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Integration of Collaborative Transport Robotics Applied to Micro-Mobility in the Local Urban Environment: Proposed Recommendations

Integración de la robótica colaborativa de transporte aplicada a la micromovilidad en el entorno urbano local: propuesta de recomendaciones

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Abstract

The development of collaborative transport robotics (CTR) is the result of the development of electric transport technologies and artificial intelligence applied to the transport of goods and services in the near urban environment (NUE). In the future, the appropriate integration of these devices in this environment will depend on the implementation models of the services provided by the CTRs, on the promoters associated with their deployment, whether distribution operators or public administrations, and finally, on the spatial integration and social acceptance derived from them. This contribution is part of a project carried out in collaboration with a robotics engineering research institute concerned with the challenges posed by the introduction of CTRs in this urban environment. The objectives of this contribution are, firstly, to establish a contextual framework for the management of collaborative transport robotics in the NUE; and secondly, to develop recommendations for improving the management of collaborative transport robotics in the NUE. The methodology employed is based on a documentary review of the conceptualisation of the system and a subsequent qualitative analysis considering three dimensions: technological, spatial and managerial. The results presented support the recommendation of the need for an integrated management of CTRs that incorporates public and private actors, and highlight both the potential spatial impact and the influence on citizens' behaviour that can be derived from the implementation of this system in the urban environment of proximity.

Palabras clave:
micromovilidad; medio urbano de proximidad; Robótica Colaborativa de Transporte (RCT)

Resumen

El desarrollo de la robótica de transporte colaborativo (CTR) es el resultado de la puesta a punto de las tecnologías del transporte eléctrico y de la inteligencia artificial, aplicadas al transporte de bienes y servicios en el entorno urbano de proximidad (NUE). En un futuro, la integración adecuada de estos dispositivos en este entorno dependerá de los modelos de implantación de los servicios prestado por los CTR, de los promotores asociados a su despliegue, ya sean operadores de distribución o administraciones públicas y, finalmente, de la integración espacial y la aceptación social derivadas. Esta contribución forma parte de un proyecto realizado en colaboración con un instituto de investigación en ingeniería robótica preocupado por los retos que plantearía la introducción de los CTR en este entorno urbano. Los objetivos de esta contribución son, en primer lugar, establecer un marco contextual para la gestión de la robótica colaborativa del transporte en el NUE; y en segundo lugar, elaborar unas recomendaciones para mejorar dicha gestión. La metodología empleada se basa en una revisión documental realizada sobre la conceptualización del sistema y un análisis cualitativo posterior considerando tres dimensiones: tecnológica, espacial y de gestión. Los resultados presentados sostienen la recomendación de la necesidad de una gestión integral de los CTR que incorpore a agentes públicos y privados, y destacan tanto el impacto espacial potencial como su influencia en el comportamiento de los ciudadanos que se pueden derivar de la implantación de este sistema en el entorno urbano de proximidad.

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1. Introduction

According to the United Nations (2017), 3.5 billion people live in cities today and this number is projected to increase to 5 billion by 2030. Ninety-five per cent of urban land expansion in the coming decades will take place in the developing world. The world's cities occupy only 3% of the world's land, but account for 60-80% of energy consumption and 75% of carbon emissions. As of 2016, 90% of urban dwellers breathed air that did not meet safety standards set by the World Health Organization, resulting in a total of 4.2 million deaths due to air pollution. Cities all over the world are increasing in size and complexity, and this is particularly evident in the evolution of urban mobility within and around them (Muhumed, 2022). Urban mobility is an essential activity with high added value. It has developed an economic public and private sector that generates a large number of jobs and is highly visible to the public (Ajuntament de Barcelona, 2022). However, it also generates a significant environmental impact: vans and lorries account for 23% of private vehicle mobility and are responsible for over a third of the PM10 and NOx emissions detected in Barcelona. In addition, in 2019 they were involved in more than 1,500 traffic accidents (Transports Metropolitans de Barcelona, 2022).

A first type of urban mobility is the logistics of the movement of people into, out of and within the city on a daily basis. Most of the mobility of people is two-way because all outward journeys have a return journey, except in the case of migration. A second type of urban mobility is the logistics of city professionals (maintenance, emergencies, surveillance, cleaning, etc.) who work regularly in the street (Figure 1). A third type of mobility is the logistics of transport and distribution of goods, both semi-finished materials for transformation and finished products for consumption. In a first stage, these are distributed to local businesses (B2B) and in a second stage to consumers (B2C). Currently, most of this mobility is one-way because the materials and products, when they reach their destination, are partially consumed and the rest is converted into waste (Sustainable Urban Development) that is removed by the fourth type of mobility. Finally, the fourth type of mobility, which could be called reverse mobility, focuses on the collection of waste (DUS) for further treatment, either to be discharged into the environment in specific establishments or to be reintegrated into production for revaluation.

Figure 1. New forms of urban micro-mobility

Source: Own elaboration. Note: These are proliferating, mainly based on low-emission propulsion technologies that improve road safety (lower speed) and environmental quality (lower emissions).

The first type of mobility has gradually been subjected to urban planning developed in collaboration with large urban transport operators, and the second type of mobility is gradually moving in the same direction, with the collaboration of professional vehicle fleets. The third type of mobility, Urban Distribution (DU), has recently emerged as an aspect to be improved and regulated (Ajuntament de Barcelona, 2022). The fourth type of mobility, which is fully the responsibility of the public administration, is developing even within the sphere of the second type.

Logistics experts agree that all current urban mobility is less efficient than peripheral and territorial mobility (Muhumed, 2022). This is because it takes place in densely populated and spatially fragmented environments, it meets highly personalised demand and urban mobility technology is still based on the combustion engine, which is noisy and polluting.

