Emerging Information and Communication Technologies: City Logistics as a Pillar of the Smart City

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Abstract

Recently, the evolution of emerging information and communication technologies (e-ICTs) has been opening the road for developing and implementing new integrated and dynamic city logistics solutions, and subsequently for identifying new frontiers of intelligent transport systems (ITS) supporting the development of smart cities. In this context, the paper reviews the new e-ICTs, pointing out the opportunity that they are offering in implementing actions within the goals identified by the Agenda 2030.

1 Introduction

Urban freight flows play a key role in satisfying the users' needs. The freight produced at a given location is transported to other places for consumption, in particular within urban and metropolitan areas, where more than 50% of worldwide population lives (UN 2017). Therefore, it is critical to the life of the city and has been for the last two decades one of the main discussion themes at the international level (Russo and Comi 2004). On the other hand, urban freight transport contributes significantly to unsustainability problems in terms of pollutant emissions, congestion, as well as road accidents (Russo and Comi 2020). For example, in Europe, around 25% of CO_2 emissions from the transport sector come from urban transport, and a significant share of road accidents involves freight vehicles (EEA 2022). Furthermore, loading and unloading operations, if not performed properly, can significantly impact urban traffic. In fact, local conditions could push freight vehicles to stop for loading and unloading outside designated spaces, as well as to stop at junctions or along a lane, in both cases causing a road capacity reduction, with subsequent deterioration of network performances, or road accidents (Comi et al. 2022).

In recent years, there has also been growth in urban freight transport due to two reasons. With regard to the supply, the distribution and e-delivery system has become increasingly more complex due to new users' requests and the sprawl of activities to be restocked (including home deliveries). In terms of demand, the e-commerce has been growing considerably, with a large share of user purchases taking place on line (Cagliano et al. 2017; Wang et al. 2021; Castiglione et al. 2022; Meister et al. 2023;

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Campisi et al. 2023). The interaction between these two elements led to an ever-increasing number of deliveries and light commercial vehicles in residential areas, generating important impacts on the sustainable development of cities, as well as on the economy. If the arrival of freight is delayed or unreliable, economic losses can occur: lost sales, consumer dissatisfaction, and increase of inventory costs for unsold products. The growth of e-commerce has accentuated these aspects opening new challenges for city planners and operators. In fact, the number of parcels delivered to end consumers is rising, and freight vehicles contribute significantly to congestion especially during peak hours. Couriers have to plan driving and walking routes given that many deliveries destined to end consumers are within limited-traffic areas (Thompson and Zhang 2018). Besides, local conditions could force freight vehicles to stop for loading and unloading outside designated spaces and far from final delivery places. As a result, delivery costs increase causing non-optimised deliveries (both in terms of internal and external costs).

The need therefore emerges to identify measures/actions that allow to pursue the objectives of sustainability ensuring orderly functioning of urban distribution. The objectives to be pursued can be formulated in different ways. The formalization shared internationally is that presented in the Agenda 2030 in terms of Goals (UN 2015) and in terms of targets and indicators (UN 2018). It should be noted that the Sustainable Development Goal (SDG) 11 is of primary interest in relation to city logistics, as it relates to the development of cities. The sustainable organization of the urban distribution of goods has direct impact on other goals and makes city logistics one of the important tools for pursuing sustainable development. However, the city logistics (through their metrics) impacts on three groups of SDG indicators (UN 2018), which can be evaluated by transport system modelling:

- direct impacts, i.e., SDG 3 and 11, defining as direct impacts those that derive from decisions taken only in mobility plans, by the sectors of the public administration that deal with mobility;
- indirect impacts, i.e., SDG 4, 8, 9 10, defining as indirect impacts those deriving from measures decided and implemented also in the development of plans that do not directly involve mobility, by the sectors of the public administration that *do not* deal with mobility;
- conditioned impacts, i.e., SDG 7, 13 and 17, defining as conditioned impacts those deriving from measures decided and implemented in mobility plans or industrial development plans that directly involve mobility, by sectors of the public administration at a different level than the urban one (regional, national, international), or by the private sector.

