Mobility

Intermodal Logistics Chains in Cities

How standardized containers can optimize the "last mile"

ONO

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Foreword

Cities are dynamic ecosystems in which mobility significantly affects the quality of life. If the aim is not only to preserve but also to enhance them, urban mobility needs to be adapted as quickly as possible and acceptable solutions need to be found for a series of challenges. These include constantly growing populations—especially in major cities—rising levels of carbon and particulate matter, obsolete transportation infrastructures, high levels of noise, and strict limitations on usable space.

Of tremendous importance here is what is known as "last-mile" logistics. The rapid growth of e-commerce is playing a very prominent role in the ever-greater difficulties and tensions plaguing urban logistics. Rising volumes of cargo and high customer expectations for rapid and flexible delivery stand in opposition to the associated effects on quality of life from air pollution, traffic congestion, and high loads on urban infrastructures, which are simultaneously facing huge cost pressures and limited capacities.

Industry and public services need to take a collaborative approach to meeting these environmental, social, and economic challenges. Bringing the major actors together to work on a trans-sector basis is the only way to find efficient solutions for transporting more cargo in the same amount of time in less space and with fewer emissions.

The intermodal logistics chain presented here, which combines road and rail transport, is a promising way to put both environmental and economic strategies for urban contexts into practice. It can help decarbonize urban mobility, increase profitability for providers, and make urban space more livable. In drawing up this white paper, several private-sector companies and a university assessed an intermodal logistics chain to raise awareness among industry and government decision-makers for what pilot projects can offer. This project is supported by EIT InnoEnergy, the driver of sustainable energy in Europe (www.innoenergy.com).

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INSIGHTS

//01

Inner-district logistics have to be reexamined. Higher freight levels require intermodal and sustainable routes and solutions. A completely new approach is needed.

//02

Container transport is a revolutionary approach to worldwide trade from the 1950s. Adapting this method to urban contexts would shorten loading and unloading times and enable more flexible forms of last-mile delivery.

//03

Optimal use of existing urban (rail) infrastructure is of crucial importance. Moving transport from road to rail is the first step toward an intermodal transformation in values and systems for the final mile.

//04

Alternative approaches to mobility such as cargo trams and electric cargo bikes lower carbon, nitrogen oxide and noise emissions and reduce traffic for the last mile.

Enabling reliable delivery to households, retail, and production sites and ensuring individual means of mobility are the main challenges facing a growing number of cities whose infrastructures have long since reached their limits. Transportation is a major source of noise, particulate matter, and harmful carbon greenhouse gases.

Private car ownership is rising, as are commercial deliveries to downtown areas that help keep cities alive. Commercial transports account for 25 to 30 percent of urban traffic.[1] Above all, ever more small items need to be delivered. That makes it all the more pressing to develop innovative logistics concepts as one component of complex metropolitan mobility structures that sustainably reduce traffic levels via efficient use of roads. Current debate is therefore focusing increasing attention on calls for alternative forms of transport.

A combination of conventional and locally emission-free vehicles, trams, and electric cargo bikes throughout entire delivery chains down to and including the last mile offers strong alternatives to current urban logistics systems. When used together, these three modes of transport have the potential to provide sustainable, cost-saving, and comprehensive mobility solutions. In addition to these three vehicle types, further potential to optimize last-mile logistics lies in the use of containers as a universal medium. Standardized containers already revolutionized global trade in the 1950s. Today, a container developed for urban purposes can fundamentally change how goods are delivered in urban and suburban contexts.

[1] Innenstadtlogistik mit Zukunft, Chamber of Commerce and Industry, Stuttgart region, 2012

01

Urban logistics— current developments in city centers

Some 3.65 billion packages were delivered by courier, express, and parcel services in Germany in 2019. This figure is expected to rise by approximately 4 percent annually until 2024.[2] Growth is not the only challenge that needs to be met. Carbon neutrality is a central topic, with efforts to achieve it figuring in everyday life and the strategies of many companies. This will require new approaches to urban space, alternative logistics strategies, and intermodal transport options.

Ever more people are living in cities. The UN estimates that around 70 percent of the world's population will be living in urban areas by the year 2050.[3] By comparison, the current figure is around 55 percent, and in 1950 it accounted for less than a third of the world's population. This ongoing trend is leading to an ever-greater shortage of space and to competition over its use. Road networks are increasingly running up against capacity limits—a dilemma long evident in Asia, where traffic jams are part of everyday life in cities like Beijing, Manila, and Kuala Lumpur. The problem has long since arrived in the metropolitan centers of Europe as well. In 2019, Germans spent an average of 46 hours in traffic jams. That represents an economic loss of 2.8 billion euros.[4] In addition, calls for low-emission and climate-friendly mobility are becoming ever louder. These trends cannot be addressed solely on the level of infrastructure performance—which is, after all, only one part of an overall ecosystem. Of greater relevance are city-friendly, resource-saving, and infrastructure-compatible logistics strategies and new technologies capable of transforming downtown areas. The goal is to bridge the apparent conflict between high-quality urban life and cost-efficient supply of goods. Urban logistics can make a major contribution to lowering traffic levels and emissions.