The implementation of Collaborative Transport Robots (CTR) in the local urban environment (last-mile) is seen as one of the possible solutions to these problems. CTRs could potentially have a lower environmental impact (electric mobility), improve efficiency by reducing congestion (artificial intelligence applied to logistics) and facilitate the current mobility conditions of citizens, both private individuals and professionals, in the distribution of goods and urban maintenance. However, given the complexity and concurrence of the local urban space, the insertion of CTRs in the current city will not be free of obstacles and adversities to be overcome by all the agents involved, including logistic operators, CTR technicians and users. Bourzac et al. (2021) analyse the relationship between mobility infrastructures and the public space generated, a relationship that transcends its utilitarian sense and is established as a process of social, economic and environmental transformation of urban environments.

The main aim of this paper is to draw up a list of recommendations on the integration of collaborative robotics into the urban environment, considering urban planners, the public space and the transport technology. The content of the paper is divided into four sections, as well as the introduction and the references. The first section is on the state of the art and focuses on the conceptualisation of micro-mobility applied to the urban logistics of product distribution. The second section presents the methodology used to define the list of recommendations. The third section includes the results and the discussion, based on the defined list of recommendations for the integration of collaborative robotics into the urban environment on the three levels mentioned above – planning agents, urban space and robotics technology – and using the twelve attributes defined in the methodology. The last section presents the conclusions of the research.

2. State of the Art

2.1. Vectors of change in urban neighbourhood mobility

The UN Sustainable Development Goals (SDGs) set out to provide access to safe, affordable, accessible and sustainable transport systems for all by 2030, with a focus on the needs of people in vulnerable situations and on-air quality (UN, 2017). Currently, there are several active vectors of change with respect to different types of urban mobility. The first is a reduction of private car traffic. Private cars are considered negative for citizens because of noise discomfort, static presence in the public space, polluting emissions from engines, energy inefficiency and a high accident rate (Whittle et al., 2019). The second vector is the implementation of electric and smart micro-mobility in the city. In recent years, a change in urban micro-mobility has been foreshadowed by improving road safety, traffic fluidity and environmental quality by reducing presence, noise and emissions (Figure 2). The third factor is changing patterns of work, social relations and leisure in the city: the circuits of urban micro-mobility are being redefined because online work, customised production, home-based leisure and other factors are being introduced (300,000 km/s, 2019).

Figure 2. New forms of urban micro-mobility

Source: Own elaboration.

Today, goods are mainly manufactured outside of cities and transported to inner-city neighbourhoods. The resulting waste is evacuated from the city centre to the outskirts. When the entire supply chain of goods from the manufacturer to the final customer is considered, the last mile refers to the journey of goods between the last distribution centre managed by the carrier and the final customer (Bachofner et al, 2022). After centuries of moving domestic activities (education, food, culture, health, education, etc.) to public facilities (schools, supermarkets, cinemas, hospitals, etc.), certain habitability services have returned to the home in online format (Arcas, 2013).

In today's cities, everyday uses disappear and the infrastructures that made them possible become obsolete. The spaces freed up by these abandoned infrastructures become spaces of opportunity. In addition, the number of people, carers or cared-for, who travel together on urban roads has increased. This includes school groups, tourist groups and elderly people under guidance or guardianship. In addition, e-commerce has grown significantly for retail purchases, especially those involving large companies. Home delivery of food and restaurant meals was accelerated by the Covid-19 pandemic.

Technically, the last-mile distribution of goods and services is costly and inefficient (Bachofner et al., 2022). It is inefficient because the quality of the service provided (delivery) is demanding: delivery should preferably be made by hand and in person, which leads to many disagreements; the quantity of goods distributed in each delivery is as small as possible (personalisation); the driver is no longer just a haulier but also a shopkeeper; the waiting time between the consumer making the order and the delivery of the goods by the supplier is part of the value that is paid for and, finally, it is still difficult to add value to the return journey.

Many European cities are looking for solutions to redesign their public space according to this transition. In Spain, the Ministry of Transport, Mobility and Urban Agenda, now called the Ministry of Transport and Sustainable Mobility, has implemented good practice recommendations for micro-mobility in urban environments as part of its general mobility planning (MITMA, 2021). The aim is to encourage the use of micro-mobility in urban environments based on complementarity between modes of transport by promoting fast functional transfers at accessible and well-signposted interchange stations; providing universal access to information and energy during a journey; enhancing the energy efficiency, regulation and safety of journeys; and increasing the use of personal, light means of transport and mobility for local journeys (< 8 km) in intermodality with public means of transport.

2.2. *Personal micro-mobility*

Urban mobility began with the movement of a physical body using its own natural means of transport in the immediate environment (micro-mobility). However, it quickly evolved technically (Table 1). Micro-mobility is currently changing very rapidly due to the fast development of electric technologies and assisted navigation.

Table 1. Personal micro-mobility profiles and applied technical resources

Micro-mobility profiles	Technical resources		
Assisted mobility: a personal technical device allows any citizen to get faster, further or even move in an adverse environment (air, water, slope), especially if he/she has a disability.	Walkers, crutches, wheelchairs, etc.	 1a	Citizens move safely around the city even when their abilities are impaired by age or illness due to assisted mobility aids and the fact that the city is a largely predictable, enabled environment. Source: authors
Extended mobility: a commercial technical device allows citizens to move beyond the limits of the body, leaving the body free for other purposes.	Bicycle, motorbike, scooter, skateboard, etc.	 1b	The city also has a dimension of mobility at height for specific jobs, which has generated certain tools. Source: authors
Delegated mobility: a shared technical device moves the citizen, or his/her goods, under the responsibility of another.	Bus, taxi, distribution truck, etc.	 1c	Taxis are a personal mobility service that is widespread around the world, where the value is centred on privacy, comfort and the professionalism of the driver. Source: authors

Source: Own elaboration.

Citizens regularly move individually within their immediate urban environment.

Table 2. Citizen movement in the urban environment

By themselves (on foot), with or without their own goods or purchased goods			
 2a	Operators working on the street also move around on foot and are visually recognisable by their uniforms.	 2b	Citizens move around with the goods they have bought in their daily shopping in local shops.
Using various means of individual or shared micro-mobility			
 2c	Most micro-mobility trips are made individually but with assistance.	 2d	The availability and costs of micro-mobility technologies often make it advisable to share them to make them more affordable and efficient.
With different procedures for accessing micro-mobility			
 2e	Access to a micro-mobility technology implies foresight, financial resources, availability of space, etc.	 2f	Access to the use of micro-mobility technologies can be through purchase, rental, chauffeur-driven services and, more recently, sharing.