The evolution of emerging information and communication technologies (e-ICTs) opened the road for developing and implementing new integrated and dynamic city logistics solutions (Comi and Russo 2022; Taniguchi and Thompson 2018) in the context of smart city development, in which transport, and then city logistics, is one of the main pillars (Russo and Comi 2018). These e-ICTs can result in significant advancement for city logistics in all cities within all countries. They give win–win results when the same device systems are used with a cooperative approach among different stakeholders. Key functions include, for example, collecting data, storing data, and analyzing data for improving existing urban freight transport systems. Several projects have been funded within this research addresses (CINEA 2022). Since 2002, the CIVITAS initiative has been working to make sustainable and smart urban mobility a reality for all in Europe and beyond. Projects are being developed to improve many cities. Besides, data related to freight transport (e.g., vehicle tours/trip chains) are obtained analyzing global positioning system (GPS) traces, which are available on a large scale for such uses as fleet management or vehicle insurance. In fact, these GPS data, known also as floating car data (FCD), were largely used for investigating delivery tours as well as for setting up a methodology for demand forecasting (Battaglia et al. 2022; Comi et al. 2021; Romano Alho et al. 2019; Thoen et al. 2020).

The paper is organized as follows. Section 2 summarizes the e-ICTs and discusses how they impact on urban freight transport operations. It also points out the relationships between smart city and city logistics. Section 3 presents the innovations in freight delivery, analyzing pros and cons through the analysis of the results obtained from a real case study. Finally, conclusions are drawn, and the road ahead is discussed in Sect. 4.

2 Emerging Technologies and Freight Transport Management Systems

The e-ICTs become every day larger and more popular (Atzori et al. 2010; Knapskog and Browne 2022; Schroten et al. 2020), and focusing on those that are likely to have direct impact on city transport and logistics, we can mention:

- internet of things (IoT), it describes the set of two meta-elements, i.e., physical objects—“things”—that are embedded with sensors, software, and other technologies for the purpose of exchanging data, and a network qualified to link these objects with other devices and systems;
- big data (*BD*), although it is difficult to find a shared and universal definition, it is possible to speak of big data when the data set is so large and complex that it requires the definition of new tools and methodologies to extract, manage and process information in a reasonable time;
- block-chain (*BC*), it is defined as a chain of blocks, in which each block contains value data that are shared and validated;
- artificial intelligence (*AI*), although a large and diversified classification of AI exists, the term synthetically indicates the algorithms that, by analyzing a set of (normal or big) data, allow a decision to be made.

In particular, *IoT* and *BD* are expected to provide significant contribution to the near future of the city logistics in towards *smart* city logistics and, further on, Logistics as a Service (LaaS).

Two definitions are needed here. The first concerns the definition of *emerging technology*, because in this paper a technology is considered “emerging” with respect to the field of applications in transport and logistics. In fact, the four ICTs considered above are already “mature” in their respective fields of the original application (Schroten et al. 2020). The second, that of *advanced ICTs*, considers ICTs that are currently under development, in their respective fields of application, but which, it seems, could soon be internalized in the transport and logistics sectors. An example is the IC technology of the digital twin, which in the case study is the virtual representation of the real system of logistics services.