At issue here is not a single, all-encompassing approach. Instead, an array of different strategies offers more potential for improvement over the long term. Cities and municipalities are responding to higher levels of passenger and commercial vehicles with limits and prohibitions on the one hand, yet also with new strategies on the other. The French capital Paris is set to ban all diesel vehicles by 2030, and is planning to prohibit all diesel cars within its limits by 2024 when it hosts the Olympic Games. Initial measures include car-free days and zones within its ring road.[5] Barcelona, as part of its urban mobility strategy, has put new approaches to urban logistics into practice. These include temporary loading zones, urban distribution depots, and delivery services using alternative vehicles (e.g., cargo bikes and electric bicycles/tricycles).[6] These approaches still require delivery to the depots by truck or van, because two- and three-wheeled vehicles cannot carry the full volume of goods from distribution facilities outside the city to its central districts. Barcelona has also tried nighttime deliveries,[7] although these are limited by the associated noise problems.

Self-service parcel stations are another trend that is continuing to rise worldwide. This strategy simply shifts part of the service to end customers, and reduces the volume of goods at least in the "very last mile."

All the strategies listed above are sound and help to optimize logistics overall in city centers, yet they all continue to make extensive use of road infrastructures. There is, however, a completely different approach. Whereas a large share of urban transport currently uses the roads, other infrastructures such as rail systems have thus far not been incorporated into the search for solutions. Past examples show that rail systems definitely have the potential to provide alternative means of transport, especially in areas that already have rail-based infrastructures. Shifting cargo to the rails and utilizing the resulting intermodal logistics chains represent an extremely promising approach, which will be described in detail below.

Of crucial significance for improving traffic and air quality is the fact that all the approaches listed here are not mutually exclusive but instead can complement and augment each other.

[2] KEP-Studie 2020 – Analyse des Marktes in Deutschland, Federal Association of Parcel and Express Logistics Services (BIEK), 2020
[3] World Urbanization Prospects: the 2018 Revision, United Nations, 2018
[4] Global Traffic Scorecard, INRIX Research, 2020
[5] https://www.faz.net/aktuell/wirtschaft/paris-und-oxford-fahrverbote-fuer-diesel-und-benziner-ab-2020-15243020.html
[6] Urban Mobility Plan of Barcelona 2013–2018, Ajuntament de Barcelona, 2014
[7] Smart choices for cities: Making urban freight logistics more sustainable, Civitas, 2020

02

COVID-19 a challenge and opportunity for the last mile

» A crisis is a productive state. You simply need to eliminate the overtone of catastrophe.

// Max Frisch

COVID-19 is dominating current discussions. It is posing an acid test to our life as a society and to the resilience of our cities. While some large cities like New York City and Tokyo are seeing a veritable urban exodus,[8,9] that does not appear to be the case in Germany. The pandemic is presumably only temporarily pulling the brake on urbanization. The attraction and appeal of cities and their infrastructures, especially with respect to cultural and social offerings, will remain unchanged over the long term.[10] Instead, the pandemic's main challenges have to do with everyday life. Shopping trips are only possible in conjunction with certain hygiene protocols, as is the use of public transportation. This has led to a decline in sales for brick-and-mortar retail businesses, and losses of billions of euros for Deutsche Bahn and municipal public transportation companies.

On the other hand, the COVID-19 crisis has triggered strong growth in the online retail sector. The willingness to purchase goods by clicking on an icon has never been so high. This brings an enormous need for logistical resources, which will continue to increase as levels of e-commerce rise. A number of markets have seen significant growth over the course of the COVID-19 pandemic. Online sales of consumer goods have risen by 56 percent, and of food by 70 percent.[11] Using current logistics chains, this means more traffic and higher carbon and nitrogen oxide emissions in urban areas. A shift to "green logistics" has to find intelligent ways of combining existing infrastructures and new mobility prospects. As for the last mile, that explicitly means using the free capacities of public transportation as well as bicycle infrastructures. Bicycles have been enjoying ever-greater popularity as a means of transport in Europe for years now, all the more so in the course of the pandemic. Pop-up bike paths have appeared in many places, and can serve as long-term solutions for urban mobility. A focus on approaches to last-mile logistics has spotlighted enormous gaps in the logistics chain during the pandemic. For example, cities around the world have been imposing limits on car traffic, and allowing van and truck deliveries only at certain times of day.

[8] https://www.tagesschau.de/ausland/coronakrise-new-york-flucht-101.html
[9] https://www.dw.com/de/coronavirus-japaner-zieht-es-aufs-land/a-53889746
[10] S. Siedentopp, R. Zimmer-Hegmann, "Covid-19 und die Zukunft der Städte," in ILS-Impulse 01/20; Institute for Regional and Urban Development, Dortmund, 2020
[11] https://www.innoenergy.com/last-mile-urban-transport/

03

Containers: an additional last-mile logistics solution

Standardized containers have already revolutionized the transport of goods in the past, and raised world trade to a new level. Malcom McLean, an American ship owner and transport entrepreneur, is considered the inventor of intermodal shipping. In the 1950s he envisioned developing a container that would be compatible with different means of transport and thereby streamline cargo transfers. This led to a reduction in transport costs of up to 22 percent.[12]

Current developments in last-mile transport call for similarly innovative solutions. By combining containers that can be used in intelligent and flexible ways with diverse modes of transport (trucks/vans, trams, electric cargo bikes), the challenges of urban logistics can be met in cost-efficient ways while lowering levels of emissions and traffic.