Source: Own elaboration.

Finally, while electric technology is proven and already widely applied, autonomous navigation technology is likely to be developed and used in a more gradual, layered manner (Society of Automotive Engineers International, 2021), as follows:

- Level 1: navigation autonomy is low and requires the driver's assistance for all actions that involve decision making.
- Level 2: autonomy already includes some features such as acceleration, braking assistance, etc. but always under human supervision.
- Level 3: autonomy is limited to controlled and predictable environments (e.g. piloted parking and autopilot mode), in which the driver can always regain control.
- Level 4: includes full autonomy but allows the driver to take control if he/she deems it necessary.
- Level 5: full autonomy, with no need for human intervention.

2.3. The micro-mobility of DUM

Cities are rapidly transforming from centres of collective production (nineteenth century) to centres of individual consumption (twenty-first century). Product sales strategies for household products have boosted e-commerce and the home delivery that accompanies it. This means that deliveries are smaller, more personalised and more frequent.

Various types of DU can be distinguished: distribution of goods (DUM) to commercial establishments in the city; business to business (B2B) or distribution to consumers (business to consumer or B2C), either directly from distribution centres or directly from commercial establishments in the city; and urban distribution of services (DUS) aimed at consumers and commercial establishments and including waste collection, repairs, removals, etc. (Arango, et al. 2017).

Shladover (2022) points out the many technical advantages of local parcel delivery compared to shared transport. Without humans in the CTR, the vehicle can be designed to be smaller and lighter than a conventional delivery vehicle and does not require space, crash protection, or heating, ventilation, and air conditioning (HVAC) systems for personal comfort.

In addition, with no humans in the vehicle, the automated driving system does not need to meet safety criteria to protect vehicle occupants and can prioritise the safety of other road users in potential pre-crash situations. CTR driving can be performed slowly and very cautiously, but continuously, without the driver becoming impatient or uncomfortable with the pace of progress towards the destination. Furthermore, CTR driving can be designed to be deferential to other road users (very courteous), which is likely to facilitate public acceptance of sharing space on the road (Figures 2a & 2b).

Figure 2a. New commercial mobility actors are emerging in the city to take responsibility for B2C DUM

Figure 2b. Regulations are emerging in the city to make new types of mobility compatible with existing types

Source: Own elaboration.

As arbiters of the city (Generalitat de Catalunya, 2022), local governments are starting to propose and take measures to mitigate the harmful effects of increased DUM traffic in the city. These measures include increasing the use of urban points for collecting online purchases, extending the network of urban goods' distribution centres (UDCs) and locating them as a priority outside public spaces (e.g. in municipal car parks), making parking facilities more flexible for loading and unloading DU, ensuring the availability of logistics land that is better integrated into the urban fabric, reducing the accident rate and lack of discipline in this area and promoting DUM fleets powered by alternative energies, such as cycling (Figures 12 & 13).

2.4. Collaborative micro-mobility

In any of the three types of mobility mentioned above, the interested party can either take the initiative to travel to collect the goods or wait to receive them at home. The professionalisation of the logistics sector has led to a gradual shift towards the second type of mobility, which is more efficient.

In their daily micro-mobility journeys, citizens move around the urban environment carrying, safeguarding, accompanying, etc. goods and travelling companions, who may be dependents, for various reasons, in a quantity (weight, volume and number) limited by the citizen's physical capacities. Moving on public roads is therefore more complex than individual travel because citizens must be attentive to the rules of urban traffic and attentive to their companions, whether passively or actively. This joint mobility may take place in a subordinate way, with the means available to each citizen (person, worker and distributor) or in collaborative way.

Dual collaborative mobility is a type of urban micro-mobility that is highly integrated into everyday life. One of the agents is considered the principal agent, or person responsible, with respect to the subordinate partner or collaborator. Urban social relations are usually established between the principal agents while the secondary agents remain subordinate.

Collaborative herd mobility (groups of schoolchildren, groups of tourists, groups of cyclists or groups of friends, among others) (Figures 3a & 3b) are somewhat more complex. One of the actors is considered a guide or leader with respect to the herd. This mobility takes place on a dependent basis.

Figure 3a. Dual mobility is very common in the urban environment (owner & pet, mother & child, traveller & suitcase, customer & taxi driver, carer & pushchair, etc.)

Figure 3b. Groups, even if sporadic, disrupt urban mobility, which is by nature individual. Demonstrators, schoolchildren, tourists and groups of cyclists must follow specific mobility rules to reduce the volume of conflicts

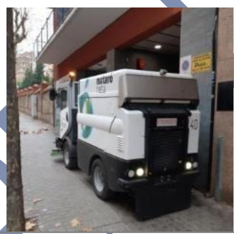
Source: Own elaboration.

The emergence of autonomous mobility (robotics) opens up an urban scenario of collaborative mobility between citizens and robots for any of the journeys listed in Table 3. The citizen and the collaborative transport robot (CTR) can interact in person (direct contact) or virtually (telecontact). The rest of the citizens who are not actively participating in this collaboration can interact or simply coexist in the same urban environment with the CTRs (collaborative transport robots).

Table 3. Mobility profile from a functional perspective

Transported object	Reason for travel
Personal property	Travel for shopping
door-to-door (retail) **service** (Transport of goods in demand)	3a 
Gift or present	Trip for social relations
Distraction ride (Travel with reduced luggage) **Visit to acquaintance or shop assistant** (Transport of gift or present)	3b 
Commercial goods	B2B delivery to a B2B establishment
Commercial supply (wholesale) **to point of sale or customer** (Economic activity)	3c 
Tool trolleys	Home delivery service
Emergency assistance to accident victims	3d 

Table 3. Mobility profile from a functional perspective (continuation)

Municipal soil waste	Transport to “green spots”
Occasional removal of rubble from building works (Temporary deposit while waiting for the agreed collection)	3e 
Workstation	Support for SAT urban communication network
Equipment for repairing infrastructure in the public road (Transport of tools, parts and removal of rubble)	3f 
Tools, storage	Cleaning itinerary
Periodic cleaning of the public road (Sweeping, vacuuming and collecting rubbish)	3g 

Source: Own elaboration.

