BRNO UNIVERSITY OF TECHNOLOGY

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FACULTY OF MECHANICAL ENGINEERING

FAKULTA STROJNÍHO INŽENÝRSTVÍ

INSTITUTE OF MACHINE AND INDUSTRIAL DESIGN

ÚSTAV KONSTRUOVÁNÍ

DESIGN OF AN AUTONOMOUS METRO UNIT

DESIGN AUTONOMNÍ JEDNOTKY METRA

MASTER'S THESIS

DIPLOMOVÁ PRÁCE

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VEDOUCÍ PRÁCE

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Master's Thesis Assignment

Institute: Institute of Machine and Industrial Design
Student: **Bc. Benedikt Müller**
Degree programm: Industrial Design
Branch: no specialisation
Supervisor: **M. A. Tanguy Hervé André Pierre Prévot**
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As provided for by the Act No. 111/98 Coll. on higher education institutions and the BUT Study and Examination Regulations, the director of the Institute hereby assigns the following topic of Master's Thesis:

Design of an Autonomous Metro Unit

Brief Description:

Urban transport is facing increasing demands for the movement of people and goods. Autonomous metro represents a potential for the modernization of urban logistics. Units can be designed as either combined or dedicated freight. Integrating freight transport into the metro system brings challenges in the areas of interior design, safety, operational flexibility and ergonomics, but opens up possibilities for efficient combined transport in smart cities.

Type of work: development – design
Output of work: applied result (Fužit, Fprum, Gprot, Gfunk, R)
Project: Specific university research

Master's Thesis goals:

The main goal is to design an autonomous metro unit that will enable alternative transport ofgoods in metro corridors traditionally intended for passenger transport in such a way as toincrease the efficiency of underground transport, benefits for urban logistics, positive impacts onurban infrastructure and life in it.

Partial goals of the diploma thesis:

– identify opportunities and risks resulting from integrating goods transport into the metro infrastructure,

– propose solutions for individual problems and evaluate their degree of benefit for the global goal,

– implement the selected solutions into the design of an autonomous metro unit,

– validate the resulting solution with the customer Škoda Group, argue the benefits realized in the design.

Required outputs: accompanying report, summary poster, technical poster, ergonomic poster, designer poster, model photo, physical model.

Scope of work: approx. 72,000 characters (40 – 50 pages of text without images).

The time schedule, work structure and accompanying report template are binding:

https://www.ustavkonstruovani.cz/texty/magisterske–studium–ukonceni/

Recommended bibliography:

MORRIS, Richard. The fundamentals of product design. Lausanne: AVA, c2009. ISBN 978-2-940373-17-8.

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Deadline for submission Master's Thesis is given by the Schedule of the Academic year 2025/26

In Brno,

L. S.

prof. Ing. Martin Hartl, Ph.D. Director of the Institute	doc. Ing. Jiří Hlinka, Ph.D. FME dean

ABSTRACT

This thesis explores the possibility of utilizing existing metro infrastructure for future urban freight transportation in response to the rapid growth of e-commerce, traffic congestion, and environmental challenges associated with conventional last mile delivery. The project proposes the design of an autonomous metro freight unit together with a related logistics system focused on minimizing interaction between freight operations and public passenger space while enabling rapid cargo handling compatible with metro traffic conditions. The result of the thesis is a future-oriented concept intended to demonstrate a feasible alternative approach to sustainable and high-frequency urban logistics.

KEYWORDS

autonomous metro, urban logistics, last mile delivery, freight transportation, transportation design

ABSTRAKT

Tato diplomová práce se zabývá možností využití stávající infrastruktury metra pro budoucí městskou nákladní dopravu. Reaguje na rychlý růst e-commerce, přetížení městské dopravy a environmentální problémy spojené se současným “last mile delivery”. Výsledkem je návrh autonomní nákladní jednotky metra a navazujícího logistického systému, který minimalizuje kontakt nákladní dopravy s cestujícími a veřejným prostorem. Koncept zároveň umožňuje rychlou manipulaci s nákladem v časových podmínkách běžného provozu metra a představuje možný směr udržitelné vysokofrekvenční městské logistiky.