[12] A. Cosar, B. Demir, "Shipping inside the Box: Containerization and Trade," ERIA Discussion Paper Series (2017)

04

Promising solution: an intermodal logistics chain

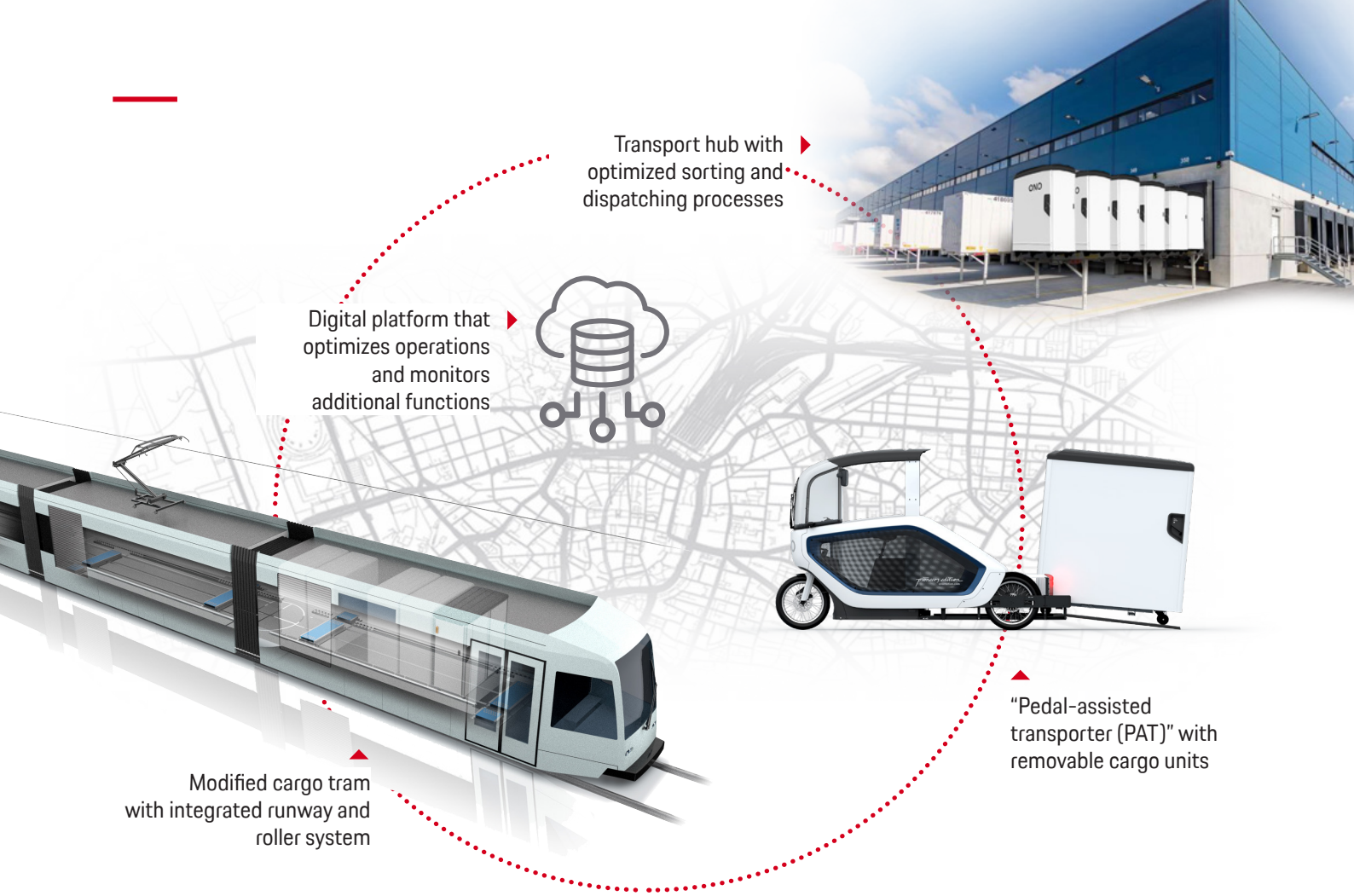


Fig. 1. Conceptual diagram of an intermodal logistics chain

History of the cargo tram concept

The year 2007 witnessed a revolutionary reexamination of last-mile logistics and transportation systems. For its City-Cargo project, the city of Amsterdam introduced a prototype as part of efforts to reform last-mile approaches. The proposed solution was to shift cargo from roads to the public transportation system, and to use the rail infrastructure not only for passengers but also for goods. The idea was to operate the cargo trams separately from the passenger trams. For the pilot project, the operating company Gemeentevervoerbedrijf, or GVB for short, made two trams available. They were refurbished for the project and loaded with cargo at terminal stops at the city's periphery. Overall project plans called for setting up multiple distribution centers within the ring road, where cargo would be transferred to electric vehicles for delivery to end customers. However, funding shortages and political complications meant that the project was not expanded to regular operations. New transport lines and transfer hubs would have had to be built, and conversion costs would have amounted to around one million euros per kilometer of line. Total investment in trams, infrastructure, main transfer bases, and electric vehicles would have been 70 million euros,[13] and the project ultimately failed. In addition to the high costs, a final blow was dealt by the worldwide economic crisis of 2008, which sealed the fate of the CityCargo project.