2.5. Collaborative transport robotics in logistics

Urban technicians are therefore faced with the challenge of properly introducing electric and autonomous devices (CTR) for the transport of goods or waste, either by themselves (remote-controlled) or in collaboration with their customers, in a local urban environment that is not specifically prepared for this new on-site activity because pedestrian routes currently have their own inadequacies, which can be overcome by humans but probably not by CTRs. In addition, citizens do not initially have shared patterns of coexistence with CTRs. Streets for vehicles are already too congested to introduce, without further ado, other types of vehicles such as CTRs.

The physical infrastructure that has so far supported urban public space in cities evolves slowly, because it is slow and costly to plan and implement. In general, the urban infrastructure of any city tends to solidify its own social and functional relationships. The emergence of CTRs will probably require mutual adaptation of the city and the CTRs, to make the introduction of this technology beneficial for all citizen groups.

“Appropriate” incorporation of CTR robots raises a number of questions from the outset:

- What is the admissible limit of their incorporation in the city (traffic density, traffic speed, robot’s gauge)?
- Should this incorporation be segregated or integrated? Is it reasonable to explore other urban road platforms that are not currently used by citizens, such as rivers, air or underground?
- Will collaborative urban micro-mobility flows be unidirectional (e.g. one-way delivery) or bidirectional (e.g. incorporation of waste collection)?
- Can the delivery robot (collaborative transport) take the new goods together with the operator and his tools, and at the same time remove the obsolete goods and install the new goods?
- Will the delivery robot (collaborative transport) be strict in its route or will it be able to deviate slightly to share resources and add efficiencies (e.g. picking up additional goods en route)?

Can all urban scenarios have the same collaborative micro-mobility model? The most efficient use of CTRs could be achieved in higher density urban areas, where many customers would be within walking distance of the companies that serve them. However, these locations also tend to have the narrowest, busiest pavements and the most complicated interactions with other road users. Therefore, they are the most technically challenging. In contrast, moderate-density suburban locations would be considerably easier for the technology to manage, but would require longer average trip lengths and times, leading to lower productivity per vehicle.

Should collaborative micro-mobility be positioned with reference to existing mobility networks or should it be mapped anew?

According to Cila & Lupetti (2021), the initial enthusiasm that currently characterises any emerging technical novelty may overshadow the contingent need to understand how new autonomous artefacts, and the related services they can provide, can transform current urban society and whether the future that will be shaped by their presence will correspond to the needs and aspirations of the urban community.

This whole process will be easier, more efficient and more affordable for all citizens if the recommendations of urban experts are taken on board. These are aimed at improving the efficiency of the city while ensuring that all citizens benefit and the environment is not damaged.

The recommendations made here are in this line. They are intended as a guide for the process of integration so that all participants work together in a coordinated manner and citizens can better appreciate the advantages gained with respect to the disadvantages incorporated.

3. Methodological framework

The methodology proposed to formulate these recommendations is qualitative, descriptive and based on previous studies focused on the detection of technical conflicts and opportunities arising from the potential future implementation of CTRs.

The recommendations should be validated in each case and updated according to the evolution of the urban environment and the CTR services. They are presented according to the twelve attributes considered in previous studies, taking into account the technological requirements.

The recommendations have been illustrated with images of the streets of Barcelona Metropolitan Area, selected as relevant due to its reputation, diversity and proximity.

A secondary objective is to target the recommendations to the various actors involved. These include economic operators who promote commercial logistic services, designers of CTR devices, and urban regulators of the aspects that can be addressed through by-laws, planning or the physical implementation of urbanisation.

4. Discussion and results

4.1. Recommendations for city managers

Both citizens and operators, public and private, look to city managers to regulate the activities of CTRs and their physical insertion in the city. This arbitration role is rightfully theirs and allows them to establish the admissible uses in each zone and the relevant timetables, with varying intensities in space and time. According to Shladover (2022), there are potential disadvantages of inappropriate insertion of CTRs if they are not implemented in a regulated manner. These include displacement of people who currently earn their living as drivers and who need to become drivers/supervisors of these new vehicles; increased distances travelled by CTRs, especially if the costs of each trip decrease significantly; reduced traffic safety if the licensed CTR technology is implemented prematurely, before it has been thoroughly debugged; and, finally, a reduction in overall city traffic efficiency if the licensed CTR technology is too cautious in its interactions with other traffic. Excessive braking events (false positives) may restrict the application of CTRs to low speeds and short trips. The small carrying capacity of CTRs further limits them to low-to-moderate density urban scenarios.

According to Shladover (2022), the scale and timing of CTR deployment is still very uncertain for city managers due to unknowns such as how safe CTRs are and what impacts they could have on the functioning of the current urban transit system. Other questions are what the general public's attitude towards CTRs will be and how will this influence local government decisions on their implementation and regulation. As in the case of scooters, bicycles or skateboards, regulations are developed a posteriori and outside the framework of conventional vehicles (no registration, no insurance, no code, etc.).

Shladover (2022) also considers that it will only be practical to implement a cost-effective service based on the use of CTR in urban scenarios where two fundamental conditions can be met. First, there must be sufficient demand for the use of CTR to support the service and second, CTRs must fully develop all their capabilities (electrification, autonomy and collaboration) during the entire service.

Generally, the most profitable urban implementation scenarios for CTR-based services are those with the highest demand density, which also translates into more challenging operating conditions for CTRs. While CTR technology is maturing, it is also likely that the only technically feasible urban implementation scenarios at present are those that are less dense, and therefore have limited profit potential, or those that require only the most elementary CTR services.

Given these challenges, which are inherent to any advanced technology in the process of socialisation, it will probably take time for CTRs to reach the technical feasibility necessary to provide a wide range of services with confidence and security.