KLÍČOVÁ SLOVA

autonomní metro, městská logistika, last mile delivery, nákladní doprava, transportní design

BIBLIOGRAPHIC CITATION

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AUTHOR'S DECLARATION OF ORIGINALITY

I declare that I have completed this diploma thesis independently under the professional supervision of M. A. Tanguy Hervé André Pierre Prévot. At the same time, I declare that all sources of visual and textual information used in this thesis are properly cited in the list of references. I further declare that generative artificial intelligence was used during the preparation of this academic work. The tool was used exclusively for grammar checking and stylistic refinement of the English language. All content, arguments, and the overall structure of the thesis are my own original work.

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Author's signature

CONTENTS

1 INTRODUCTION

The rapid growth of e-commerce and on-demand delivery services is continuously increasing the pressure placed on contemporary urban logistics systems. Delivery times are becoming shorter, the frequency of transported goods is higher, and cities are gradually filling with delivery vehicles, temporary logistics infrastructure, and pickup systems. At the same time, modern city centres are already struggling with traffic congestion, environmental impact, and the growing occupation of public space by transportation and logistical operations.

One of the most problematic parts of this system is the so-called last mile delivery process. Although contemporary logistics networks are highly optimized on a global scale, the final stage of transportation within dense urban environments remains expensive, inefficient, and heavily dependent on conventional road traffic. Current delivery systems based primarily on vans and surface transportation are beginning to reach the spatial and operational limits of existing city infrastructure.

At the same time, modern cities already contain one highly efficient transportation system operating largely independently from surface traffic - metro infrastructure. Metro systems provide high-frequency transport, predictable operation, and fully separated transportation corridors capable of moving large volumes through dense urban environments. Despite this, metro infrastructure is currently utilized almost exclusively for passenger transportation.

This thesis explores the possibility of partially utilizing existing metro infrastructure for autonomous urban freight transportation. The project proposes a conceptual autonomous metro freight unit designed specifically for the transportation of cargo boxes within underground metro systems and the framing logistic system.

The developed concept includes the design of the metro unit itself, the cargo box system, unloading scenarios, ergonomics, construction principles, graphical identity, and considerations regarding environmental and financial impact. The proposal additionally explores multiple operational approaches including manual, autonomous, and hybrid unloading systems while maintaining a flexible modular transport platform adaptable to future logistical scenarios.

The aim of the thesis was to create a comprehensive conceptual proposal demonstrating how existing underground transportation infrastructure could potentially become part of future urban logistics systems. The project does not attempt to define a single universal solution for future freight transportation but rather presents one possible direction for how autonomous systems, public infrastructure, and industrial design may interact within the future development of cities and urban logistics.

2 RESEARCH

2.1 Research Methodology

The research presented in this thesis is based on a structured and systematic approach combining theoretical analysis, design-oriented investigation, and technical review. The primary objective of the research phase is to establish a comprehensive knowledge base that supports the subsequent design development of an autonomous metro unit with application in urban logistics.

The research process was carried out as a multi-stage procedure, consisting of the definition of research questions, identification of relevant sources, systematic filtering, and analytical evaluation of collected data. Emphasis was placed on ensuring both relevance and diversity of sources to capture the complexity of the topic, which spans across transport engineering, industrial design, ergonomics, and urban logistics.

2.1.1 Search Strategy and Data Sources

The initial phase focused on defining the thematic scope and establishing a set of keywords to guide the research. The main areas of interest included autonomous metro systems, public transport, vehicle design, ergonomics, and the integration of freight transport into urban mobility systems.

Based on this scope, a structured set of keywords was developed. These included terms such as *autonomous metro, subway train design, urban logistics,* and *freight integration*. The keywords were combined and expanded to cover different aspects of the topic and to ensure sufficient breadth of the search.

Two complementary search strategies were applied. The first approach involved systematically combining keywords into search queries to obtain targeted results. The second approach was based on expanding the research through references of already identified relevant sources, allowing the discovery of additional materials and connections between topics.

The research was based on a combination of academic and industry sources. Academic publications were obtained from scientific databases, ensuring access to peer-reviewed and up-to-date research. Industry-related materials, including manufacturer websites and technical documentation, were used to complement theoretical knowledge with real-world applications and current technological developments.

2.1.2 Selection and Processing of Sources

To ensure the quality and relevance of the research, a set of selection criteria was defined. These criteria included thematic relevance, recency of publication, and overall credibility of the source. Preference was given to materials reflecting current developments in autonomous transport systems and contemporary design approaches.

The selection process followed a systematic filtering procedure inspired by the Prisma methodology, which is commonly used for structuring literature reviews. Initially, a broad range of sources was identified through keyword-based searches. These were subsequently screened based on their titles and abstracts, followed by a more detailed evaluation of selected materials.