[13] Kai-Oliver Schocke et al, LastMileTram – Empirische Forschung zum Einsatz einer Güterstraßenbahn am Beispiel Frankfurt am Main; Frankfurt University of Applied Sciences (2019)

New attempt, better conditions

The cargo tram project is undergoing a revival in 2021, and a new concept has been developed. It is based on the use of existing infrastructures such as tram lines, tram cars, and zero-emission electric cargo bikes. In addition to operating strategies, a strong network of partners is needed to make the pilot project a success. In order to pursue this promising cargo-tram approach without repeating the mistakes of the past, the InnoEnergy, ONOMOTION, Hörmann Gruppe, EurA, Hermes, and Porsche Consulting companies joined forces with the Frankfurt University of Applied Sciences to revisit the project and optimize its technical and operational aspects. The aim is to highlight the potential of this type of logistics chain and to spark enthusiasm for pilot projects among cities and public transportation companies. The companies involved in this concept study bring a wide range of expertise along the transport chain and on various value-adding levels to the project.

Considerable adjustments were made for implementation throughout the delivery chain. A digital logistics platform should control and monitor the operating processes. The focus here is on tasks such as optimizing deployment and routes, making full use of capacities, and distribution.

The project now envisions an intermodal, three-step approach.

01 Existing fleets of trucks should handle delivery of goods from depots to the city periphery. At the periphery, tram stops should serve as loading points for the cargo trams. Comparable freight capacities of truck and cargo tram mean that load-transfer processes should not need large amounts of space.

02 Cargo trams should then carry the goods directly from the city periphery into its districts and center. They should use suitable stops where the containers can be unloaded. Preliminary sorting should ensure rapid unloading, and should not negatively affect regular passenger service. A priority should be placed on making loading and unloading processes considerably simpler and more effective. For the previous project in Amsterdam, the goods were transferred directly in break-bulk form to electric trucks. That led to high idling times, and considerably limited flexibility. In this new approach, the process is streamlined by using standardized containers across the entire transport chain. In addition, modern track-and-trace communication systems enable prompt pick-ups. Inner-district stops would therefore require only small buffer spaces to accommodate a few containers per stop. The containers would not need to be picked up "just in time," but could be stored on a temporary basis instead. This optimizes operations for the trams and electric cargo bikes.

03 Delivery to end customers should then be done by transferring the containers to electric cargo bikes. The proposed logistics chain thereby makes the best possible use of existing infrastructures as well as low-emission modes of transport. Moreover, cargo bikes can accelerate delivery in downtown areas. They are not restricted solely to the streets, and can therefore avoid congestion. As an additional benefit, they can be parked more easily on thoroughfares and in adjacent residential and industrial areas.

Cargo tram operating model

Multiple scenarios were compared to determine the best possible way to use cargo trams. Flexibility, volume, and time are the key reasons to recommend a "single-use" operating model focusing solely on cargo-tram logistics and freight.

Operating model	Single Use (Recommendation)	Mixed Use	Trailer
Description	The tram is being converted and used specifically for the transport of goods. No more passenger transport is possible.	A section of the tram will be converted to make it usable for freight transport so that goods and people can be transported in the same tram at the same time.	A special trailer for goods transport is being developed, which can be attached to an ordinary passenger tram.
Advantages	▸ Flexible use of tramlines ▸ Independent of passenger use ▸ Higher volume of container units	▸ Possible higher use of existing tram lines ▸ Fills empty-train gaps in public transportation systems	▸ Physical separation between passengers and cargo
Disadvantages	▸ Conversion costs	▸ Transport only on passenger lines and in compliance with timetables ▸ Unclear regulations ▸ Long idling times negatively affect passenger and cargo transport ▸ Mixed use reduces cargo and passenger volumes ▸ Conversion costs	▸ Transport only possible on passenger routes and in compliance with timetables ▸ Trailer provision and production costs ▸ Adverse time factor

Fig. 2. Operating model scenarios for cargo trams

05

Product components and requirements

An end-to-end solution consists of multiple components. The four most important are a distribution center, a cargo tram (converted from passenger use), an electric cargo bike from ONOMOTION (including containers), and an overarching digital platform.

01 Distribution center

An intermodal logistics chain requires only minor adaptations to the processes at distribution centers. The goods only need to be placed in the containers and dispatched to delivery trucks or vans, which then bring them to transport hubs and unload them for cargo trams. To facilitate parcel shipment, the distribution centers should be located near city peripheries, ideally with good road connections to terminal tram stations.

02 Cargo tram

With an eye to sustainability, this concept study uses a completely refurbished type R tram from Siemens/Duewag. It can carry 23 containers made by ONOMOTION. To enable rapid loading and unloading, roller systems are integrated into the footwell, and the tram has six roller doors. The retrofit also modified the door openings to allow the prepacked containers to be loaded and unloaded. The ceiling was raised and new lighting was installed in the interior. For the exterior, new paint was applied and the existing windows were darkened. Some of the roof components had to be adapted or removed to ensure sufficient ceiling height for the containers.