Although CTRs can also circulate on the common roadway platform, they are oriented towards entering the last-mile space to access the interior of buildings. The first step is standardised transit on the pavement. This has a number of advantages and disadvantages (Shladover, 2022). The appropriate speed is very low, comparable to the walking speed of pedestrians to be able to coexist with them on the pavements. CTRs are not required to comply with state road traffic codes but are subject to each municipality's ordinances on the use of pavements.

CTRs must be prepared to interact closely and courteously with a wide range of pedestrian behaviours, from potentially curious and playful children to potentially hostile teenagers and potentially fearful older people. The increasing extension of pavement seating further limits the scarce space available for walking. As CTRs are relatively small vehicles, they are vulnerable to harassment, vandalism and theft. In cities with inclement weather, pavements often have accumulations of snow, ice, mud, etc., which can make it even more difficult for CTRs to travel. As CTRs are small and slow, they have limited potential to cause collision injuries; and in neighbourhoods with narrow and uneven pavements, interactions of CTRs with other users of these pavements can be difficult (who has right of way?). In accordance, Table 4 proposes a series of intervention recommendations for local governments.

Table 4. Recommendations for city managers

Orientation
- Establish a collection service for disoriented or abandoned CTRs, as for other vehicles.
Energy autonomy
- Promote public or private establishments, with conditions for recharging (immediate or deferred).
Route or itinerary
- Progressively authorize CTR fleet routes in scenarios prepared for coexistence between urban operators: emergencies, cleaning and removal of Municipal Solid Waste, public order, gardening, mobility of people, lighting, supplies to businesses. - These operators must accept and tolerate the integration of CTR operators who disrupt their routine: take up space and time, obstruct, congest, hold up, etc. - Keep personal CTRs very close to their supervisors at all times, to resolve and deal with incidents. - Establish priority rules at crossings that can be clearly interpreted by CTRs.
Load, volume, gauge and format
- Establish gauge and maximum weight conditions on these authorised routes.
Setpoint speed
- Each authorised route must have a setpoint speed that can be modified according to the identified citizen activity in each scenario (night, weekend, demonstration, holiday, public holiday, etc.).
Stability
- CTRs circulating in the city must be homologated and have clear limitations of use to ensure their stability along the route (no overturning, no zigzagging, no off-route).
Foreseeability
- Prioritise in the forthcoming deployment of routes for CTRs those that allow for more predictable and routine service conditions.

Table 4. Recommendations for city managers (continuation)

Shutdown, shelter and maintenance
- Encourage the establishment of an initial network of public-private intermediate stopping, shelter or maintenance points outside on authorised routes. - Establish minimum standards and conditions for public-private intermediate stopping, shelter or maintenance points in backwaters.
Intercommunication
- The authorities must standardise the successive protocols for intercommunication between CTRs and the public: light signals, written signals, acoustic signals, etc.
Appearance (presence)
- Authorities should indicate on which face the identification or intercommunication displays or labels should be clearly located on the CTR.
Remote assistance
- Regulate the provision of this activity on a guarantee and competition basis. Any CTRs in circulation must subscribe to a remote assistance service and display evidence of this subscription.
Pick up point and delivery point
- Encourage the establishment of an initial network of public-private outdoor pick-up and drop-off points on authorised routes. - Establish the minimum standards and conditions for an indoor CTR collection and delivery point.

Source: Own elaboration.

4.2. Recommendations for the NUE

In the existing city, redesign and redevelopment works will have to be carried out in the public space to implement the use of CTRs. This is not unusual because there are historical precedents for the successive incorporation into the city of new vehicles such as bicycles, trams, underground railways, etc. and new services associated with these vehicles such as home delivery of mail, taxis or solid urban waste collection. These redevelopment works, which are by their nature costly, time-consuming and cumbersome in their execution, should also serve to resolve other inherent problems that are pending.

A complex urban scenario is envisaged of mixed micro-mobility between spontaneous vehicles (with drivers) and autonomous vehicles (CTR), between vehicles running on separate platforms and vehicles that can transfer from one platform to another, as demonstrated by bicycles. It therefore seems advisable to, on the one hand, locate the passive support spaces required by CTRs (e.g. parking, repair, power supply, etc.) in the private spaces of their operators (whether public, private or strictly private) to avoid congesting the existing urban public space and, at the same time, provide an opportunity to reuse many available ground-floor premises. Furthermore, the current relationship between the various urban road platforms is one of protection: all the usual obstacles to walking are preferably located on the borders between platforms (bollards, rail guards, lampposts, signs, trees, etc.). For CTRs, this is a hindrance. Therefore, any boundaries between platforms should be made safer and more functional by incorporating, for example, interchange places that are useful for CTRs and other road operators.

Table 5 proposes some more specific recommendations, ordered according to the attributes of the CTRs, considering recommendations for urban planning and for urbanisation.

Table 5. Recommendations for urban planning and urbanisation of NUE

Orientation
- Be able to establish parking spaces (either exclusive or shared) where CTRs can regain their lost orientation. - Be interpreted immediately. Every second that passes without an initial clear interpretation contributes to confusion. - Have a personalised presence that makes it unique, distinguishable and recognisable in the context of the urban landscape. - Minimise the risks arising from use and handling, under normal and foreseeable adverse conditions. - Be able to be marked without leaving a trace. Current paint systems on asphalt pavements have not achieved this. - Clearly distinguish variable (seasonal) information elements from stable elements on which ordinary guidance is based.

Table 5. Recommendations for urban planning and urbanisation of NUE (continuation)

Energy autonomy

- Ensure that public recharging spaces (ideal for private CTRs) are not mixed with the network of private recharging spaces (ideal for fleet CTRs).
- Present a variety of configurations according to the range of neighbourhoods and urban settings. Be able to be localised and understood immediately.
- Harness renewable energies in suburban charging stations.
- Reconfigure in the event of foreseeable rapid changes in demand (day-night, summer-winter, weekday-holiday) to maintain service availability.