Supporting the optimization of delivery operations as well as of the vehicle-kms travelled, both internal and external costs can be reduced. Furthermore, referring to the different actors involved in urban freight transport and logistics (for details, see Comi and Russo (2022)), the benefits can be summarized as follows:

- *end consumers* can benefit, on one hand, as citizens, thanks to the reduction of traffic due to city logistics optimization and for the increase of livability due to the improvement of safety and the reduction of polluting emissions; on the other hand, as consumers, with the availability of new delivery services (e.g., instant deliveries, home deliveries, deliveries at pick-up points (Dablanc et al. 2017; van Duin et al. 2020; Galkin et al. 2021; Castiglione et al. 2022; Oliveira et al. 2022);
- *transport enterprises*, among the others, want to optimize the delivery travel time in terms of last-mile operations, i.e., at-customer deliveries, and their part of reverse logistics; *IoT* and *BD* allow them to use actualized and/or real-time information coming from the transport systems;

- *public administrations*, in their different levels and branches, want to improve the sustainability/livability of the city in terms of better use of public urban space (either destined to driving or to parking for loading/unloading operations) with respect to all the different demand components (i.e., passengers and freight), using different mode-services; among other roles, they can supply information on *short-term and long-term parking* and *path in real time*.

Pushed by the ICT innovations, the use of the city is changing, and different fields of knowledge are involved with their own languages (Russo et al. 2014; Russo and Rindone 2023). Referring to the directives issued by the European Union (EC 2010, 2012, 2014), the areas of interest can be defined starting from the smart growth, through innovation, technological platforms and thematic areas: energy, transport and ICTs.

From what has been briefly recalled, it emerges that smart cities are structurally ready to use what is provided by scientific innovations (Russo and Rindone 2023). In fact, this work allows to unify the advances in transport systems and e-ICTs, having the energy problem as a priority goal: both in terms of reduction in generalized cost, and of use, in the last leg of deliveries, of low- or zero-emission systems (*environmental* impact). The current developments and future directions of people-centered solutions applied to transport and logistics operators are explored (EU 2022a). In particular, the analysis evolves in order to incorporate the learning process of travel costs related to the innovations deriving from the use of e-ICTs, and to point out the benefits in terms of internal (operational) and external costs. Therefore, how the internet of things, block chain, big data and artificial intelligence can contribute to innovate freight transport management is investigated. It should be noted that the underlying vehicle-level technologies, such as automation, are out of the scope of this study.

In this context, the first stage is the identification of all components of urban freight transport, seeking to link user needs and features of the tools. The process of updating the knowledge for the user needs to be addressed, analyzing the learning process for the generic user (belonging to the *enterprise*) with the new information that can arrive from his/her experience, or from previous and present information given by the *public administration*.

Transport operators can and should have technological solutions to improve the sustainability and efficiency of their urban freight transport operations as required both by international and local authorities. Solutions based on e-ICTs can reduce the number of kilometers travelled in urban areas, increasing safety, reducing environmental impact, and congestion. Besides, vehicle technological solutions (e.g., airbag systems, or the adaptive braking systems—ABS, traction control System—TCS) do not change the number of truck-kilometers, although they increase safety. On the other hand, automation and, in particular, the connected cooperative automated mobility (CCAM) can open new challenges in city logistics (Schroten et al. 2020), as shown below.

As said above, the main objective of the freight transport management systems is to link user needs and features of the tools. In particular, the problem arises of the modification of knowledge for the user, and it becomes crucial to analyze the learning process for the generic user (belonging to the *enterprise*) with the new information that may arrive from his/her experience, from previous and present information given by the public administration. Then, the focus is on vehicle paths, vehicle routing and scheduling, and on courier routes. Subsequently, the models developed for providing three level of integration are analyzed:

- proactive and tailored-user path advice, i.e., smart routing—*navigation systems*,
- support in defining tour/trip chain for sustainable urban delivery, i.e., *computerized vehicle routing and scheduling*,
- support to couriers in defining routes within inner areas, i.e., *strong access restrictions*.

Among the ICT-based solutions, navigation, computerized vehicle routing and scheduling (CVRS) systems allow couriers to identify optimized routes. Navigation and CVRS systems provide specific route guidance exploiting the information about traffic regulations (e.g., road works, lane directions) as well as distance/time from the final destination. They can determine the best routes among destinations (customers to serve) according to the average configuration of the road network and walking tours. The new generation of navigation and CVRS systems implement the *smart routing* paradigm (proactive and tailored-user advices).