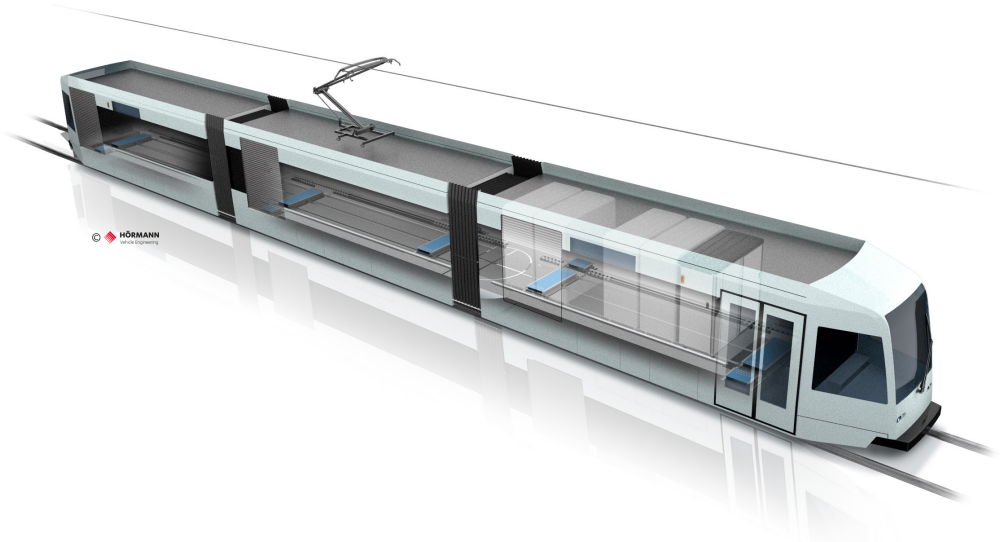


Fig. 3. Technical concept: passenger tram conversion for cargo transport

03 Electric cargo bike (ONO PAT) and container

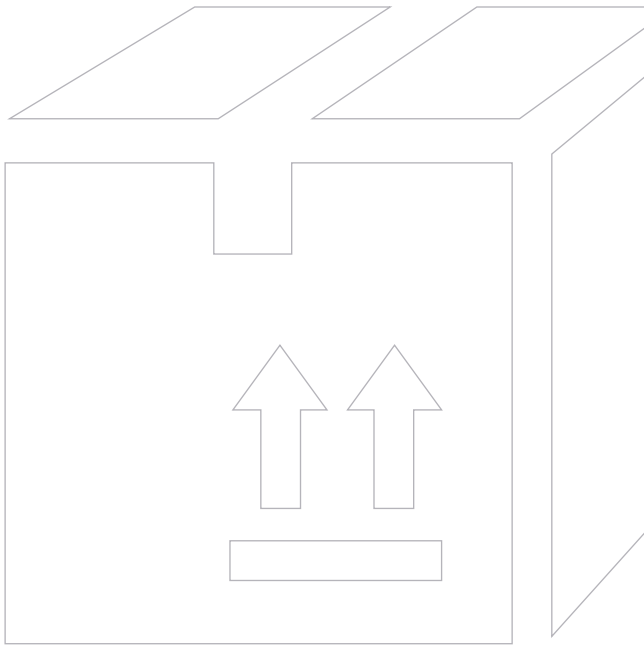
The ONO PAT (pedal-assisted transporter) provides full weather protection for the driver and cargo, and runs emission-free. It combines the flexibility and lightweight construction of a bicycle with the durability, dependability, and capacity of a small van. Its compact dimensions lessen the load on road infrastructures. Other key elements include integrated loading ramps, a simple battery-replacement system, and components of a quality comparable to the automotive industry. The bike also has a modular platform basis that allows cargo units to be easily exchanged. The unique quick-change system makes the ONO PAT suitable for a large number of applications.

The ONO cargo unit is a standardized modular structure with the width of a EU pallet size and with a cargo volume of two cubic meters and an integrated GSM module for continuous location tracking. The interior can be individually adjusted and used in variable ways. When on the vehicle, the container can be opened by remote control. An RFID locking system with its own power source is in place. Also installed are integrated lighting and a "dead man's brake" to ensure that the container is secured without risk to the driver or passersby. The ground-level loading option and two large doors at the rear and side are user-friendly. And the roller system offers a high degree of flexibility for actual deliveries. The entire cargo tram and container system can be optimized in terms of functionality and crash safety by making slight adjustments to the standard container (e.g. height or roof line adjustments).

Fig. 4. ONO PAT electric cargo bike plus container unit

04 Digital Logistics Platform

The overarching question is how the three-stage delivery chain works as a whole. A digital logistics platform serves as a key "enabler" of successful implementation. Compared to previous cargo-tram projects, a major difference here is that the platform functions as a neutral orchestrator of the respective commercial actors and lets the partners use system interfaces to feed data in or out. This not only increases transparency but also optimizes the operating processes. Goods tracking is one of the core tasks of the platform and has great added value for the operator and users, for example in the form of data analytics or in a transparent billing of services. Furthermore, the tracking of goods movements is made possible, which not only increases transparency for the consignee, but also brings advantages during operation (e.g. in securing the cold chain for certain products). In addition, the data compiled can lay the foundation for new business models, such as analyses of traffic, carbon emissions, or fine particulate pollution. The key forms of expertise needed to digitally map the delivery chain in this way are represented and accounted for among the producers of this concept study (especially Hörmann Digital, Hermes, and ONO).