Route or itinerary

- Reconfigure quickly in case of foreseeable changes (day-night, summer-winter, weekday-holiday) to maintain trafficability.
- Integrate CTR routes or itineraries in each urban scenario based on strategies of opportunity and partnership.
- Readjust the road platform gauges in renovated urban scenarios. This readjustment should be made for the benefit of smaller and more manoeuvrable vehicles.
- Meet minimum technical characteristics (clearance, self-protection, stability, etc.) of connection in accordance with the capacities of the CTR and be flexible to adapt to various urban scenarios (ISO 22737).
- In terms of intermodality, achieve the same versatility that the bicycle has achieved, e.g. bicycles parked by a metro access tunnel.
- Introduce coordination between lighting (street lamps), landscaping (trees), urban services (overhead networks) and road network (crossings and fords) teams, prior to authorisation.
- As far as road signs are concerned, they must be properly interpreted by other means of mobility to cross or share them safely.
- Signal crossing points where any vehicle stops and checks the feasibility of the crossing before returning to the road.
- For recreational areas, such as squares and promenades, allow the passage of vehicular CTRs, even if the pavement is different from that used for roads.
- Clearly identify vegetation.
- Ensure pavements are uniform, so as not to cause any unnecessary jolts when moving around.
- With regard to the transition between pavements, use elements to signal the change.
- Signpost crossings between sections appropriately so that they can be crossed with caution.
- Signpost crossing barriers appropriately so that they are not interpreted as passable.
- With regard to longitudinal barrier elements that prevent intrusion between vehicles, enhance those that are selective.
- With regard to transverse barrier elements that prevent intrusion between vehicles, enhance innovation.
- Ensure that entrances are practicable (material, length and slope).
- With regard to adapted-entrances between platforms at different levels, use viscoelastic forks to reduce impact energy.
- Intercept rainwater or run-off water at entrances between platforms.
- Locate vertical road signs, which are shared or specific to CTRs, in visual areas unobstructed by other opaque elements. The anticipated visibility should be enhanced by their unique colour, size and illumination.
- Ensure that horizontal road markings clearly delineate where the rules applicable to CTRs begin and end.
- Ensure that barriers for exceptional, urgent and temporary events, are sufficiently well known to alert the CTRs to their status.
- Ensure that coloured horizontal road signs, with an imperative meaning, are suitable for reading by CTRs.
- Take advantage of protective medians on two-way roads for CTRs.
- Look for roughness in the pavements that is suitable for this speed and with good drainage capacity. The necessary reduction of traffic speed in the last-mile scenario helps the CTR to use more meandering routes with less traffic and helps in the creation of sheltered waterproof corners (backwaters) for CTR pit stops.

Load, volume, gauge and format

- Establish maximum gauges for CTRs circulating in the urban public space.
- Create CTR-specific loading and unloading bays where it is possible to negotiate obstacles between platforms with agility, to obtain clearance or wait for instructions.
- Favour the orientation of the CTR cargo box door towards the loading and unloading bay.

Table 5. Recommendations for urban planning and urbanisation of NUE (continuation)

Setpoint speed

- Ensure that the appearance of the roadway suggests the desired traffic speed.
- Each urban setting offers different perceptual richness depending on the speed at which it is experienced. Maintain this coherence when CTRs are implemented in such an area.

Stability

- Reconfigure currently dangerous routes (e.g. curves with higher accident rates).
- With regard to transit points and permeability between platforms, ensure the stability of CTRs with appropriate urban design solutions. This can be beneficial to avoid the current high number of pedestrian falls.
- Ensure that CTR routes have good drainage.

Foreseeability

- Identify the CTR routes that are most predictable and routine.
- As far as container gardening is concerned, with a great power of conviction in the rapid transformation operations of urbanisation, container gardens should be detectable in advance.
- With regard to container gardening located as a permeable barrier in transit areas of different priority, be easily recognisable as such.
- In terms of landscaping, and as it will be strongly incorporated into the city in the coming decades due to its biophilic benefits, it should be detectable in advance by CTRs.
- With regard to street furniture, be detectable in advance as such.
- With regard to elements that are not fixed but are semi-permanently deposited in the public space, be detectable in advance as such.
- In the case of rubble sacks that have no previous location, they should be detectable in advance as such.
- In the case of buildings on the public highway, be detectable in advance as such.
- In the case of furniture that facilitates the temporary storage of goods under a consignment system, they are detectable in advance as such, even with their deposits.
- As regards commercial furniture, such as chairs and tables in catering establishments, they should be detectable in advance as such.
- As regards event elements, be detectable in advance as such.
- In the case of public service obligations, be detectable in advance as such.

Shutdown, shelter and maintenance

- Ensure that building access portals support accreditation, protection, loading and unloading activities of CTRs.

Intercommunication

- With regard to spaces freed from the current passive parking of private vehicles, they should preferably be used for service activities for vehicles on the move, such as CTRs, in order to facilitate their assistance, loading and unloading, and stand-by. There should be waiting areas for CTRs outside intercommunication and CTRs waiting for intercommunication.
- For intercommunication moments when the CTR is vulnerable, provide a protected enclosure, which identifies them, protects them and can be active (energy harvesting).

Appearance (presence)

- As regards the link between the appearance of the vehicle and the appearance of the road on which it is travelling, this identification should be reinforced in the case of CTRs.
- In terms of signage, make it clear which spaces are for the exclusive use and the passage of a vehicle, and which are shared.

Remote assistance

- With regard to existing service stations, make space available in service areas.
- Establish enclosures equipped for external telecare or the user's own telecare.

Pick up point and delivery point

- With regard to load splitting, use larger vehicles or ground floor premises designed for this purpose, but never in the middle of the public road.
- In the case of private buildings that are the origin or end of a dispatch, they must have their own loading and manoeuvring yards so as not to occupy the public highway.
- As regards interim points of origin or final destination of dispatch, protective and signalling elements must be in place.

- As regards stable private drop-off and pick-up points, provide lockers for this purpose.
- As regards sporadic asynchronous drop-off and pick-up points, have partner establishments.
- In terms of sporadic asynchronous drop-off and pick-up points, have exchange furniture located in areas of maximum congestion and footfall for maximum efficiency. As valuable goods are exchanged, they should be protected from weather, theft and vandalism.
- In terms of stable public drop-off and pick-up points, make stops available.