Proactive implies that the information is designed in order to preferably anticipate congestion and to address the behavioral choices of road users (de Moraes Ramos et al. 2020; Russo and Comi 2022). Then, to make optimal route choices, information about the traffic situation at the moment of departure is often not helpful. This is because it takes time to drive to the point where a route choice becomes relevant. At that point in time, the traffic situation could be changed. Hence, a prediction of the traffic situation is much smarter. This prediction can even include weather forecasts. Then, smart routing provides individual truck drivers with travel advice that is tailored to their personal preferences and refined based on the previous travel advice.

The CVRSs exploit the potential offered by merging objectives of assigning customers (pick-up and delivery locations) to trucks and determining the visiting order of customers and routes. Vehicle routing and scheduling have attracted considerable attention, but only recently has the research moved forward to include, in the definition of the problem, information on real-time network status, or even a large amount of information on the previous states of all the arcs/links of the network, both used and not used by the driver in his/her past delivery tours (Danchuk et al. 2023; Horn 2006; Musolino et al. 2018; Salehi Sarbijan and Behnamian 2023; Lin and Cai 2008).

In the context of these freight transport management issues, e-ICTs impact both on path choice (Di Gangi and Polimeni 2022) to move among the intermediate customers (e.g., retailers or end consumers), and on delivery-bay choice (short and long time) to serve customers. In particular, *IoT* and *BD* can be considered the main emerging technologies impacting on path choice between two intermediate stops/delivery/customers (updating both of the path utility and of the choice model), even if *AI* could develop advanced algorithms for better use of the opportunity offered by real-time information (e.g., updating the choice of path and suggesting the new one). On the other hand, *BC* allows to manage exchanges of values and protected/reserved data of the delivery (in this way, it is also called internet of values—*IoV*), while *AI* supports the route choice decisions. Few works integrate the learning process of path/travel costs enhanced by e-ICTs, opening the road to future research challenges.

3 Merging Past and Real-Time Information

Urban freight distribution concerns the pick-up and delivery of freight using a fleet of trucks. As a rule, vehicles are based in a single depot (warehouse), and the vehicle tours are performed in a single work shift and may include several pick-up and delivery points. The basic information needed is: the location of depots, the location of customers, road network conditions, travel times, traffic regulations, etc. In addition to this basic information, other specific information for each customer, including the daily request for carrying out goods, the designed time windows, designated driver, is given to identify the optimal visiting order and the route for each vehicle. The problem is to find the optimal route (visiting order of customers) that has the minimum total travel cost. Therefore, the delivery problem is formulated as a traveling salesman problem (TSP) and its evolution guided by the e-ICTs is hence formulated as follows:

$$\text{Minimize} Z\left[\tau,\tilde{t}\right]=\sum_{i=1}^{n}\sum_{j=1}^{n}C_{ij}\left[\tau,\tilde{t}\right]\cdot x_{ij} \tag{1}$$

subjected to some network and service constraints (for details refer to Crainic and Laporte (1997)), and where C_{ij} is the cost of path from customer i to customer j on time τ of day $\tilde{t}$, n are the customers to serve, x_{ij} is the decision binary variable. For more details refer to (Ghiani et al. 2013; Franceschetti et al. 2017; Comi and Russo 2022).

In brief, the solution of Eq. 1 determines a set of routes that starts and ends at the depot, each one performed by a single vehicle in a way that minimizes the global transportation cost and fulfils the demands of the customers and operational constraints.

In particular, referring to the general problem summarized in Eq. 1, e-ICTs impact on path cost merging the past and current info from the network, which is defined as *learning process of costs*. The complete specification of the costs, by which users consider their choice at time τ of period/day t, requires explicit treatment of the learning mechanism of path cost (*disutility* or utility) attributes (X) or, in other words, how experience and information about attributes of path costs on previous days influence the forecast of the current ones. Therefore, the inter-period and the intra-period dynamic processes need to be considered, and subsequently two aspects have to be taken into account:

- the users' *learning* and forecasting mechanism (utility updating model);
- the users' *choice* behavior (choice updating model).

