternative fuel vehicles, use of real-time fleet management data, etc.), logistical solutions (such as supply chain collaboration etc.), and policy solutions is needed (Kant et al., 2017).

In areas with lower densities, such as the peri-urban or rural contexts, possibly dealing with shrinkage, public passenger transport faces increasing spare capacity and anti-economical operations, often resulting in poor or no service provision and therefore in transport-related social exclusion (Stanley and Lucas, 2008). Similarly, goods carriers might experience higher costs as demand is low and sparse and therefore offer limited service, thus consequently increasing the areas’ isolation (Boyer et al., 2009; McDonagh, 2006). The growing urbanization trend is expected to result in an urban population of around 9 billions in 2100 (Savelsbergh and Van Woensel, 2016): both urban dense areas and shrinking rural or peri-urban areas will grow in number and size, bringing completely new challenges to many sectors, including that of FLM passengers and freight operations (Taniguchi and Thompson, 2018). The urban mobility system operates indeed in a constantly mutating environment, on which it has – obviously – both positive effects and negative effects, such as contributing to congestion, creating safety concerns, participating in lowering the environmental quality of the city (Mozos-Blanco et al., 2018; Bonéla Fontoura et al., 2019).
et al., 2016). A discrete amount of literature describes possible policy and actual measures to tackle the issues of urban freight transport and of the FLM freight more in general. A common element can be found in the need for support of consolidation facilities and for practices to achieve Joint Delivery Systems, aided by normative and economic pushes towards cleaner operations and innovative practices (Monios et al., 2004; Taniguchi, 2014). Not much has been written on measured impact of radical improvement strategies. This is because those strategies often fail to take off due to their complexity, while also independent measures that have been promoted and tested have repeatedly proven to be ineffective (such as investments in urban consolidation centers and cargo trans systems) (Strale, 2014; Ardvisson et al., 2016). Literature stresses how an increasing capacity to integrate freight transport and other urban activities and to cooperate among stakeholders, regardless whether public or private and whether impactful or impacted, can lead to a more economically and environmentally sustainable FLM. The following section focuses on IPFL as a way to put in practice this level of integration and coordination, while improving the urban mobility system and the freight-passenger FLM from the perspective of economic efficiency, user acceptance, environmental performance and resilience.

3. Integration of freight and passenger transport and first-last mile distribution analysis

The combination of people and cargo flows implies a strong link between urban freight transport, the urban mobility system as a whole and the key stakeholders in city management and economy: public administrations, actors involved in the trading system (such as shop-keepers, carriers, manufacturers), and residents. The combination of passengers and goods transport flows has the main objective of “design [ing] networks and related planning and scheduling policies to enable efficient and reliable delivery of each parcel” (TKI Dinalog, 2020). Such model is an integrated system, in which passengers and goods share vehicles, infrastructures, urban space or more than one of these at the same time. Needless to say, such an integration is complex and involves different aspects. Fatnassi et al. (2015), for instance, show the potential gain in sustainability of sharing goods and passengers on a network, focusing on the improvement of service time and wasting energy.

Moreover, the focus is on the mobility system’s efficiency and efficacy (or reliability), resulting in more viable operations compared to the existing model where passengers and freight transport are referred to as independent systems (Ardvisson et al., 2016; Monios, 2019). This implies lower direct and generated costs for all involved stakeholders, more care for environmental issues, higher social value. Such a scheme must be accompanied by consistent policy and coherent planning: regulatory and policy aspects are crucial in determining success for the different instances and currently constitute the biggest barrier to their diffusion (Bruzzone, 2019). Cargo and passengers transport are not only considered by governments as separated systems, but they are also referred as such by the law, regulated by different authorities, and subject to different rules and guidelines, different contractual and employment structures. Spoor (2015) notes that regulatory constraints contribute to increase the costs of the delivery chain. Ghilas et al. (2013) recognize the complexity of the system, where many stakeholders interact—namely “passenger-door-to-door transportation, package transportation and public fixed line services”—and produce different scenarios considering different integration levels. The capacity to establish profitable cooperation is a necessary condition for the success of an integration process, but it takes time and a great deal of political effort. Timing-related issues, like passengers’ sensitivity to travel times and their prioritization over goods, time-limited availability of stores for receiving delivery, just-in-time deliveries and the management of just-in-time orders through web platforms, are a significant constraint to a worry-free integration (Fatnassi et al., 2015). Other relevant constraints are related to the need of sparing transport capacity during certain times of the day or periods of the week, to the flexibility of scheduled transport, and to the reverse logistics, including both waste management and the return of empty rolls and containers. Conversely, other aspects may contribute to reduce the complexity of the combined operations, by lowering overall costs and inefficiencies. These aspects include a low passenger demand, a lack of valid alternatives to public transport (especially for the vulnerable population that cannot use the private vehicle), low freight volumes and concentrated pickup-delivery locations.

The passenger-freight integration concept is not new: the idea of outsourcing part of the delivery process has already been around for decades for what concerns long-haul air and rail operations, where mixed usage of one aircraft or train is not unusual (Ghilas et al., 2013). The central aspect lies in the fact that the possible usage of overcapacity of public transport to carry freight for short-haul FLM operations is proposed. Since the first hint towards a shared passengers and freight (urban) transport system (EC, 2007), the idea has evolved in the space dimension, not necessarily being limited to urban operations, but trying to encompass short-haul passengers and freight operations in general. Trentini and Mablene (2010) published a list of projects focused on sharing “public transport services, public road space or existing urban areas”, which can be considered as a pioneering attempt. A fully working IPFL system requires a consistent change of the operational model for its implementation, including scheduling, fares, the whole pickup, transfer and delivery process, and physical changes to assets (vehicles and infrastructure). Before implementing such a complex and resource-taking strategy, local administrations and public and private companies (including goods manufacturing and delivering companies, passengers transport authorities, service management agencies) should refer to their domestic contexts exhaustively.

In urban areas, benefits for passenger-freight FLM issues are not only financial (minor expenses) and environmental (less energy consumption), but can include also a better use of the urban space. In peripheral areas, another benefit related to the users’ perception of service is that the cost reductions resulting from the integration of transit services and freight deliveries would allow for additional, more frequent transit or delivery services. By reducing the perceived cost of public transport, this may relieve the feeling of isolation typical of several rural areas. Available literature demonstrates through the analysis of real or simulated solutions the potential for short-haul mobility operations. Ghilas et al. (2016), Jansen (2014), Spoor (2015) and Li (2016) show how the entire freight sector (manufacturers, shippers and carriers, and receivers) generally gains economic advantage from loads consolidation and FLM delivery by public transit. They agree in stating that public transport operators obtain economic advantages when making their spare transport capacity available for transporting parcels and/or small goods units. Moreover, public authorities can financially benefit from increased sustainability of transit operations, which will need lower subsidies. Benefits related to the social sphere have also been recalled: less onerous transport operations pave the way for additional, otherwise anti-economical, delivery and passenger services. These supplementary services are better suited to shrinking areas and they increase their attractiveness for current and future inhabitants, which would benefit from better FLM sustainable transport to and from major transit nodes or corridors.

This new paradigm, however, implies a significant change in the current operational and theoretical approach to mobility. As discussed in the introduction, the regulatory and legislative systems (at all levels, from the EU to the local one) are not shaped to incentive such sharing initiatives (Jansen, 2014). A further point is the necessity for both public and private investments and adaptation. To start an integration process, at least a consolidation facility and pick-up and delivery locations have to be made available at selected transit hubs. In addition, FLM requires purchasing new low-impact vehicles (with all territorial implications related to the definition of this concept, see Cavallaro et al., 2018) to cover the last mile of freight transport, and intervening on the existing
public transport fleet to make it useable for an easy, quick (especially in loading/unloading operations), reliable, and safe goods transport. An acceptance model (addressed to public administrations, private and public companies, stakeholders part of the transport and logistics systems in general) needs to be merged with an integrated business model, which should consider all phases of the innovation process: from concept and planning, to implementation, to monitoring and evaluation. At least in this preliminary phase, funding by public authorities and the design and implementation of pilot initiatives for IPFL are fundamental elements in the development strategy. Rather than a radical change in the system, small-scale applications (e.g., in a restricted sector of an urban agglomeration or in a limited-size rural area) could be the key to test proposed models, allowing to build an appropriate and reliable set of indicators and an operational model to facilitate a future broader diffusion.