Source: Own elaboration.

4.3. Recommendations for robotic technology

It seems reasonable to expect to see widespread urban use of electrified and connected but not autonomous mobility long before we see a comparable deployment of CTRs in the city. This provides more time for CTR technology developers to improve safety and interact with stakeholders. Table 6 shows more specific recommendations, ordered according to the twelve basic attributes of CTRs. These recommendations are limited to terrestrial robots that move horizontally on flat platforms until they can approach or enter buildings through existing doorways. Perhaps some of them will be capable of mixed indoor/outdoor travel.

Table 6. Recommendations for CTRs

Orientation

- Alert the addressee, sender and operator when the CTR is momentarily disoriented.
- Turn back and retrace its route.
- Indicate its disorientation status with signals that can be detected by bystanders.
- Acknowledge the presence of law enforcement officials.

Energy autonomy

- The charging network and the charging device must be in line with the availability regime of the CTR.
- Closed charging network (ownership regime): private management of recharging (universal charger available).
- Open charging network (sharing regime): capacity for online management of sharing (no universal charger available).
- Use surplus energy on the electricity grid for low-priority CTR activities.
- Present a dual CTR configuration: traction unit and charging unit (separable).
- Pay for the energy you have charged.

Route or itinerary

- Apply the object tracking technique to monitor the usual routes or itineraries of people and other vehicles (paths) so that CTRs can be programmed to avoid these obstacles and thus prevent incidents.
- Adopt a different navigation mode depending on the weather, time of day and date.
- Follow a trajectory that can be predicted by other people or vehicles on the same road platform.
- Adjust movements to avoid wear and vibrations that affect the comfort of the load during the route.
- Adapt in real time to the main cruising speed of each platform at any given time.

Load, volume, gauge and format

- Adopt a format that is efficient for its service model and at the same time adapts to the dominant gauge in its urban scenario.
- Propose a format that is specific to the new city that is now being built in anticipation of CTR traffic.
- Offer the user an ergonomic gauge that facilitates mutual interaction.
- Offer load protection (invisibility, atmospheric agents, theft, vandalism, etc.).
- Present different load configurations, in weight and volume.
- Ensure the load does not obstruct driving and facilitates loading and unloading from different sides.
- Enable turning, reversing, generation of convoys and reduction of curvature radius, etc.

Table 6. Recommendations for CTRs (continuation)

Setpoint speed
- Synchronise with the speed of citizens on foot and with the speed of micro-mobility of citizens. Following, passing or moving forward are actions with high symbolic value for citizens in their urban journeys. - Communicate your target speed and acceleration and deceleration capability to other vehicles in the vicinity to avoid conflicts and collisions. - Adapt your set point speed to the climatic conditions. - Limit operations to low speeds and with the assistance of a supervisor to manage traffic situations that exceed the capabilities of the automation technology.
Stability
- Take prompt action when a risk of instability is detected. An overturned vehicle on the road generates conflicting feelings and responses.
Foreseeability
- Clearly identify CTRs that are predictable and routine in their activity, with respect to CTRs that act as an emergency device or a particular CTR. - Have a black box to record all incidents on the journey. A distress beacon is also recommended that allows immediate location in the event of an incident.
Shutdown, shelter and maintenance
- Communicate remotely if detained awaiting information (active listening), if detained awaiting service (passive listening) or if detained because of being off-duty (no listening).
Intercommunication
- Avoid a physical collision when crossing with a pedestrian or another vehicle and be "courteous" by emitting an acknowledgement (greeting) signal indicating awareness of the existence of another moving entity and that the approach on their part is "respectful". On this approach, the CTR should reduce its set speed, give way and wait for the other moving entity to move sufficiently far away. This "polite" signal should be projected in its immediate vicinity to define a protective environment (social distance) and communicate a direction of approach, so that the other moving entity can thus anticipate it. - Be identifiable by name (name or registration number): this would allow the human citizen to call the robot by name or identification, to return the greeting and in this case, to give the impression that he or she wants to establish intercommunication with his or her supervisor (warning, conciliation, etc.). - This behaviour may not be suitable for pets or children. - Develop a comprehensive system of general intercommunication, enabling the robot to interact with the sender, the receiver and the urban actors.
Appearance (presence)
- Indicate its uniqueness and avoid confusion with other vehicles. In the case of a face-to-face collaborative CTR, it will be important to recognise the link with the nearest face-to-face supervisor.
Remote assistance
- Have automatic telecare notification and notification of urban authority agents. - Have systems to enable towing or retrieval by another CTR.
Pick up point and delivery point
- Ensure that CTRs are released as soon as possible from their cargo because their job is transport and not custody. - Have technologies for the use of authorisation (smartphone, card, code, fingerprint, etc.) and certification incorporated.

Source: Own elaboration.

The article proposes the compilation of a list of recommendations for the integration of collaborative transport robotics in the urban environment based on micro-mobility logistics. Although many studies on this subject have focused on the technological dimension, considering levels of autonomy, and on the psychological dimension in terms of human-robot interaction, this article focuses on the spatial impact of collaborative robotics in the consolidated urban environment. The potential of integrating CTRs in the city is assessed according to three complementary levels: agents involved in the urban design, public space and, finally, robotics technology for micro-mobility. These recommendations are evaluated based on twelve attributes developed in preceding research that range from the vehicle's energy autonomy to adapting the loading and unloading space. Notably, the recommendations for integrating this technology should be adapted to the development objectives of each urban environment.

5. Conclusions

The insertion of CTRs into existing cities is likely to develop in stages because it will require the simultaneous development of new logistic service models, the fine-tuning of robotic technology, an appropriate regulatory framework, and modifications to the urbanisation infrastructure of existing cities to achieve the acquiescence of all citizens.

In the short term, the insertion of CTRs will be driven by private initiative, which will seek its own economic efficiency in the provision of logistics services. This deployment will be carried out differently according to the urban scenarios and each city. In locations where the insertion of CTRs is quantitatively higher and therefore conflicts are generated, derived from their initial success, urban administrations will probably restrict this service to certain hours or certain spaces to limit potential conflicts, or to certain specific uses such as urban maintenance.