The contributions of *BD* and *IoT* to modify the utility updating model are explained in the next sub-section 3.1, while in the next one 3.2 an example is presented.

3.1 The Role of E-ICTs

Let

- $\boldsymbol{C}$ be the vector of path costs for users of Origin–Destination pair *od*, consisting of elements C_k, $k \in K_{od}$ (path choice set on O-D pair *od*);
- $\boldsymbol{X}$ be the vector of path attributes for users of O-D pair *od*, consisting of elements $\boldsymbol{X}_k$, $k \in K_{od}$ (path choice set on O-D pair *od*).

The cost of path k can be expressed as the sum of additive (C_k^{ADD}) and non-additive (C_k^{NA}) components:

$$C_k = C_k^{ADD} + C_k^{NA} \tag{2}$$

Some path costs are likewise *additive*; that is, their path value can be obtained as the sum of link values for all links making up the path. Examples of additive path costs are travel times (the total travel time of a path is the sum of travel times over individual links), or some monetary costs, which can be associated with some or all individual links. Therefore, the additive costs can be expressed as combination of h-th attributes of path k (X_{hk}^{ADD}, e.g., travel time, monetary cost) through the parameter β_h:

$$C_k^{ADD} = \sum_b \beta_h \cdot X_{hk}^{ADD} \tag{3}$$

Other path performance variables are non-additive; that is, they cannot be obtained as the sum of link-specific values. Examples of non-additive costs are monetary cost in the case of tolls that are non-linearly proportional to the distance covered or the rest time for long commercial trips (e.g., a 45 min stop after 4 and a half hours of travel, or waiting time at stops for high-frequency transit systems).

Therefore, merging Eqs. 2 and 3, the paths on time τ of day t can be expressed as a function of path attributes depending on time τ of day t, as follows:

$$\boldsymbol{C}[\tau,t] = \psi(\boldsymbol{X}[\tau,t]) = \psi(\boldsymbol{X}[\tau], \boldsymbol{X}[t-1], \boldsymbol{X}[t-2], \ldots) \tag{4}$$

Path attributes, $\boldsymbol{X}$, can be estimated by users according to a learning process.

Learning occurs both with the evolution of τ (time of the day) and the evolution of t (generic day):

- for some attributes, the value experienced (tested) in previous periods $\boldsymbol{X}[t-1]$, $\boldsymbol{X}[t-2]$,

which can be obtained by means of the information stored on *BD*;
- for other attributes, the updating that users perform for each time τ in day *t*, which represents a real-time network configuration obtained through *IoT* (e.g., real-time vehicle sensors).

Therefore, the contribution of e-ICTs determines the modifications of the generalized travel costs from static to dynamic:

- within-day changes that are achieved with the use of *IoT* (intra-period process);
- day-to-day changes that are obtained with the use of *BD* (inter-period process).

Focusing on the inter-period process, the knowledge coming from *BD* (i.e., data collected in the previous days) can be formulated, using an exponential forecasting filter, as follows:

$$X_{h,ij}^{BD,fo}[t] = \gamma \cdot X_{h,ij}^{BD,\exp}[t-1] + (1-\gamma) \cdot X_{h,ij}^{BD,fo}[t-1] \tag{5}$$

where

- γ ($\in]0, 1]$) is the weight given to the experienced/tested value;
- $X_{h,ij}^{BD,\exp}[t-1]$ is the value of attribute *h* of path *k* experienced/tested on day *t-1*;
- $X_{h,ij}^{BD,fo}[t-1]$ is the value of attribute *h* of path *k* forecasted/computed on day *t-1*.