4. Methodology

The integration of passenger and freight transport requires significant modifications to public transport and supply chain operators’ business models, especially in the delicate context of the passenger-freight FLM. This section presents a methodology for the evaluation of IPFL impacts on existing FLM operations. Based on a thorough analysis of current and proposed business models, the evaluation of operation efficiency and sustainability is performed through ad-hoc Key Performance Indicators (KPIs).

4.1. KPIs in freight and passenger transport

The development of metrics (or indicators) for evaluating the efficiency and the sustainability of public transport operations traces back to the embrace of sustainable development as a global mission at the 1992 United Nations Conference on Environment and Development. From that date on, literature about sustainability and related indicators has proliferated.1 In general terms, Eboli and Mazzulla (2012) refer to the Transportation Research Board (2004) and state that performance measurement can be defined as the assessment of an organization’s output as a product of the management of its internal resources (money, people, vehicles, facilities) and the environment in which it operates. Gudmundsson (2004) has provided a working definition of indicators, as “selected, targeted, and compressed variables that reflect public concerns and are of use to decision makers”. Seco and Gonçalves (2007), while stating that the variety of performance indicators pointed out in international references discloses that consensus on a uniform and universal methodology for evaluating transport operations has not yet been reached, list essential criteria performance indicators should follow. They include: consistency with the goals, conciseness and appropriateness with regard to the desired detail level, availability, measurability, robustness, clearness/comprehensibility, sensitivity and reciprocity. Gilbert et al. (2003) state that the main functions of indicators are: to help the comparison of similar trends across jurisdictions, to help with the comparison of different phenomena, to help with the understanding of trends within a jurisdiction, to help with evaluating progress towards or away from defined goals and targets. Performance measures play an important role in assessing the transport system in relation to the objectives of the community, in diagnosing problems, in allocating resources and in monitoring and improving operations. Meyer (2000) uses comprehensive classification categories, namely general performance indicators (such as population, trips, vehicle kilometers and hours), effectiveness measures (with subcategories service supply, quality of service, availability), and efficiency measures (cost efficiency, operating ratios, vehicle utilization, labour productivity, energy use, fares). Litman (2009) lists three general types of performance indicators for transit operations: measures of service quality, indicators of outcomes, and indicators of cost efficiency. Similar classifications can be found, according to Eboli and Mazzulla (2012), in Carter and Lomax (1992) and Vuchic (2007). Several other applications of performance indicators have been used within transport practices, for instance regarding urban resilience (Da Mata Martins et al., 2019), accessibility (Vasconcelos and Farias, 2012; Lessa et al., 2019), sustainability performance (Munira and San Santos, 2017; Díez et al., 2018), safety (Castro-Núñez and Arevalo-Quijada, 2018), and energy use (Gustafsson et al., 2018).

As for freight transport and the supply chain, a review by Guasekaran and Kubo (2007) finds that commonly identified components to be evaluated are related to the use of resources, operations and flexibility. They provide a proposal for supply chain KPIs, splitting the process in stages (plan, source, make, deliver). A similar approach is also adopted by Chae (2009), who adopts an agency-oriented perspective. Alternatively, Posset et al. (2010) propose a division into financial, operational, service, and environmental aspects; starting from this framework, Cavallaro et al. (2020) define specific KPIs referred to Combined Transport. Pu and Jenelius (2018) evaluate driving efficiency, delivery reliability, energy efficiency and service efficiency of night goods deliveries through the definition of specific KPIs.

Focusing on case studies on short-haul mixed passenger-freight operations, limited evidences exist in literature. Some new research efforts come from the Netherlands, where public investments have been conspicuous (Sampaio et al., 2019), resulting in a series of publications discussing both urban case studies (Strale, 2014; Leijenhorst, 2014) and rural ones (Jansen, 2014; Bakker, 2015; van Doorn et al., 2019). General mathematical models have been proposed as well (Pimentel and Alvelos, 2018), together with a limited number of studies for other European (Mason et al., 2017; Gatta et al., 2019) and worldwide cases (Zhou and Zhang, 2019). However, to the best of the authors’ knowledge, the merge between indicators and case studies has not yet been experimented, with the exception of some preliminary efforts for the area of Venice, Italy.

4.2. Definition of the framework for data collection

The proposal of a new IPFL system requires an analysis of ongoing passengers and freight transport operations within the chosen territorial context, and the data collection about expected operations with the proposed IPFL setting. Information should be gathered as to have a full representation of the transport system, including all public transport and freight operations. In terms of passenger transport, it is fundamental to reconstruct schedules (with time of operations and covered distances), to know the types of vehicles used and their spare capacity, the needs and constraints of transport operators and of agencies and authorities, fares and subsidies, and any other data useful to produce a complete framework for understanding operations’ morphology, sustainability (financial, economic and environmental), weaknesses and strengths. Regarding freight transport, similar information should be collected. In dealing with non-fixed schedule operations, however, more attention should be put on the architecture of the system (consolidation facilities, location of deliveries), on the efficiency of operations (type and spare capacity of delivery vehicles, detours and idling times, distance per delivery) and on policy or operational constraints. Typically, they include time windows for operations, fuel and emissions policy, competition for space, operators’ and final consumers’ time constraints.

While designing the new IPFL system, constraints verified during the analysis of existing operations must be combined with the potential for innovative business models. The direct involvement of stakeholders, such as authorities, freight and passengers transport operators, final retailers and decision makers could be a key for a successful and realistic IPFL setting. The identification of suitable plans and programs for IPFL, in compliance with European indications (EC 2007, 2011) plays a

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1 The topic is too vast to be presented in this section. For a more detailed analysis, readers may refer to JRC (2009).
relevant role in terms of process sharing and acceptance within the
involved community. As such, it should be included in the analysis and
evaluation of IPFL operations compared to traditional settings where
passengers and freight transport are treated separately.

4.3. Definition of KPIs for IPFL

In defining the most suitable indicators for IPFL, formal and content-
related aspects have to be taken into account. Referring to the former
aspect, performance criteria have to satisfy five properties, in order to
achieve objective and unbiased performance measures (Sinha and Labi,
2007):

- Suitability: the performance measure should be actually influent and
  appropriate for the purpose at-stake;
- Measurability: it should be possible and easy to measure the per-
  formance in an objective manner. Measurement results should be
  within an acceptable degree of accuracy and reliability;
- Realism: it should be possible to collect, generate or extract reliable
data relating to the performance measure without excessive effort,
cost or time;
- Universality: every parameter considered should be generalizable
  with respect to such premises, chosen KPIs for IPFL are presented in Table 1 and
  better described by Formulas (1-7).

Indicator I1: average daily traffic (ADT). This KPI describes the traffic
variation in terms of freight vehicles (f), public transport (p) and private
vehicles (v) before (B) and after (A) the introduction of the shared
transport system. The indicator, expressed as number of equivalent vehicles,
takes into account the whole traffic, not limiting to the freight or
public transport components, thus allowing evaluating the pressure
variation that the proposed setting would generate on the existing
infrastructural system. The transformation of vehicles in equivalent vehicles may adopt the coefficients proposed by the Highway Capacity Manual (TRB, 2020), which distinguishes between a light vehicle (coefficient \( c_v = 1 \)), a heavy vehicle (coefficient \( c_v = 1.5 \)) and a PT vehicle (\( c_p = \text{coefficient } 1.2 \)). This indicator is expressed by Formula (1):

\[
I_1 = \frac{\left( \sum ADT^f_p c_f + \sum ADT^p_v c_v + \sum ADT^p_c c_v \right) - \left( \sum ADT^p_v c_v + \sum ADT^p_c c_v \right)}{\left( \sum ADT^p_v c_v + \sum ADT^p_c c_v \right)}
\]  

(1)

- Defensibility: the performance measure should be clear and concise
  so that the manner of assessing and interpreting its levels can be
  communicated effectively within a circle of decision makers and to
  the public. This is often possible when the performance measure is
  clear and simple in its definition and method of computation;

Referring to the contents, the macro-categories identified by Poss et
al. (2010) may be a valid general framework: they state that indicators
have to assess operational, environmental and social performances of
the proposed IPFL settings. Particular attention has to be put in choosing
indicators capable of evaluating the system from the multiple perspec-
tives of the operators (PT and goods carriers), of PT customers, and of
residents and retailers, as well as of different stakeholders and
decision-makers. KPIs compare two different temporal frameworks,
namely A (i.e., the condition after the introduction of the IPFL scheme),
with B (before its introduction). Conditions A and B are not temporally
distant, meaning that the introduction of structural changes to the
context of study and to its infrastructural assets are not viable. According
to such premises, chosen KPIs for IPFL are presented in Table 1 and