06

Assessment scope and scenarios

80% of inner-district deliveries

or

28% of city-wide deliveries

can be handled by an intermodal logistics chain

Large cities see enormous volumes of cargo, and the feasibility of alternative logistics concepts depends on their geographic and cargo-specific factors. Previous studies have shown that an intermodal logistics chain consisting of cargo trams and electric cargo bikes can handle significant delivery volumes in downtown areas.[13] The CEP sector,[14] deliveries to brick-and-mortar retail shops, and e-grocery services are relevant use cases. Taking the example of a city like Frankfurt am Main, the deliverable volume can be quantified as follows: of a total of 41,000[15] parcel deliveries a day, somewhat more than 14,500[15] are to geographically favorable parts of the city. The existing tram network and suitable tram stops encourage the use of cargo trams and electric cargo bikes. However, there are some restrictions on large-scale deliveries due to volume and weight limitations for the containers and/or electric bikes. When these are taken into account, an industry average of 80 percent[15] of the approximately 14,500 inner-district parcels can be delivered by cargo tram and electric cargo bike. Here it should be noted that the percentage of bulky goods can vary per individual logistics service provider. In Frankfurt's inner districts, 80 percent of intermodal transportable goods would translate to around 11,600 deliveries. This would leave 20 percent or 2,900 deliveries to be made in traditional ways. The Frankfurt example was also used to further assess the intermodal logistics chain vis-à-vis its single-step counterpart, and to quantify costs and carbon emissions. The assessment scope for these additional questions covers only the theoretically usable number of 14,500 parcels.

[13] Kai-Oliver Schocke et al, LastMileTram – Empirische Forschung zum Einsatz einer Güterstraßenbahn am Beispiel Frankfurt am Main; Frankfurt University of Applied Sciences (2019)
[14] CEP (courier, express, and parcel)
[15] Expert interview, Frankfurt University of Applied Sciences (2021)

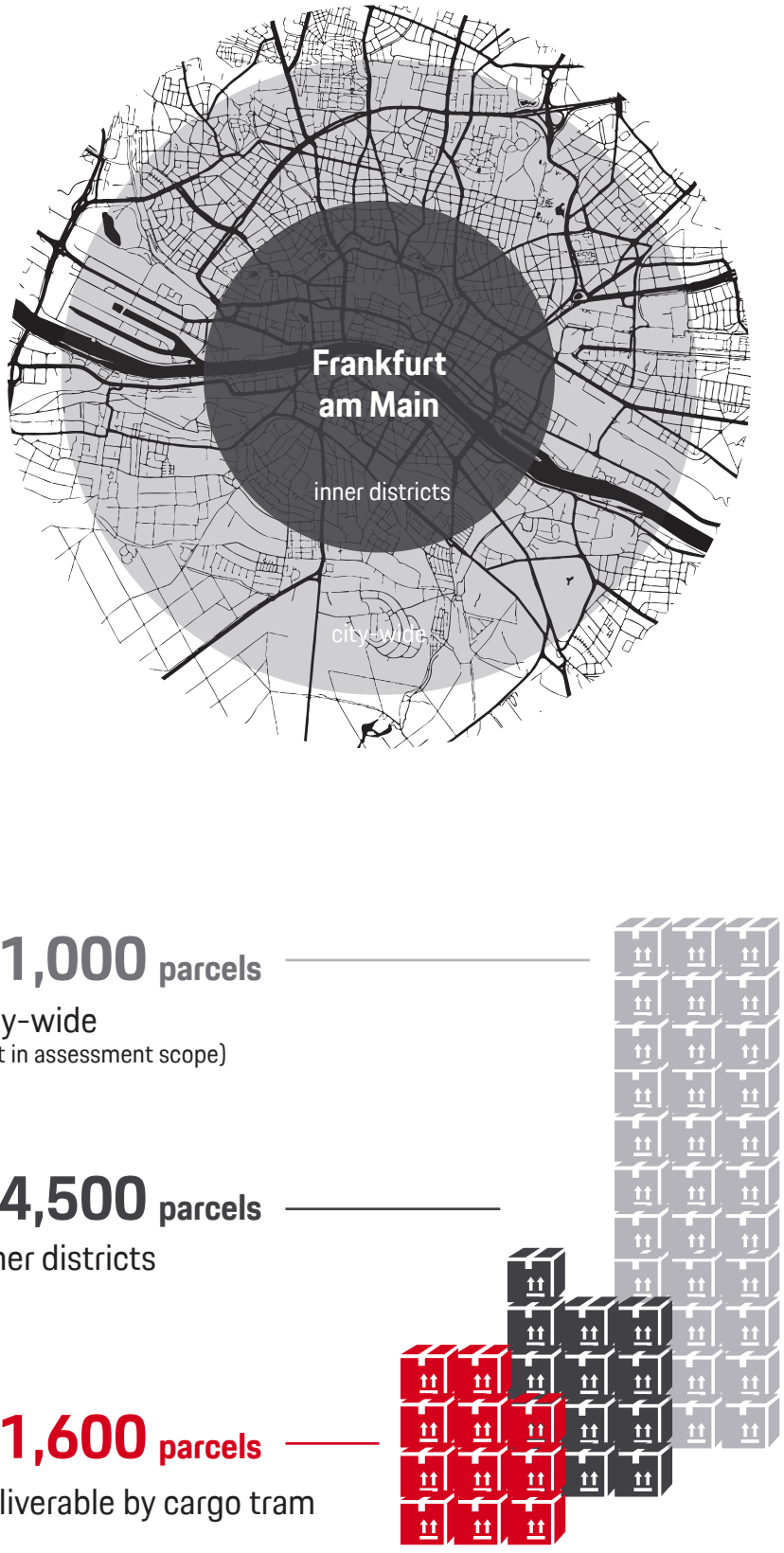


Fig. 5. Daily parcel volume in Frankfurt am Main and cargo tram assessment scope[16]

[16] Expert interview, Frankfurt University of Applied Sciences (2021)

Two scenarios compared

- **Conventional delivery method**
  versus
- **Intermodal solution**
  (combination of:
  truck or van—cargo tram—electric cargo bike)

We will now compare the conventional method of urban transport from depot to destination using delivery vans (scenario A: one-step logistics chain) with the intermodal logistics chain consisting of a truck or van, cargo tram, and electric cargo bicycle (scenario B: hybrid logistics chain). The latter scenario is termed "hybrid" because size and weight limitations mean some shipments need to be accounted for and handled by conventional means. Detailed analyses of costs and carbon emissions were conducted for both scenarios.