The exponential filter of Eq. 5 allows to update the path costs taking into consideration the previous experience of the user and its current forecast. Besides, according to its specification, the past experience weights less as time passes, i.e., the user tends to forget the old experiences.

Finally, the forecast value of *h*-th path attribute at time τ of day $\bar{t}$, $X_{h,ij}^{fo}[\tau, \bar{t}]$, can be obtained combining *BD* and *IoT* info as follows:

$$X_{hk}^{fo}[\tau, \bar{t}] = \xi \cdot X_{hk}^{BD,fo}[\tau, \bar{t}] + (1-\xi) \cdot X_{hk}^{IoT}[\tau, \bar{t}] \tag{6}$$

where

- $X_{hk}^{BD,fo}[\tau, \bar{t}]$ is the value of attribute X_{hk} without real-time info, given by *BD* at time *t* of day $\bar{t}$;
- $X_{hk}^{IoT}[\tau, \bar{t}]$ is the value of attribute X_{hk} realised at τ of the current day $\bar{t}$;
- ξ ($\in]0, 1]$) is the weight given to the forecasted value without real-time info given by *IoT* at time τ of current day $\bar{t}$.

Equation 6 models the user's behavior to combine the past experience represented by the stored information (*BD*) with the current one, coming from *IoT*. This combination considers different user-attributed weights for the two types of information by means of the parameter ξ.

3.2 Example of Sustainable Urban Delivery

To show the opportunities offered by this approach, a case study is recalled here (Russo and Comi 2021). The proposed planning framework was applied to a case study in Rome. It is assumed that an operator has to serve 10 customers during a working day. For avoiding overlapping, attention is paid to the customer sequence, and only *travel time* is considered as a path attribute (X = path travel time). The results are summarized in Table 1. The first column shows the truck departure time from the depot (*D*), and from each customer (*1*, …*10*). The second column gives the ordered list of customers to be served after the current visit. The third and the fourth columns contain the driving time and the working time (which consists of driving time plus the time spent at customer sites for delivery) of the optimal tour identified in the second column. Finally, the last two columns give the variations of driving and working times offered by the best order list of customers to serve, calculated at the end of the current customer visit

Table 1 Sequence of customer visits through average and real-time travel time merging ($\xi = 0.70$)

Departure time	Order of customer visits											Driving time (hh:mm:ss)	Working time (hh:mm:ss)	Δ driving time (%)	Δ working time (%)
Average	*D*	*4*	*7*	*8*	*10*	*9*	*2*	*1*	*6*	*3*	*5*	*D*	*02:28:45*	*05:08:45*		
09:30	D	2	1	6	3	5	4	7	9	10	8	D	02:34:00	05:14:00	3.53	1.70
10:15	2	3	1	7	4	6	5	8	9	10	D		02:04:08	04:44:08	−16.55	−7.97
10:53	3	6	1	5	4	7	8	9	10	D			01:55:01	04:35:01	−22.68	−10.93
11:17	6	1	5	4	7	8	9	10	D				02:17:51	04:57:51	−7.33	−3.53
11:38	1	4	5	7	8	9	10	D					02:01:17	04:41:17	−18.47	−8.90
12:03	4	5	7	8	9	10	D						02:04:53	04:44:53	−16.05	−7.73
…																

Source Russo and Comi (2021)

with respect to the average one (i.e., that calculated using the average configuration of the network).

Focusing on the point of view of transport and logistics operators, the proposed approach allows significant reduction of operational time (*economic* sustainability; about 20%). Besides, shorter paths for serving the same set of customers allows significant reduction of the impact on other network performance indicators (e.g., congestion, pollutant emission and interference with other road users) with significant benefit in terms of environmental and social sustainability.

4 Conclusions and the Road Ahead

The work carried out allowed to reach some conclusions, starting from the consideration that the areas of further development interest the following three thematic areas in the smart city field: energy, transport and ICTs.