Table 1 Identification of KPIs for IPFL

| Category         | Indicator | Title                        | Description                                                                 |
|------------------|-----------|------------------------------|-----------------------------------------------------------------------------|
| Operational      | I1        | Traffic variation            | Average daily traffic variation between B and A                             |
|                  | I2        | Covered                      | Variation in distances covered by PT and freight vehicles between B and A   |
|                  | I3        | PT load factor               | Variation in load factor between B and A                                     |
|                  | I4        | Freight service frequency    | Variation in frequency of freight deliveries between B and A                |
| Environmental    | I5        | Energy used                  | Variation in energy requirements for performing operations between B and A |
|                  | I6        | Air pollution external costs | Variation in external costs due to polluting emissions between B and A      |
| Social           | I7        | Cost of labour               | Variation in costs for human resources between B and A                      |

Indicator I2: variation of travelled distances. This KPI provides an
estimation of the variation of distances (\( d \), expressed in km) travelled by
the number of freight (f) and public transport (p) vehicles before (B) and
after (A) the implementation of the proposed business model, according
to Formula (2):

\[
I_2 = \frac{\left( \sum_{n}^{m} d_f + \sum_{n}^{m} d_f \right)_{b} - \left( \sum_{n}^{m} d_f + \sum_{n}^{m} d_f \right)_{a}}{\left( \sum_{n}^{m} d_f + \sum_{n}^{m} d_f \right)_{b}}
\]  

(2)

Where \( n \), \( o \) are the number of freight vehicles; \( m \) and \( q \) are the number of
PT vehicles circulating in A and B. Differently from \( I_1 \), in this case the variation between B and A is calculated according to the overall distance travelled by PT and freight transport, without assigning any weight to
the type of vehicle considered. This indicator is suitable to assess the
general sustainability of the IPFL solution and is the computational basis
for successive indicators.

Indicator I3: PT load factor. It describes the variation in load rates (L)
of passengers (p) aboard PT vehicles before (B) the implementation of
the proposed business model, and of passengers (p) and freight (f)
aboard PT vehicles after (A) the implementation. The load rate \( L \) can be expressed in different ways. In order to guarantee the comparability between freight and passenger components, we have calculated it as the
percentage of occupied square meters out of the total spaces available for
the service, thus hinting at the efficiency of transit operations. To do
that, freight volumes, which are typically expressed as weights or volumes,
have to be pre-dimensioned and divided by a standard height, which
is dependent from the transport system considered. The indicator
can be obtained through Formula (3):

\[
I_3 = \frac{\left( L^p_f + L^p_p \right)_{a} - \left( L^p_p \right)_{b}}{L^p_p}
\]  

(3)

Differently from previous indicators, after the introduction of IPFL, a
positive variation is expected. The indicator hints at feasibility of transit
operations while demonstrating that spare capacity is not completely absorbed and thus the main scope of PT, i.e. providing quality passenger service, is not put at risk.

**Indicator I₄**: service frequency. This indicator compares the number \((n)\) of daily freight deliveries \((f)\) to retailers and/or final users in \(B\) (before the implementation of the integrated system) with the number of daily freight deliveries through PT vehicles \((p)\) in \(A\) (after the integration). However, passenger transport is not considered by this indicator, since the aim of the IPFL approach is to determine how freight distribution can be improved by merging it with PT, without any change to its current scheme. This KPI determines to what extent the combination of the two systems could provide for better opportunities for residents and businesses throughout the served territory. The KPI can be obtained through Formula (4):

\[
I_4 = \frac{\left( n_f - n_p \right)}{n_p}
\]

**Indicator I₅**: energy requirements. This indicator expresses the energy required for the performance of the whole transport system (including the passenger and freight components) before and after the introduction of IPFL. According to Sinha and Labi (2007), it depends on several variables related to the transport system, which can be grouped in some macro-categories related to travel, facility, driver characteristics, vehicle, fuel, and environment. According to the level of detail, a distinction between micro- and macro-models can be made (Nocera et al., 2017). In its simplest form, the variation of energy consumption in \(B\) and \(A\) can be considered, using Joules \((J)\) as unit of measure (Formula (5)):

\[
I_5 = \frac{(J_{fa} + J_{fa}) - (J_{pa} + J_{pa})}{(J_{fa} + J_{fa})}
\]

**Indicator I₆**: air pollution external costs. This indicator can be obtained by identifying the most relevant pollutants that affect an area, modelling their emissions \(e\) (Nocera et al., 2017, 2018) in \(A\) and \(B\) caused by freight \((f)\) and passenger \((p)\) and then multiplying them by their unitary economic value \(c\), as proposed by reference manuals (such as the Handbook on External Costs of Transport, EC, 2019). The transformation into a common economic value is necessary to have a reliable indicator, since the unit of measure of the different pollutants may be different (e. g., for carbon dioxide the reference unit of measure is g/km, whereas for particulate matter is microgram/km). The operation has to be iterated for all relevant pollutants \(x\) and results are then to be summed, as expressed by Formula (7).

\[
p_x = \frac{\left( e_f^x + e_p^x \right)}{\left( e_f^x + e_p^x \right)} \times c_x
\]

\[
I_6 = \sum_{x=1}^{n} p_x
\]

**Indicator I₇**: human resources. This indicator can be calculated by analysing the variation of total workforce \(I\) before \((B)\) and after \((A)\) the integration of the freight and passenger mobility systems. It can be expressed as the number of workers that are involved in the transport operations. After the implementation of the IPFL scheme, a reduction of values has to be expected, because of the redefinition of the operational activities. This operative KPI deserves a particular attention from a social perspective: indeed, the potential reduction in workforce might not necessarily be acceptable for the society as a whole.

\[
I_7 = \frac{\left( I_A + I_A^* \right)}{\left( I_B + I_B^* \right)}
\]
Recalling section 4, this represents the scenario “A”. In detail, the proposed IPFL setting envisions the delivery of all goods categorized as “of the most common categories, transported by third-parties” by COSES (2002) through vessels providing public transport along routes 12 and 13, by using their spare capacity at specific times. Fig. 2 shows a scheme of the proposed business model.

In order to set a reliable scenario, the existing regulatory constraints (time and space windows) have been explored through a direct interaction with operators, and with the main institutions (i.e., City of Venice and Municipality Venezia-Murano-Burano). They have been taken into account to define the framework of a realistic scenario. More specifically, the setting considers only the itinerary Murano – Burano/Sant’Eraso – Treporti. This is the route of PT lines 12 and 13, chosen due to service frequency and to existing overlapping pattern with the main axes of freight transport in the area. Other PT lines are excluded from the simulation due to strong seasonal variations and/or scarce coverage of the study area or of the time of the day of interest. In terms of operational aspects, the simulation considers the winter PT schedule and the highest freight and passenger volumes typical of the summer months, to consider the condition with the highest occupancy. Correctional factors have been added to spare capacity and loading capacity of ACTV vessels. This guarantees enough capacity for passenger transport, even in the worse condition. Referring to the freight transport, the model has been limited to third-party transported goods because of excessive unpredictability of demand of other categories (Cappelli and Nocera, 2006). Private boats navigating for recreational purposes have been omitted: their number varies according to season, weather, day of the week, but is generally negligible. The existing timeframe constraints have been considered also in this scenario, limiting the service to the morning delivery window (from 4 a.m. to 11 a.m.). A potential implementation of the IPFL scheme in scenario “A” is presented in Fig. 3. The red part represents the space that would be occupied by freight in the PT vessel cabins, the plain gray is the cabin space available for passengers and the dotted gray area is the maximum theoretical freight load (based on spare capacity).

Table 3 shows the size of space left to goods aboard each vessel for each route section. Fig. 3 shows the space occupied by freight within PT vessels’ passenger cabins. The space available for passengers is not limited to the cabin but includes bow, stern and open spaces (not shown in the figure). Fig. 3 clearly shows that the freight capacity is higher than the needed one to deliver all considered goods within the timeframe of reference. This would allow absorbing unpredicted peaks of both passengers and freight volumes.