In the established city, current governance arrangements with other vehicles in transit and people "in" the city will need to be updated, and these arrangements will need to be translated into new bylaws. The existing urbanisation style books of each city will need to be updated and aspects of their current materiality reconsidered to better accommodate CTRs and improve the conditions for other citizens and vehicles to move around. It will be essential to periodically update these recommendations, based on the experiences acquired and shared by each city in terms of the insertion of CTRs on the roads, the installation of distribution points, the reception of goods for CTRs and software applications that facilitate this smart, electric, collaborative mobility.

Subsequently, in the medium term, as the use of CTRs matures and increases, the urban scene itself, under pressure from citizens, will react and gradually redevelop, specialising in particular in exchange nodes (where deliveries take place, authorisations are formalised and parking depots are located), and tracks for CTRs transit and intersection nodes with other road platforms.

The forthcoming introduction of CTRs in the city will probably only be properly consolidated if each stage of the process presents a more favourable balance of advantages and disadvantages than current micro-mobility from an economic, social and environmental point of view.

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7. Credit authorships contribution statement (CRediT)

First author was in charge of formal Analysis, investigation, validation and writing. Second author was in charge of conceptualization, investigation, methodology, supervision, visualization, writing. Third author, in charge of funding acquisition, project administration, resources, investigation.

8. References

Arango, M., Gómez, C., & Serna, Conrado. (2017) Logistics models applied in the urban goods distribution. *Revista EIA, 14*(28), 57-76. https://doi.org/10.24050/reia.v14i28.1055

Ajuntament de Barcelona (2022). *EDUM 2030.* [online] Retrieved 16th june 2025 on https://www.barcelona.cat/mobilitat/ca/serveis/distribucio-urbana-de-mercaderies-dum/estrategia-per-la-millora-de-la-distribucio-urbana-de-mercaderies

Arcas, J., (2013). *On també vivim: cap a una redefinició de l'habitabilitat des de la diversitat.* [doctoral tesis, Universitat Politècnica de Catalunya, Departament de Construccions Arquitectòniques I http://hdl.handle.net/2117/94914

Bachofner, M., Lemardelé, C., Estrada, M., & Pagès, L. (2022). City logistics: challenges and opportunities for technology providers. *Journal of Urban Mobility*, 2, 100020. https://doi.org/10.1016/j.urbmob.2022.100020

Bourzac, M. T. P., Sánchez, C. A. C., & Yerena, M. L. G. (2021). Espacio público y transporte masivo: usos y percepciones. Paseo Alcalde y línea 3 SITEUR en el Área Metropolitana de Guadalajara, México. *ACE: Arquitectura, Ciudad y Entorno, 16*(47). https://doi.org/10.5821/ace.16.47.9631

European Institute of Innovation and Technology - Urban Mobility (15th of January 2019). *European Institute of Innovation and Technology (EIT) events to encourage positive changes in the way people move around cities in order to make them more liveable places*. [online]. Retrieved 16th june 2025 on https://www.eiturbanmobility.eu/category/events/

Generalitat de Catalunya (15th of March 2022). *El govern aprova la memoria preliminar dper regular l'última milla del comer electrònic*. Generalitat de Catalunya [online]. Retrieved 16th june 2025 on https://ccam.gencat.cat/ca/detalls/noticia/20220315_acord_govern_comerc_electronic

Cila, N., Lupetti, M. L., & Zaga, C. (28 of June – 2 of July 2021). *Learning from robotics artefacts: A quest for strong concepts in Human-Robot Interaction* [Paper] DIS 2021 - Proceedings of the 2021 ACM Designing Interactive Systems Conference, United States of America. https://dl.acm.org/doi/abs/10.1145/3461778.3462095

(MITMA) Ministerio de Transportes y Movilidad Sostenible (2021). *Estrategia de movilidad segura sostenible conectada 2030. Resumen ejecutivo*. Ministerio de Transportes y Movilidad Sostenible, MITMA. [online] Retrieved 16th june 2025 on https://cdn.mitma.gob.es/portal-web-drupal/esmovilidad/ejes/211223_es.movilidad_accesibilidad_BAJA_vf.pdf

Muhumed, A. M. (2022). *Autonomous delivery robots for urban settings*. [Thesis Bachelor of Business Administration, Metropolia University of Applied Sciences [online]. Retrieved 16th june 2025 on https://urn.fi/URN:NBN:fi:amk-2022060315318

Society of Automotive Engineers International (2021). *Taxonomy and definitions for terms related to cooperative driving automation for on-road motor vehicles, surface vehicle information report j3216*. Society of Automotive Engineers, SAE. [online] Retrieved 16th june 2025 on https://www.sae.org/standards/content/j3216_202107/

Shladover, S. (2022). Opportunities, challenges, and uncertainties in urban road transport automation. *Sustainability, 14*(3), 1853. https://doi.org/10.3390/su14031853

Transports Metropolitans de Barcelona. *Principales datos de su actividad de gestión del transporte público de Barcelona*. Transports Metropolitans de Barcelona, TMB [online] Retrieved 16th june 2025 on https://www.tmb.cat/es/sobre-tmb/conocenos/transporte-cifras

(UN) United Nations (2017). *The sustainable development goals report*. United Nations, UN [online] Retrieved 16th june 2025 on https://unstats.un.org/sdgs/report/2017/

Whittle, C., Haggar, P., Whitmarsh, L., Morgan, Ph., Xenias, D. & Parkhurst, G., (2019) *Decision-making in the UK transport system. Future of mobility: evidence review*. Foresight, Government Office for Science [online] Retrieved 16th june 2025 on https://assets.publishing.service.gov.uk/media/5c4b1e70e5274a6e4614fb14/decisionmaking.pdf

300000km/s (2019). *Last-mile logistics. Predicting and designing the last mile*. 300.000km/s. [online] Retrieved 16th june 2025 on https://300000kms.net/case_study/data-city-last-mile-logistics/