Considering urban *transport* and mobility, it should be noted that the common tools were designed to solve the single-source shortest path problem for a static network, then guided by the needs to find the shortest path in stochastic and congested networks, considering dynamic situations, several advancements can be identified:

- smart advisors (navigation), i.e.,
  - stochastic network, i.e., the actual link travel times may differ from historical or forecasted one, and the outcome of any decision depends partly on the user's decisions and partly on randomness; the future research challenge is to move from applications using historical data for characterizing the road performances towards those developed for providing dynamic time-dependent advice, and towards those that take into consideration drivers' attitudes and updated choices;
  - optimal travel strategy-based advices; the newest tool should introduce uncertainty into minimum path/tour/route searching and new ways to suggest advice (e.g., travel strategy);
  - list of minimum paths, i.e., the new challenge is the generation of a set of paths not limited to the shortest one, i.e., not only the first best, but also the second best, etc., up to the *g-th* best, until obtaining a set of specific paths;
- from CVRSs to courier delivery problem: couriers, when planning deliveries to citizens as well as to business users (including retailers), need to consider both driving and walking routes (i.e., from delivery bay to customers) to optimize their activities; therefore, there is the need to determine the best delivery bay which allow to minimize the delivery route (*times*) considering dynamic slot openings and taking into consideration that couriers often serve multiple customers from the same delivery bays; the evolution should cover the following challenges, i.e.,
  - to identify the set of preferred delivery zones (*IoT* provides info on their availability);
  - to estimate route costs (disutility/utility; *BD*);
  - to identify the optimal driving and walking route to the customers merging real-time and past costs to forecast the route costs (*AI*);

Besides, the value exchanges can be managed as well as more comprehensive track-and-trace capabilities can be provided (*BC*).

The evolution of what was proposed pushes towards a further advanced level providing, i.e.,

- the formal unitary treatment of the inclusion of e-ICT in the traveling salesman problem (TSP; i.e., routing);
- the opportunity to design a multilevel delivery path (tour) with nodes (points) where walking for reaching the final customers (e.g., retailers or end consumers' homes) is introduced (i.e., courier problem);
- the choice behavior of users (i.e., choice updating model);

- the conditions relating to the search for the solution when different dynamic filters other than the exponential are present;
- double dynamic assignment process.

More generally, it is worth noting that, if the formalization proposed with Eq. (1) is valid in the study of systems from the point of view of the courier/carrier, it is necessary to develop dynamic models that instead consider the point of view of the planner—public administration—(Nuzzolo and Comi 2014), which must know the set of decisions taken by all the courier/carriers, and therefore necessarily introduces additional probability conditions with respect to those previously presented, and here due only to carrier's (courier) uncertainties. In addition, the introduced learning process of path costs can be extended including a further advanced level, providing the opportunity to design a multilevel delivery path (tour) with nodes (points) where walking for reaching the final customers (e.g., retailers or end consumers' homes) is introduced.

Focusing on the opportunity offered by *ICTs*, it emerges that the future developments should exploit collaboration among freight operators and public administration to improve the information available on specific attributes (e.g., the public administration can offer information services on the travel time on the road network that can be used by operators for optimizing their operations). It is the public administration (PA), owner of the intelligent objects, that can organize an IoT^{PA} with other operators for collecting the data, and handle them with a big data (BD^{PA}) approach. Besides, city logistics services should be included into the NASs (national access points) (EU 2022b).

Companies can offer new services to customers thanks to the *BC*. For example, they can use information to provide proof of legitimacy or authenticity, and consumers can benefit knowing whether a product has been ethically sourced, is an original item, and was preserved under the right conditions. Besides, very relevant is the contribution on contracts as well as the sharing of data among stakeholders (transport and logistics operators, and retailers) for optimizing deliveries. Smart contracts in *BC* are an important function that is designed to automatically facilitate, verify and enforce the negotiation. This allows the implementation of digital contracts without any central authority.