5.3. Results of IPFL in the Northern Lagoon of Venice

The evaluation of the IPFL setting for FLM operations in the Northern Lagoon of Venice is based on the set of performance indicators (KPIs) described in section 4, by comparing the layout before (B) and after (A) the introduction of the new scheme, as described in 5.1 and 5.2. As regards the temporal dimension of the analysis, KPIs consider the boats performing third-party freight transport and ACTV vessels operating between 4 and 11 a.m., a restricted time frame still sufficient to fully execute delivery without affecting availability of PT. The only exception is PI1, which analyses the total daily number of vehicles circulating. Each indicator is calculated by disaggregating PT and freight itineraries in the northern lagoon in 6 subsections based on main PT stops. 4 of them belong to line 12 (Murano-Burano-Treporti and vice versa), 2 to line 13 (Sant’Eraso-Treporti and vice versa).

\( I_1 \) analyses the number of passenger and freight vessels that circulate daily. Considering the peculiarity of the water vehicles, the coefficient \( c \) recalled in Formula (1), which transforms vehicles into equivalent vehicles, has been set equal to 1 both for freight and passenger vessels. In B, the number of vehicles vary according to the stretch considered (Table 4). Overall, 242 passengers and 305 freight vessels are registered (Table 4, rows 4.a and 4.b). In scenario A, the number of freight vehicles may be reduced up to 224, merging the third-party vehicles but keeping the others (self-transport and traditional carriers). According to Formula (1), \( I_1 \) is equal to \(-0.14\), which means a potential decrease by 14% in daily traffic.

\( I_2 \) calculates the variation in distances run. The unitary length between the subsections is reported in Table 5, row a) and is taken from official cartographic maps. These values have been multiplied by the number of vehicles that circulate in A and B in the time window 04–11 a.m. For freight transport, this quantity is equal to that calculated in PI1 (Table 4, rows 4b and 4d); for passenger transport, it is the subset of values valid for the timeframe considered in our analysis (Table 5, rows 5c and 5e). The sum of the freight and passenger components is equal to 266 in A and 347 in B. By multiplying the distance by the number of vehicles, results for B (5g and 5.h) show that between 04 and 11 a.m. freight boats cover 1634 km, while PT vessels cover 313 km, for a total of 1947 daily km. The adoption of the IPFL scheme would lower this...
value up to 1515 km. By using Formula (2), this is equal to a reduction of \(-0.22\).

In marine traffic, “hours” of operations are normally used, instead of (or besides) distances, as they are more suitable to describe real operational conditions. For this reason, a variant of indicator \(I_3\) has been calculated for this specific case study. The number of circulating boats in each route section has been multiplied by travel times (Table 5, row 5b), as retrieved from official ACTV timetables. As the speed limit in the northern lagoon is low and comparable (minimum and maximum speeds span from 7 to 20 km/h), it has been assumed that travel times between each O/D are the same for each type of vessels. According to rows 5.1 and 5.1, the daily saving in hours of navigation is 34.

\(I_j\) considers PT vehicles and calculates how their usage for freight distribution in the Northern Lagoon of Venice affects the overall transport capacity. Primary data on the total capacity in the time window of reference and on used capacity in the B setting, as well as the volumes of goods to load, are visible in Table 2. Freight volumes (ID 2.l) are converted into square meters, by considering a height of 1.80 m, applying a 20% security factor with respect to the height of PT vehicles’ doors and meeting standard roll containers height. Table 6 shows available and used capacity, with the latter that varies from 46% in B to 63% in A. The application of Formula (3) to the context of the Northern lagoon of Venice gives a final value of 0.38. The indicator reveals that the combination of passengers and cargo flows is operationally possible without any variation in PT schedules, leaving a margin in case of unpredicted peaks of passengers or cargo volumes. Indeed, maximum used capacity in the “A” setting is found to reach 70% (Table 6, row 6.g) while at least 102 m² of space remain available on board (Table 6, row 6.f) to accommodate extra passengers or good peaks.

\(I_j\) calculates the frequency of freight deliveries. From the previous indicator, it has been verified that the frequency of PT service in A can be equal to B. Accordingly, final users of the logistics supply chain may benefit from an increase in the level of service, given that items currently delivered on a non-normal basis could be delivered daily, multiple times and according to the PT scheduling. Indeed, in B they rely completely on third-party freight operators, which impose only one possibility to distribute the goods in the different localities (with unknown scheduling). However, in A the availability of alternatives is dependent from the number of PT connections, which are significantly higher (Table 7, row 7.b). Formula (4) thus gives a value of 9.33: this value represents the theoretical variation in number of connections.

\(I_5\) assesses the energetic performance through the variation in required kWh (or Joules). According to the market availability, diesel-powered PT vessels with a Cursor 9-380 Engine are considered, whose fuel consumption is calculated at 76 L/h (FPT Industrial, 2020). By multiplying the hourly consumption by the hours of daily operations, 1870 L of diesel per day are used by PT vehicles in both B and A. This quantity is equal to 2.02 tonnes of oil equivalent (T.O.E), according to the conversion factors of 1.08 for diesel and 1.20 for gasoline (ENEA, 1992). As far as freight boats are concerned, their fuel consumption depends on the size of the vessel. Boats longer than 10 m are equipped with diesel engines, which on average use 30 l/h. Boats shorter than 10 m are petrol-powered and consume 12 l/h. In B, the total daily consumption of freight vessels in the Northern lagoon of Venice is obtained as the product of the number of boats of each type (Table 8) by operational times and by unitary consumption described above. As visible in Table 8, this value is equal to 2653 L of diesel and 485 L of gasoline daily (overall 3.45 T.O.E.). In A, boats longer than 10 m are found to consume daily 1990 L of diesel and 360 L of gasoline daily (2.58 T.O.E.). Finally, it is possible to transform values expressed in T.O.E as MWh, by adopting a coefficient factor of 11.8 (ISPRA, 2003). The energy requirement is 23.83 MWh/day for PT, 40.71 MWh/day for freight in the B setting and

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### Table 2: Freight and passenger mobility in the Northern Lagoon of Venice.

| ID | Type of transport | Description | Unit of measure | Burano-Murano | Murano-Burano | Treporti-Burano | S.Erasmo-Treporti | Treporti-S.Erasmo |
|----|------------------|-------------|----------------|---------------|---------------|----------------|----------------|----------------|----------------|
| 2.a | Public transport | Runs | n | 15 | 218 | 6 | 1398 | 1398 | 325 |
| 2.b | Public transport | Unitary capacity (passengers) | n | 12 | 975 | 5 | 3900 | 3900 | 218 |
| 2.c | Capacity | pax | 4875 | 35 | 3900 | 35 | 3375 | 3375 | 87 |
| 2.d | Space offered before 11a.m. | m² | 1218.8 | 10 | 975 | 10 | 893.8 | 893.8 | 777.3 |
| 2.e | Security factor | % | 10 | 55 | 10 | 55 | 10 | 55 | 30 |
| 2.f | Spare capacity | % | 55 | 55 | 55 | 55 | 53 | 53 | 23 |
| 2.g | Space used | m² | 548.4 | 55 | 438.8 | 55 | 402.2 | 402.2 | 140 |
| 2.h | Volume available | m³ | 556 | 10 | 366 | 10 | 337.5 | 337.5 | 87 |
| 2.i | Space available | m² | 556 | 10 | 366 | 10 | 337.5 | 337.5 | 87 |
| 2.j | Volume available | m³ | 237 | 10 | 163 | 10 | 140 | 140 | 10 |
| 2.k | Freight transport | Freight volumes (third-party, frequent categories) | m³ | 670.3 | 12 | 536.3 | 12 | 491.6 | 491.6 |
| 2.l | Freight transport | Freight vessels used (third-party, frequent categories) | n | 50 | 6 | 34 | 6 | 20 | 7 |

Note: PT and freight transport have been analysed in the time window 04-11 a.m., the only daily period when freight transport is allowed.

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3 This and the previous data have been collected through a survey addressed to the five main freight operators located in the area.
30.44 MWh/day in the A setting. By applying Formula (5), the KPI gives a value equal to –0.16.