Here it should be noted that this assessment used a stable condition with the corresponding capacity and resulting scale effects. That means it used the entire inner-district volume of 14,500 shipments for both scenarios. In general, it should be noted that new logistics concepts like the cargo-tram scenario described here, as well as micro-depot pilot projects by cities and logistics service providers, need to hold their own against the still relatively inexpensive scenario of road transport by diesel delivery vehicles, not only in economic but also in environmental terms. This poses an enormous challenge especially for the market start-up stages with low unit numbers. Scaling is the only the way to address the tough cost pressures in the logistics sector, in order to design the intensive material and personnel components of an intermodal logistics chain in cost-effective ways.

A

Single-step scenario

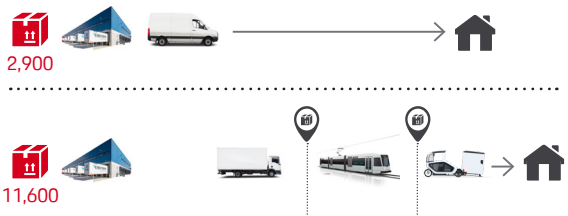
Delivery van
(diesel)

B

Hybrid scenario

Delivery truck/van
Cargo tram
Electric cargo bike

Logistics chain



Costs per m³ [€]

Vehicle	9.84€	Vehicle	2.61€	0.48€	1.85€	2.31€
Driver	20.75€	Driver	5.22€	0.33€	0.67€	13.85€
		Infrastruktur				0.30€
Total	**30.59€**	Total				**27.62€** (-9.7%)

Emissions

3,1 t CO_2

1,1 t CO_2 (-64%)

Assessment

- ✓ Familiar operations with optimized processes
- ⚡ Additional traffic volume on roads
- ⚡ CO_2 and NO_x emissions
- ⚡ Tense parking situation

- ✓ Lower road loads by shifting cargo transport to rails
- ✓ Substantial reduction in CO_2 and NO_x emissions
- ✓ Simpler parking by cargo bikes
- ✓ Cost-neutral vis-à-vis status quo despite additional operating processes (e.g., loading/unloading)
- ⚡ Start-up funding needed
- ⚡ Not possible in every city

Fig. 6. Assessment of single-step (A) and hybrid (B) scenarios for costs and carbon emissions

Scenario A
Single-step logistics chain

The single-step scenario covers the delivery chain from a depot outside a city to a downtown destination with a single means of transport. This is the status quo for urban logistics in most cities. In most cases a delivery truck or van is used. The scenario assumes that 100 percent of goods in inner-district space can be delivered in the last mile by a vehicle with a conventional drive system. The assessment scope does not include delivery of letters. A logistics chain of this type under current commercial and technical framework conditions produces 3.1 tons[17] of carbon emissions and costs 30.59 euros per cubic meter for a volume of 14,500 parcels. The majority (around two-thirds) of the costs apply to the driver. An influential factor here is the parking situation, which is a major disadvantage for delivery services using this scenario. Double parking is a common practice — and a considerable nuisance to local residents and other road users. This assessment took into account the time needed to search for parking places, maneuver in tight spots, and walk distances from the vehicle to the building door and back.

As for the carbon footprint, it can be considerably improved if this type of logistics chain uses vehicles with electric drive systems. However, that would not lower traffic levels on the roads.

Of positive note is the fact that a single-step logistics system can be used in every city because it is not dependent on a rail infrastructure. Moreover, this scenario has optimization potential over the long term via the use of automated vehicles.

Scenario B
Hybrid logistics chain

This scenario assumes that of the 14,500 shipments to downtown destinations, 80 percent can be handled by a three-step logistics chain consisting of a truck, cargo tram, and electric cargo bike (11,600 deliveries). Due to size and weight considerations, the remaining 20 percent (2,900 shipments) are delivered by traditional means analogous to the one-step scenario. A simulation of cargo flows and means of transport was conducted specifically for scenario B. In so doing, the experts applied a stress test to the system as part of a sensitivity analysis. They raised the parcel volume by 60 percent to examine peak loads, e.g., in the pre-Christmas period (see Fig. 7). The simulation shows that the overall system is sufficiently robust to accommodate peaks with the help of overtime and/or additional personnel as well as a greater number of electric cargo bikes.

[17] Carbon footprint tank-to-wheel

	Normal conditions				Peak loads (e.g., before Christmas)			
	Truck	Cargo tram	E-cargo-bike	Delivery van (for bulky items)	Truck	Cargo tram	E-cargo-bike	Delivery van (for bulky items)
Number Parcels		11,600		2,900		18,560		4,640
Number of vehicles	2	2	84	30	2	2	102	30
Operating times of vehicles	7.73 h	7.50 h	7.65 h	8.06 h	12.19 h	11.96 h	10.07 h	9.75 h
	Handling assured under normal conditions				Can be handled with overtime and/or additional personnel			