ICTs can address the development of support systems for making decisions in delivering (*AI*). For example, further challenges refer to the modelling of the choice mechanism and to the use of the sequential choice approach, given that users can update their utility to modify the path costs. For example, when a path k is chosen, and during the travel the user is informed that another path has become attractive (e.g., along the path k there is a road accident or a specific event and the traffic is delayed), the user can update his/her utility in an intelligent *en-route* way.

Furthermore, a unified platform is needed to share technologies with the aim at building the logistics community system—LCS, evolving from Port Community System. A further advancement regards the possibility to organize an integrated software-hardware system, a *digital twin*, where the methods for planning and those for assessing the general Product as a Service business models will be tested for city logistics. The digital twin will be the virtual twin of the real LCS.

Currently used in the city, the optimization approach is devoted to consider each "final" impact and then to introduce measures to limit the impact. A new approach should be developed, which considers the overall urban system with a unified view. Production cycles can be revised by improving their environmental impacts through the management of the energy cycles and the management of the transport and logistics cycle. Examples are: self-production in the city village (wind, photoelectric, solar thermal energy), energy efficiency (storage batteries, grid optimization), energy consumption, digitization of processes. Also, in the context of the *energy* challenge, there is the big theme of the efficiency of propulsion and automation.

Finally, the next research frontier is represented by autonomous deliveries, e.g.

autonomous delivery robots (ADR). ADRs are electric-powered motorized vehicles that can deliver items or packages to customers without the intervention of a delivery person. ADRs can be divided into two types (Arntz et al. 2023; Figliozzi and Jennings 2020; Yuen et al. 2022): sidewalk autonomous delivery robots (SADRs), which are pedestrian sized robots that only utilize sidewalks or pedestrian paths; on-road or simply road autonomous delivery robots (RADRs), which are vehicles that travel on roadways shared with conventional motorized vehicles.

Despite the benefits of using ADRs, challenges also impede adoption and acceptance of ADRs:

- end consumers' point of view
  - ADRs may be perceived as less convenient,
  - consumers who are less technologically inclined may experience technical difficulties with ADRs;
- operators' point of view
  - the need for barrier-free infrastructure,
  - the need for proper regulations,
  - theft prevention mechanisms.

The interest in the non-military use of drones has increased dramatically with successful operations in the delivery of medicine, food, and mail orders (Goodchild and Toy 2018). Focus has been heavily placed on the *economic* and *social* impacts:

- companies anticipate a reduction in transportation costs,
- concerns exist regarding individual privacy rights, and airspace congestion.

However, environmental impacts are highly dependent on the energy requirements of the drone, as well as the distance it must travel and the number of recipients it serves. Drones are likely to provide a CO_2 benefit when service zones are close to the depot, have small numbers of stops, or both.

To gain insight into the practical opportunities offered by e-ICTs, or advanced ITSs, and its impact on generalized path costs analyzed in the earlier sections, the following analyses can be considered. For example, the route advisors can evolve moving from those that use historical data to characterize the road performance to those developed for providing dynamic time-dependent advice, passing through those that take into consideration drivers' attitudes. Historical data-based methods analyze historical information in order to extract information about the road network and provide more robust route advice. Historical traffic information can be analyzed with the aim at computing traffic-tolerant paths over time-dependent road networks. Other historical data-based methods analyze and mine trajectory data in order to extract popular routes, given that drivers usually choose routes according to their direct experience and/or their knowledge about traffic. By mining such data, more robust route recommendation can be provided. This work is important for the technicians of companies that can combine information coming from different sources, obtaining the best results for freight delivery. The work is useful both for e-ICT researchers, because it allows one to identify how and where e-ICTs are used in the transportation field, and for transport researchers, because it allows them to define the field of the use of the different e-ICTs, and then to proceed in modelling. However, this modelling framework stresses the interoperability among different fields of knowledge and opens new challenges in the direction of multi-disciplinarity.

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