$I_6$ is calculated at aggregated level for carbon dioxide (CO$_2$) and nitric oxides (NO$_x$), so to include in the evaluation both a global and a local air pollutant. Their variation between B and A is based on fuel consumption, as calculated by Indicator $I_5$ (Table 8). More in detail, both CO$_2$ and NO$_x$ emissions are obtained through the transformation of consumed liters of fuel in kgs (based on fuel density, 0.725 kg/l for petrol and 0.835 kg/l for diesel) and the multiplication by an emission factor, equal to 3140 gCO$_2$/kg for diesel and 3200 gCO$_2$/kg for petrol; and equal to 42 gNO$_x$/kg for diesel and 9.7 gNO$_x$/kg for petrol (Jun et al., 2002). CO$_2$ and NO$_x$ emissions thus calculated in B (Table 9, row 9.a and row 9.e) and A (Table 9, row 9.b and row 9.f) are multiplied by their unitary economic value, as proposed by EC (2019): 90 €/ton and 10.824 €/kg, respectively. This allows a sum of the two components, which guarantee a daily saving of about 500 € (difference between 9.i and 9.j). According to Formula (7) the indicator gives a value of –0.15.

According to the declaration of the operators, $I_7$ assumes that boats shorter than 10 m require one operator, whereas longer vessels need two operators (Table 10). Since the time window under observation is 7 h (04–11 a.m.), only one shift of workers has to be considered. The number of freight boats of each size, as calculated in Table 8, determines the number of total needed resources to conduct freight boats in B and A. The value for A is then integrated with one additional freight worker per PT vessel, who would take care of the loading/unloading procedure and of very last mile pickup-delivery operations. PT workers are two per service (one pilot and one sailor) and remain unvaried in the context of this case study. Formula (7) thus gives a value of –0.07.

6. IPFL for the suburban area of Velenje

6.1. Current PT and freight transport

The Slovenian Municipality of Velenje$^4$ hosts around 32,950 inhabitants (2019), distributed in 25 local communities (SSstat, 2020). Its morphological and demographic characteristics make it a typical example of a dispersed area. To overcome the transport issues related to such areas, the Municipality has decided to serve the built areas with 5 bus routes, operated weekdays only. This service, which costs around €32,000/month, is free of charge for users (Municipality of Velenje, 2020a). This choice requires an optimization of the service. The application of the IPFL scheme could contribute to make it more affordable for the local public authority. For the sake of this case study, out of the 5 routes mentioned above, only the suburban blue, green and orange lines are considered, whereas the yellow (which provides frequent service within the urban core) and the red ones (which is a section of a longer interurban route) are not included in the analysis (Fig. 4).

The bus service for the three selected lines is currently composed of high-floor vehicles, equipped with storage compartments beneath the passenger compartment’s floor, similar to intercity buses. During peak hours, which coincide with origins/destinations from/to schools, regular routes do not run and specific services are operated (Municipality of Velenje, 2018 & 2020b). In the base scenario (B), operations are clearly distinguished between passenger and freight transport. Registered values are presented in Table 11.

6.2. IPFL setting

In accordance with the Municipality of Velenje, it has been decided to test an IPFL business model limited to the distribution by PT of parcels and packages under the jurisdiction of the national postal service. This

$^4$ Together with IUAV Università di Venezia and other partners from the Adriatic-Ionian area, the Municipality of Velenje is involved in the EU-funded projects Smile and Smart-Commuting, which guarantee a constant and privileged contact. Data and information about PT and mail services in Velenje have been mostly retrieved thanks to direct communication with the city’s Municipal offices, and integrated with the city’s public website.
Table 3
Freight aboard PT vessels in the Northern Lagoon of Venice.

| ID | Description               | Unit of measure | Formula    | Murano-Burano | Burano-Murano | Burano-Treporti | Treporti-Burano | S.Erasmo-Treporti | Treporti-S.Erasmo |
|----|---------------------------|-----------------|------------|---------------|---------------|----------------|-----------------|-------------------|------------------|
| 3.a| Loads on each PT vessel  | m\(^3\)         |            | 37.1          | 30.5          | 19.8           | 14.8            | 23.3              | 14.5             |
| 3.b| Loads on each PT vessel  | m\(^2\)         | (3.a/1.8m) | 20.6          | 16.9          | 11             | 8.2             | 13                | 8.1              |
| 3.c| Load size (side 1)       | m               |            | 4             | 4             | 4              | 4               | 2                 | 2                |
| 3.d| Load size (side 2)       | m               | (3.b/3.c)  | 5.15          | 4.22          | 2.75           | 2.05            | 6.5               | 4.05             |

Table 4
Daily traffic variation in the Northern Lagoon of Venice.

| ID | Description                        | Unit of measure | Murano-Burano | Burano-Murano | Burano-Treporti | Treporti-Burano | Treporti-Sant'Erasmo | Sant'Erasmo-Treporti | Total |
|----|------------------------------------|-----------------|---------------|---------------|----------------|-----------------|---------------------|---------------------|-------|
| 4.a| Passengers vehicles in B           | n\(^-\)        | 56            | 56            | 40             | 42              | 23                  | 25                  | 242   |
| 4.b| Freight vehicles in B              | n\(^-\)        | 84            | 81            | 50             | 44              | 23                  | 23                  | 305   |
| 4.c| Passengers vehicles in A           | n\(^-\)        | 56            | 56            | 40             | 42              | 23                  | 25                  | 242   |
| 4.d| Freight vehicles in A              | n\(^-\)        | 62            | 60            | 37             | 32              | 16                  | 17                  | 224   |

I\(_1\)  -0.14
Table 5
Distances and travel times in the Northern Lagoon of Venice.

| ID  | Description            | Unit of measure | Formula                          | Murano-Burano | Burano-Murano | Burano-Treporti | Treporti-Burano | Treporti-Sant’Erasmo | Sant’Erasmo-Treporti | Total   |
|-----|------------------------|-----------------|----------------------------------|---------------|---------------|----------------|-----------------|---------------------|---------------------|---------|
| 5.a | Distance               | km              |                                  | 6.74          | 6.74          | 3.55           | 3.55           | 4.10                | 4.10                | 28.78   |
| 5.b | Travel time            | h               |                                  | 0.55          | 0.55          | 0.25           | 0.25           | 0.33                | 0.33                | 2.26    |
| 5.c | PT vehicles in B       | n°              |                                  | 15            | 12            | 12             | 11             | 6                   | 6                   | 62      |
| 5.d | Freight vehicles in B  | n°              |                                  | 84            | 81            | 50             | 44             | 23                  | 23                  | 305     |
| 5.e | PT vehicles in A       | n°              |                                  | 15            | 12            | 12             | 11             | 6                   | 6                   | 62      |
| 5.f | Freight vehicles in A  | n°              |                                  | 62            | 60            | 37             | 32             | 16                  | 17                  | 224     |
| 5.g | Distance covered daily in B | km   | (5.a*5.c)+(5.a*5.d) | 667          | 627           | 220            | 195            | 119                | 119                | 1947    |
| 5.h | Distance covered daily in A | km   | (5.a*5.c)+(5.a*5.f) | 519          | 485           | 174            | 153            | 90                 | 94.3                | 1515    |
| 5.i | Time travelled in B    | h               | (5.b*5.c)+(5.b*5.d)            | 54.45         | 51.15         | 15.5           | 13.75          | 9.57                | 9.57                | 154     |
| 5.j | Time travelled in A    | h               | (5.b*5.c)+(5.b*5.f)            | 42.35         | 39.6          | 12.25          | 10.75          | 7.26                | 7.59                | 120     |–0.22

Table 6
PT capacity usage in the Northern Lagoon of Venice.

| ID  | Description            | Unit of measure | Formula                          | Murano-Burano | Burano-Murano | Burano-Treporti | Treporti-Burano | Treporti-Sant’Erasmo | Sant’Erasmo-Treporti | Average |
|-----|------------------------|-----------------|----------------------------------|---------------|---------------|----------------|-----------------|---------------------|---------------------|---------|
| 6.a | Potential PT capacity  | m²              |                                  | 1219          | 975           | 975            | 894            | 327                | 327                | 327     |
| 6.b | Capacity available in B| m²              |                                  | 670           | 536           | 536            | 492            | 180                | 180                | 180     |
| 6.c | Capacity used in B     | %               |                                  | 45            | 45            | 45             | 45             | 47                 | 47                 | 46      |
| 6.d | Capacity available in B| %               |                                  | 55            | 55            | 55             | 55             | 53                 | 53                 | 53      |
| 6.e | Freight on PT in A     | m²              | (2.1/1.8)                        | 309           | 209           | 132            | 89             | 48                 | 78                  | 78      |
| 6.f | Capacity available in A| m²              | (6.b*6.c)                        | 361           | 327           | 405            | 402            | 132                | 102                 | 102     |
| 6.g | Capacity used in A     | %               | [100-(6.f*100)/6.a]              | 70            | 66            | 58             | 55             | 60                 | 69                  | 69      | 0.38