Fig. 7. Distribution and operating times for vehicles in scenario B

The major advantage of this scenario, apart from the reduced road traffic, is the reduction of carbon emissions. For the exemplary quantity of 14,500 parcels in the inner-city area, this scenario causes only 1.1 tons of carbon[18] across the delivery chain. That represents a reduction of approximately 64 percent over the one-step scenario. At the same time, at 27.62 euros per cubic meter, this scenario costs slightly less than the status quo (scenario A). Because fewer delivery vans mean lower costs and lower parking and waiting times, this can compensate for the additional costs needed to operate the cargo trams and electric cargo bikes. This assessment includes rent for interim storage space at tram stops, rent and operating costs for micro depots as operational bases for the e-cargo bikes, and costs for one additional worker per tram to load and unload. Overall, this scenario is attractive in environmental and transport policy terms, and also provides the economic framework conditions for revolutionizing logistics chains in cities over the medium term. Further optimizations are also conceivable, such as delivery via electric trucks or vans, as well as direct rail links to distribution centers.

[18] Carbon footprint tank-to-wheel

07

Summary and outlook

We cannot solve our problems with the same thinking we used when creating them.

// Albert Einstein

This sharp quote by Albert Einstein captures the approach of intermodal delivery chains more than ever before.

There are signs of a new era dawning. Cities like Paris and Barcelona have embarked upon a transformation of mobility systems in the interest of sustainability and social responsibility. These metropolises are a positive example of alternative approaches to infrastructure, for example by expanding bicycle infrastructures and placing strict limits on passenger and commercial vehicles in city centers.

If logistics systems now have to accommodate rising volumes of shipments, they need disruptive approaches for the last mile. Decades ago, world trade demonstrated the considerable potential in distributing cargo transport across multiple means of transportation. The use of standardized containers makes this possible, and also enables acceleration. That in turn is a key form of leverage for the future of city center logistics. Given the constantly increasing demand for individual and rapid options such as same-day delivery, plus the associated deluge of parcels, problems are on the rise and limitations appear ever more often.

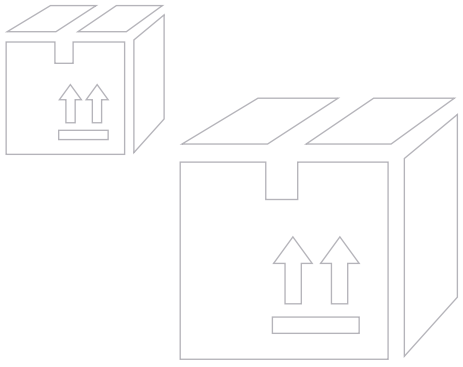
There are multiple ways of designing logistics to be viable for the future. Depending on regional conditions, conceivable solutions include self-service pick-up stations and comprehensive downtown delivery via micro depots. But to reduce traffic and emission levels on a sustainable basis, primary consideration goes to intermodal delivery chains consisting of trucks/vans, cargo trams, and electric cargo bikes. For purposes of assessment, today's conventional logistics chain using delivery trucks (scenario A: single-step logistics chain) was compared to the three-step option described here (scenario B: hybrid logistics chain). Although scenario A can be used everywhere and has been largely optimized due to familiarity with its operating processes, it has limitations. The associated traffic levels, substantial carbon emissions, and exacerbation of tight parking situations speak against this scenario. Even if alternative drive systems have the potential to optimize last-mile practices in this conventional logistics method, the method's scalability is limited. All in all, scenario A is an approach that will continue to exist in the future, but will not handle future volumes of urban deliveries on its own.

Scenario B therefore appears to be a complementary solution for the medium and long term. An intermodal logistics chain consisting of trucks/vans, cargo trams, and electric cargo bikes offers enormous potential. Its technical feasibility is beyond doubt, and the tasks it requires can be handled by manufacturers and operators. Appropriate technical concepts have already been developed and evaluated. Economic, environmental, and traffic-policy perspectives also confirm its feasibility. It is expected to produce fewer carbon emissions and lessen road loads on a cost-neutral basis. All these

arguments speak for using a three-step transport model for the last mile. A dynamic simulation was conducted to explore initial-use scenarios and to model different load levels. For example, the simulation confirmed the ability to handle seasonal peak loads such as in the period before Christmas. Additional optimizations are conceivable over the medium term. For instance, having electric trucks carry shipments from depots to cargo trams is an obvious and easily achievable measure that would further lower carbon emissions.

Nevertheless, challenges still remain in putting this type of scenario into practice. In addition to the initial investments needed to establish an intermodal logistics chain, scalability is a crucial factor in achieving the cost benefits described here. In light of current developments, this appears possible within a medium-term period of time. For one thing, the political will is evident.[19] In addition, tighter restrictions on urban traffic can be anticipated, which will fuel plans for intermodal logistics chains. The most important factor, however, is commitment on the part of city authorities and public transportation companies, because they are the ones chiefly responsible for infrastructure matters.

The need to relieve loads on infrastructure makes the use of rail systems all the more relevant. A concept like that for cargo trams can also be adapted in the near future to underground, commuter, regional, and national rail systems, based on the use of containers. It would also be conceivable to provide direct rail links to logistics hubs like airports and freight distribution centers. Cities and municipalities need to act now in order to benefit over the medium term from this practical "green logistics" solution and to prevent total traffic gridlock. A pilot project to demonstrate feasibility and to test and establish cost effectiveness is the next logical step toward optimized transport and a sustainable future.



[19] https://www.zeit.de/news/2020-02/15/naechtliche-paketauslieferung-per-u-bahn?utm_referrer=https%3A%2F%2Fwww.google.com%2F

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