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Table 7
Frequency of freight deliveries in the Northern Lagoon of Venice.

| ID  | Description                        | Unit of measure | Murano-Burano | Burano-Murano | Burano-Treporti | Treporti-Burano | Treporti-Sant'Erasmo | Sant'Erasmo-Treporti | Total |
|-----|------------------------------------|-----------------|---------------|---------------|----------------|----------------|----------------------|----------------------|-------|
| 7.a | Freight deliveries in B            | n°/day          | 1             | 1             | 1              | 1              | 1                    | 1                    | 6     |
| 7.b | Maximum freight deliveries in A    | n°/day          | 15            | 12            | 12             | 11             | 6                    | 6                    | 62    |
| 7.c |                                    |                 |               |               |                |                |                      |                      | 9.33  |

Table 8
Fuel usage by boats in the Northern Lagoon of Venice.

| ID  | Description                        | Unit of measure | Formula | Murano-Burano | Burano-Murano | Burano-Treporti | Treporti-Burano | Treporti-Sant'Erasmo | Sant'Erasmo-Treporti | Total |
|-----|------------------------------------|-----------------|---------|---------------|---------------|----------------|-----------------|----------------------|----------------------|-------|
| 8.a | Large freight boats (>10m) in B    | n°              | 72      | 62            | 19            | 11             | 7               | 15                   | 1870     |
| 8.b | Large freight boats (>10m) in A    | n°              | 52      | 49            | 14            | 8              | 5               | 11                   | 8        |
| 8.c | Small freight boats (<10m) in B    | n°              | 12      | 18            | 31            | 33             | 16              | 8                    | 360      |
| 8.d | Small freight boats (<10m) in A    | n°              | 10      | 13            | 23            | 24             | 11              | 6                    | 5        |
| 8.e | Fuel used by PT vehicles in B and A| L/day           | (5b*x*5°) | 627           | 502           | 228            | 209             | 152                  | 1870     |
| 8.f | Fuel used by small freight boats in B| L/day          | (8c*x*5°) | 79            | 119           | 93             | 99              | 63                   | 485      |
| 8.g | Fuel used by large freight boats in B| L/day          | (8a*x*5°) | 1188          | 1023          | 142            | 83              | 69                   | 2653     |
| 8.h | Fuel used by small freight boats in A| L/day          | (8d*x*5°) | 66            | 78            | 69             | 72              | 43                   | 360      |
| 8.i | Fuel used by large freight boats in A| L/day          | (8b*x*5°) | 858           | 808           | 105            | 60              | 49                   | 1990     |
| 8.j | Fuel used by PT vehicles in B and A| T.O.E./day     | [8.a*1.08]/1000 | 0.68         | 0.54          | 0.25           | 0.23            | 0.16                  | 2.02     |
| 8.k | Fuel used by freight boats in B    | T.O.E./day     | [8.f+1.20]+(8.g*1.08)/1000 | 1.38         | 1.25          | 0.26           | 0.21            | 0.15                  | 2.02     |
| 8.l | Fuel used by freight boats in A    | T.O.E./day     | [8.h+1.20]+(8.i*1.08)/1000 | 1.00         | 0.97          | 0.20           | 0.15            | 0.10                  | 2.58     |
| 8.m | Energy used by PT vehicles in B and A| MWh/day       | (8.j*11.8) | 8.02          | 6.37          | 2.95           | 2.71            | 1.89                  | 23.83    |
| 8.n | Energy used by freight boats in B  | MWh/day        | (8k*11.8) | 16.28         | 14.75         | 3.07           | 2.48            | 1.77                  | 40.71    |
| 8.o | Energy used by freight boats in A  | MWh/day        | (8l*11.8) | 11.8          | 11.45         | 2.36           | 1.77            | 1.18                  | 30.44    |
service can be extended in a later stage and after a verification on the availability of further spare capacity on PT vehicles, including other deliveries from other carriers in the shared parcels-passengers FLM stage, based on the example of the Northern lagoon of Venice presented above. The selection of the postal service is coherent with PT service, both in terms of locational and temporal aspects: indeed, the central office lies in the city center, close to the central bus station, from where vans depart to serve on a daily basis (weekdays only) the different

Table 9
External costs of CO$_2$ and NO$_X$ emissions in the Northern Lagoon of Venice.

| ID | Description | Unit of measure | Formula | Total |
|----|-------------|-----------------|---------|-------|
| 9.a | CO$_2$ emissions in B | t/day | (8.f*0.725*3200)+(8.e*0.83*3140) | 12.98 |
| 9.b | CO$_2$ emissions in A | t/day | (8.h*0.725*3200)+(8.i*0.83*3140) | 10.96 |
| 9.c | External costs from CO$_2$ emissions in B | €/day | (9.e*90) | 1168 |
| 9.d | External costs from CO$_2$ emissions in A | €/day | (9.f*90) | 986 |
| 9.e | NO$_X$ emissions in B | kg/day | (8.e+8.g)*0.83*12.5 | 162 |
| 9.f | NO$_X$ emissions in A | kg/day | (8.e+8.i)*0.83*12.5 | 138 |
| 9.g | External costs from NO$_X$ emissions in B | €/day | (9.e*10,824) | 1753 |
| 9.h | External costs from NO$_X$ emissions in A | €/day | (9.f*10,824) | 1494 |
| 9.i | Total external costs from emissions in B | €/day | (9.c+9.g) | 2921 |
| 9.j | Total external costs from emissions in A | €/day | (9.d+9.h) | 2480 |

Table 10
Human resources for the transport system in the Northern Lagoon of Venice.

| ID | Description | Unit of measure | Formula | Burano-Murano | Burano-Treporti | Burano-Sant’Erasmo | Treporti-Treporti | Total |
|----|-------------|-----------------|---------|---------------|----------------|-------------------|------------------|-------|
| 10a | PT workers in B and A | n° | (2.a*2) | 30 | 24 | 24 | 22 | 12 | 12 | 124 |
| 10.b | Freight workers in B | n° | (8.a*2 + 8.c) | 156 | 142 | 69 | 55 | 30 | 23 | 475 |
| 10.c | Freight workers on boats in A | n° | (8.b*2 + 8.d) | 114 | 111 | 51 | 40 | 21 | 28 | 365 |
| 10.d | Total freight workers in A | n° | (10.c + 2.a) | 129 | 123 | 63 | 51 | 27 | 40 | 433 |

Fig. 4. Bus routes, households and other buildings within a 500m radius in Velenje.
The IPFL scheme foresees parcels and mail transport aboard PT vehicles, using the storage spaces beneath the passenger cabin, thus having no impact on the space available for passengers. According to this scheme (Fig. 5), the bus driver or a co-worker loads/unloads parcels at selected pickup/delivery points at each served stop, where they can be stored in automated or attended facilities prior to pick-up or delivery by/to final users. Alternatively, from selected locations mail service employees perform the very last mile for recipients which are impaired or not users. Moreover, the IPFL scheme would allow for direct same-day delivery within the served territory, avoiding the now necessary overnight layover at the post office. Mail vehicles are stopped and only the very last mile service is performed by zero emissions post vehicles (such as e-bikes, e-vans, etc.). In the evaluation, it has been assumed that recipients making use of pickup/delivery points do not cover any distance with traditional fuel, but rather walk/cycle to their nearest location or stop while performing other activities, thus not causing any additional traffic. Almost half of the residential buildings within the municipality are located along corridors served by public transport. More precisely, around 3200 buildings out of a total of 12194 are within a 250 m distance from a PT line and around 6400 buildings are within 500 m from a PT line. Most of the remaining households are located in the urban core of Velenje, at short distance from the central post office, which guarantees a good coverage of the entire territory.

Table 12 reports data regarding the B and A scenarios for IPFL in the Velenje suburban area. Yearly data have been calculated for the weekday service, considering an average of 300 days per year (excluding Sundays and public holidays), according to current PT and mail operations. Through a GIS analysis on the distribution of households, it has been possible to calculate the distances covered by postal LCVs to serve locations along the bus routes of interest. They are equal to 56 km daily and 16,800 km early (Table 12, row 12.a). Similarly, a tracing of bus routes on Google Earth Pro has allowed to determine the distance covered (Table 12, row 12.b) by the bus serving the blue, green and orange lines. The distance is found to be 148 km daily, equal to 44,400 km yearly. According to the type of vehicles and their engines, it is then possible to calculate the fuel consumption of PT and freight vehicles (Table 12, row 12.f). For PT, a 10 m, 2006-purchased suburban diesel bus has been considered (GT, 2020; for freight vehicles (Table 12, row 12.g), a Euro6-standard diesel-powered Ford Transit Courier van (UK Vehicle Certification Agency, 2020). Values thus calculated, together with the coefficients provided by EMEP/EEA (2018) and referred to Slovenian road transport, allow a determination of CO2 and NOx emissions due to PT (Table 12, rows 12.j and 12.k) and mail delivery operations (Table 12, rows 12.g and 12.h). The storage capacity aboard Velenje local buses (Table 12, row 12.d) has been gathered from the Municipality of Velenje and storage capacity aboard mail vans (Table 12, row 12.e) has been retrieved from the website of the producer, considering the most capable (4.2-4.8 m3) as security factor.

6.3. Results of the IPFL scheme

$I_1$ calculates the variation of total traffic in the area induced by the implementation of the IPFL system. The average daily traffic would not drop significantly by transferring mail and parcels on PT vehicles independently from the total traffic value, as just the three mail LCVs are stopped on a daily basis. Hence, the benefit can be considered negligible. However, it has to be pointed out that congestion and traffic-related issues in such rural area have not been identified as a primary issue.

$I_2$ finds the variation in distances covered by PT and mail vehicles to serve the area in B and A. In B, mail vans are found to cover 16,800 km

| ID | Description | Source | Unit of measure | Formula | Scenario B | Scenario A |
|----|-------------|--------|----------------|---------|------------|------------|
| 12.a | Distances covered by diesel mail vehicles | GIS-based calculation | Km/yr | (km/day*300) − 56*300 | 16,800 | 0 |
| 12.b | Distances covered by diesel buses | Google Earth calculation | Km/yr | (km/day*300) − 148*300 | 44,400 | 44,400 |
| 12.c | Spare capacity aboard buses | Municipality of Velenje | m³ | | | |
| 12.d | Mail van capacity | Ford, 2020 | m³ | | | |
| 12.e | Fuel consumption from mail vehicles | UK Vehicle certification agency, 2020 | Diesel L/yr | (12.e*0.835*3.17)/1000 | 790 | 0 |
| 12.f | CO₂ emissions from mail vehicles | EMEP/EEA (2018) | tCO₂/year | (12.e*0.835*3.17)/1000 | 790 | 0 |
| 12.g | NOx emissions from mail vehicles | EMEP/EEA (2018) | kgNOx/year | (12.e*0.835*14.1)/1000 | 9.3 | 0 |
| 12.h | Fuel consumption from buses | GTT (2020) | Diesel L/yr | (12.h*2.78) | 15,971 | 15,971 |
| 12.i | CO₂ emissions from buses | EMEP/EEA (2018) | tCO₂/year | (12.h*0.835*3.17)/1000 | 42.27 | 42.27 |
| 12.j | NOx emissions from buses | EMEP/EEA (2018) | kgNOx/year | (12.h*0.835*33.3)/1000 | 444 | 444 |
| 12.k | External costs of mail service | EC (2019) | € | (12.k*10 + 12.l*8.24) | 289 | 0 |
| 12.l | External costs of bus service | EC (2019) | € | (12.l*90 + 12.j*10,824) | 8611 | 8611 |

Fig. 5. IPFL scheme for the case study in Velenje.
yearly (Table 12, row 12.a) while buses cover 44,400 km yearly (Table 12, row 12.b). Since in A the postal service would rely completely on PT, up to 16,800 km/year would be saved, out of a total of 61,200 km. Indicator $I_2$ is thus equal to $-0.27$.

$I_3$ illustrates the variation in capacity usage aboard PT vehicles. Since in Velenje high-floor buses with separated storage space are used, mail and parcels can be stored separately in currently unused compartments, not affecting passengers’ comfort (Table 12 row 12.c). Depending on the model of the bus, at least a compartment of 1.25 m$^2$ is available (1 m $\times$ 0.50 m $\times$ 2.50 m). If compared to the loading capacity of a mail van (Table 12 row 12.d), between 4.2 m$^3$ and 4.8 m$^3$, the bus service (4 daily runs on each considered route) would offer equivalent or higher capacity to that currently guaranteed by the post company. No variation in PT capacity for passenger has to be considered. Accordingly, Formula (3) indicates no reduction in the overall capacity.

$I_4$ assesses the frequency of freight deliveries. By assuming that the frequency of PT service in A is equal to B, final users of the mail service may benefit from an increase in the level of service, given that items currently delivered on a daily basis could be delivered multiple times and according to the PT scheduling. Indeed, in B they rely on the organization of the postal service, which imposes only one possibility to distribute the goods. However, in A the availability of alternatives is dependent from the number of PT connections, which are higher (Table 11). Formula (4) thus gives a value of 4, which represents the potential increase in number of daily deliveries.

$I_5$ calculates the energetic performance through the variation in required kWh (or Joules). Diesel-powered PT buses with a Euro 4-standard Engine are considered, whose fuel consumption is calculated at 2.78 km/l (GT, 2020). By multiplying the fuel consumption by the total yearly distance, 15,971 L of diesel per year are used by PT vehicles in both B and A. This quantity is equal to 17.25 tonnes of oil equivalent (T.O.E), according to the coefficient factor of 1.08 (ENEA, 1992). As far as mail LCVs are concerned, their fuel consumption is found to be 21 km/l (UK Vehicle Certification Agency, 2020), making for a total consumption of 790 L of diesel per year (0.85 T.O.E). Values expressed in T.O.E can then be transformed into MWh, by adopting a coefficient factor of 11.8 (ISPRA, 2003). The energy requirement thus obtained is equal to 203.55 MWh/day for PT and 10 MWh/day for mail service (in B only). By applying Formula (5), this KPI gives a value equal to $-0.05$.

$I_6$ is calculated for carbon dioxide (CO$_2$) and nitric oxides (NO$_x$), basing on fuel consumption (Indicator $I_5$). Emissions of both pollutants are obtained through the transformation of consumed liters of fuel in kgs (based on fuel density for diesel, 0.835 kg/l) and the multiplication by an emission factor specifically referring to the Slovenian road transport, equal to 3.17 g CO$_2$ and to 14.1 g NO$_x$ for kilogram of consumed fuel (EEA, 2018). CO$_2$ and NO$_x$ emissions thus calculated for bus service in B and A (Table 12, row 12.i and 12.j) and for mail service in B (Table 12, row 12.f and 12.g) are multiplied by their unitary economic value, as proposed by EC (2019): 90 €/ton and 10,824 €/kg, respectively (Table 12, rows 12.k and 12.l). According to Formula (6), the indicator gives a value of $-0.63$.

Finally, $I_7$ investigates the variation in the employment rate, both in bus and mail operations. In this case study, savings are not achievable in this field as the limited number of postal service employees that are relieved from delivery service are needed for managing the very last mile leg and pickup-delivery points.

7. Discussion of results

According to the principles of IPFL, the two case studies presented in Sections 5 and 6 have been developed considering the current layout and operational characteristics of both passengers and freight transport systems and by limiting the new design to cope with existing patterns. In Venice, the performance indicators have shown positive operational results, with a better use of the capacity ($I_2$) and less pressure in terms of km travelled in the lagoon ($I_3$, $I_4$). This has resulted in a reduction in external costs ($I_4$), without reducing the social aspects related to mobility ($I_4$ indicates a better freight connection to remote islands, thanks to the use of PT vessels for the distribution of goods). In Velenje, the IPFL setting could allow for an increase in the delivery frequency of mail and parcels of up to 4 times for users willing to use pickup/delivery points located at PT stops. This form of transport is becoming an increasingly popular alternative to at-door delivery (Yuen et al., 2018). Moreover, intra-area shipments could be delivered within a few hours, thus avoiding an overnight layover at the central post office. Integrated operations would also allow for environmental benefits and boosted performances, especially within the mail delivery service ($I_2$, $I_5$).

In both case studies, the contribution of IPFL to the improvement of the FLM is multifaceted. On the one hand, the integration of passengers and goods, while boosting operations efficiency and reducing spare capacity, addresses typical FLM issues such as competition for limited space, congestion, environmental and noise pollution. On the other hand, IPFL contributes to a FLM that is more sustainable for shippers from a financial point of view, allowing for more frequent service towards isolated areas, at virtually no extra expense to subsidies for PT provision. This aspect will eventually become more important with a further diffusion of e-commerce and urban polarization trends, aspects that are associated with a progressive abandonment of suburban and rural communities (Jansen, 2014). Particularly in the Venetian lagoon, this trend is constant and the necessity to increase the attractiveness of these areas is evident (Città di Venezia, 2012). IPFL provides for more economically sustainable PT and freight services in the FLM, thus allowing a better level of service and directly addressing attractiveness issues, while gaining environmental and operational benefits.

The KPIs presented in section 4 are not valid for each context, but have to be adapted or integrated according to the territorial specificities that are deemed relevant for the analysis. For instance, the case studies do not consider increased travel times of the PT service consciously: in this kind of operations average speeds are low, the number of freight pickup/delivery locations are generally limited, and freight volumes are reduced. Moreover, freight loading/unloading can be performed in parallel with passenger operations, due to the different location of freight on the vehicle (like in the case of Velenje, where the storage compartment is beneath the passenger compartment’s floor of the bus: see 6.1). Hence, the incidence of freight operations on PT travel time is limited and affects the choice of travellers only marginally. Other aspects (such as the frequency and the quality of the service) are considered more important by users (White, 2015). This is particularly evident in a context such as the lagoon of Venice, where PT by boat is the only option to reach Venice and the mainland for the inhabitants of the islands and travel demand may be considered as inelastic. On the contrary, such an assumption would not be valid for urban services, where variations in travel times could make significant changes to the line of argument: in this context, a trade-off between passengers’ sensibility to travel time and freight operations has to be considered (Ghilas et al., 2016). In both cases, but mostly in the presence of inelastic demand, the implementation of new PT schemes has to consider the related social equity issues that may be generated, namely accessibility, movement and activities, health-related, financial related and community-related (Jones and Lucas, 2012).

The Covid-19 pandemic will pose new challenges to the definition of the model, for instance by redefining the maximum capacity of a mean and its importance. Indeed, the public acceptance of a space reduction above the minimum vehicle size for servicing goods might be lowered compared to the previous condition. Despite the analysis presented in this paper was developed before the outbreak of Covid-19, new operational conditions and priorities should be considered. This implies a multi-level and multiactor redefinition of the service, which is related to the decisions taken at the national level by the Ministries in charge of transport and health issues and made operational by the single service providers. Hence, solutions may be very different according to the country and the evolution of the pandemic.
Regarding the strategic implications of the proposed scheme, the case studies suggest a rigorous discussion about the improvement of PT service in terms of frequency, quality, and operational model (e.g., through the introduction of a more flexible transport). This could be done by reallocating part of the budget currently used for freight service and no longer needed under the new transport scheme, opening a variety of new scenarios with wide impacts on private mobility as well. In this article, we have assumed that IPFL is set up with no changes to the variety of new scenarios with wide impacts on private mobility as well. Further research could investigate the strategic impacts of a change in the current layout, according to a different use of budget available deriving from the reduction of the freight component. In this context, the choice of the transport modes involved in the IPFL is of the utmost importance. This would also imply a (more rigorous) revision of the labour market, which in our model is summarized by indicator $I_1$. The redefinition of activities deriving from the merging of passenger and freight transport should lead to different job opportunities. For example, in the case of the Venice lagoon, personnel previously employed for the freight distribution can be used to guarantee the last mile connection. This aspect, which has relevant working implications, is related with the definition of specific business models, which depends on the types of transport considered.

Finally, the integration of passengers and goods flows for the improvement of the FLM has been assessed from a technical point of view, not considering the current inadequacy of the regulatory setting as a limit for its implementation. In a comprehensive analysis this aspect cannot be omitted, and the identification of appropriate instruments to promote integrated passengers/goods transport is urgent. The framework could be represented by the Sustainable Urban Mobility Plan, currently under discussion in both Venice and Velenje. From a tactical perspective, a valid instrument can be either the tender or the bid. This would include and regulate the integrated transport system, defining clear rules and giving all operators time to organize and compete according to their competences. In this scenario, the implementation of the IPFL system would be supported by a powerful strategic planning instrument as the SUMP and promoted by the operators which would compete to affirm their role within the new system, thus lowering the risk of an otherwise likely resistance.

8. Conclusions

This paper has discussed a possible solution for tackling some of the issues related with the passengers-freight First-Last-Mile, by pursuing a higher integration level between transport systems. First and last legs of journeys normally show some performance issues: it is likely that the current trend showing a general growing urbanization, a rather disordered growth of passenger transport and sometimes an increasing fragmentation of goods deliveries, will inflame the things further. Authorities and governments have at times tried to tackle major issues (congestion, noise, pollution) by promoting restrictive and targeted measures, which have sometimes proven to be not completely effective – and in some cases even counter-producing.

Based on the EC push for further integration between freight and passenger transport, their integration may be seen as a possible solution for achieving higher efficiency and sustainability standards for the transport system. After discussing the contribution of IPFL in improving efficiency and reducing externalities from the FLM, this article has reported the setting and results of a simulation conducted in Venice (Italy) and Velenje (Slovenia) within the EU-funded project SMILE. The evaluation process, conducted using some ad-hoc KPIs, is an element of innovation with respect to existing literature, considering that it comprehends both passengers and freight transport. Performance indicators have highlighted incentivizing results, with discrete operational and environmental benefits, while social aspects need to be further assessed. The immediate definition of KPIs makes them an appropriate instrument to govern possible attempts at traffic rationalisation, and a tool of immediate use by local authorities since they base mostly on available data. However, policy makers have to be aware that results obtained by this method are not definitive: a complex issue as IPFL requires integrative operational simulations, as well as other appraisal tools (such as Cost-Benefit Analysis, Cost-Effectiveness Analysis and Multi Criteria Analysis), in order to have a more comprehensive view of all potential implications deriving from the adoption of a similar scheme. Furthermore, the adoption of these KPIs in urban contexts requires some adjustments in their definition, as discussed in the previous section.

A relevant policy issue for the improvement of FLM through freight and passenger integration has been highlighted in the inadequacy of the governance and regulatory systems, which deals with the passengers and freight transport systems as independent sectors, while in real-life operations they share space, infrastructure, and challenges. Further research and future efforts should be directed towards the identification of common European guidelines and strategies for legal and operational acknowledgement of passengers and freight transport integration, with special focus on the FLM inasmuch its economic, environmental and operational impacts are particularly relevant for the transport sector as a whole.

Despite these aspects, the method shown here is an efficient tool for the performance monitoring of possible passenger/freight transport integrations. It is of the utmost importance to set suitable objectives and tools to verify the results all in effort to properly weigh the efficiency of a certain transport strategy. In this perspective, the performance measurement is really at the heart of the management of a process: it allows to identify the data that has to be collected and analysed, to document the developments of the activities, to highlight the areas of strength and weakness, and finally to guide the improvement processes, ensuring that the strategies are shared by all actors involved in the process: the users/customers, the service producers, the other stakeholders involved and, last but not least, the community.

Authors statement

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FC: Conceptualization, Methodology, Writing- Reviewing and Editing;
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References

Abennoza, R.F., Ceccato, V., Susilo, Y.O., Cats, O., 2018. Individual, travel, and bus stop characteristics influencing travelers’ safety perceptions. Transport. Res. Rec. 2672 (8), 19–28.
ACTV, 2016. Capacity Utilization on Routes 12 and 13. Personal Communication data summer 2016.
Ambra, T., Caris, A., Macharis, C., 2018. Towards freight transport system unification: reviewing and combining the advancements in the physical internet and synchronomodal transport research. Int. J. Prod. Res. https://doi.org/10.1080/00207543.2018.1494392.
Anderson, S., Allen, J., Browne, M., 2005. Urban logistics how can it meet policy makers sustainability objectives? J. Transport Geogr. 13 (1), 71–81.
Arvidsson, N., Paziardeh, A., 2017. An ex ante evaluation of mobile depots in cities: a sustainability perspective. Int. J. Sustain. Transport. 11 (8), 623–632.
Arvidsson, N., Givoni, M., Xenou, J., 2016. Exploring last mile synergies in passenger and freight transport. Built. Environ. 42 (4), 523–534.
Bergqvist, R., Monios, J., 2016. Inbound logistics, the last mile and intermodal high capacity transport. World Rev. Intermodal Transp. Res. 6 (1), 74–92.
Boarner, M.G., Giuliano, G., Hou, Y., Jin Shin, E., 2017. First/last mile transit access as an equity planning issue. Transport. Res. Pol. Pract. 103, 296–310.