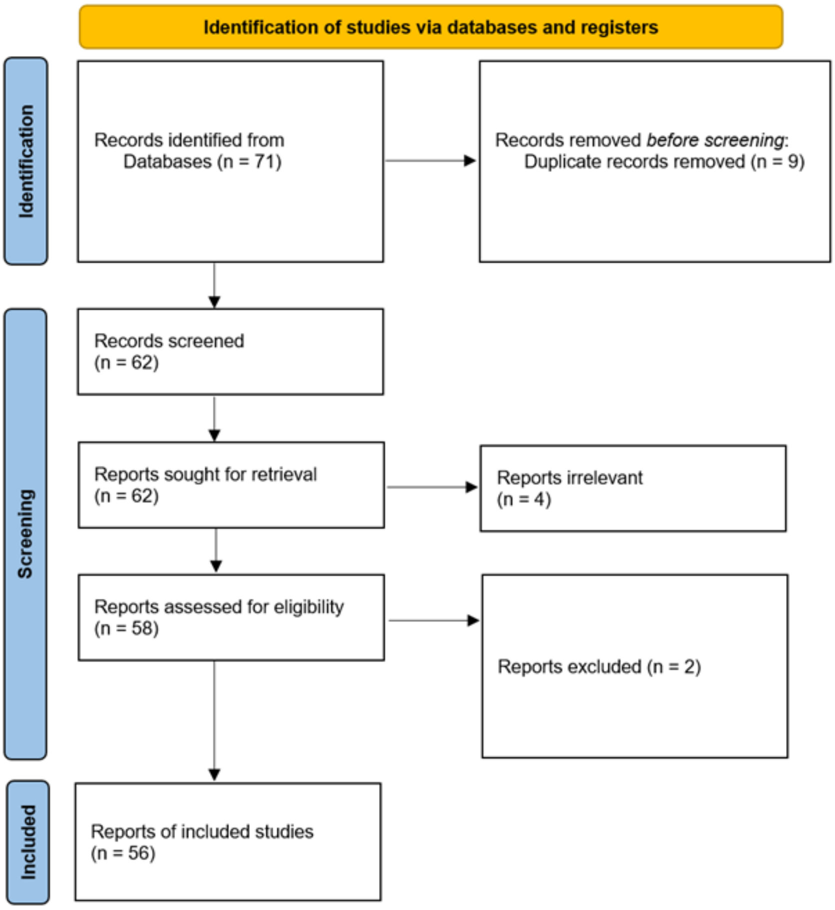

Fig. 2-1 Prisma diagram

During this process, irrelevant or duplicate sources were excluded, resulting in a focused and relevant dataset. The final selection included a balanced combination of academic publications, technical materials, and industry-related sources.

The collected data were analysed using thematic and comparative approaches. Individual sources were evaluated according to their relevance to the research objectives and grouped into key thematic areas, such as automation, design, ergonomics, and logistics integration. This process enabled the identification of recurring principles, current trends, and existing gaps in the field.

The results of this research form the theoretical foundation for the problem definition and design objectives presented in the following chapters.

2.2 Identification of Opportunities and Research Gap

2.2.1 Trends in Urban Transport and Integration of Freight

Recent developments in urban mobility systems indicate a shift towards more efficient and multifunctional use of existing transport infrastructure. Major manufacturers of metro systems are increasingly focusing on modularity, automation, and operational flexibility. For example, Siemens Mobility develops modular metro platforms designed for fully autonomous operation (GoA4), adaptable interior configurations, and energy-efficient performance [1]. Similar principles are applied in Alstom's Metropolis platform, which allows flexible interior layouts depending on operational requirements [2]. Hitachi Rail further develops driverless metro systems with an emphasis on safety, automation, and digital integration [3].

In parallel with these technological developments, research has increasingly focused on the integration of freight transport into public transport systems. One of the key concepts in this field is *Freight-on-Transit*, which proposes the use of existing public transport infrastructure, particularly metro networks, for urban cargo distribution [4]. This approach aims to utilise unused transport capacity, especially during off-peak hours, and reduce reliance on road-based delivery systems.

Recent studies propose models in which metro systems function as part of a multimodal logistics network, connecting central distribution centres with urban nodes, from which last-mile delivery is carried out using smaller transport modes [7].

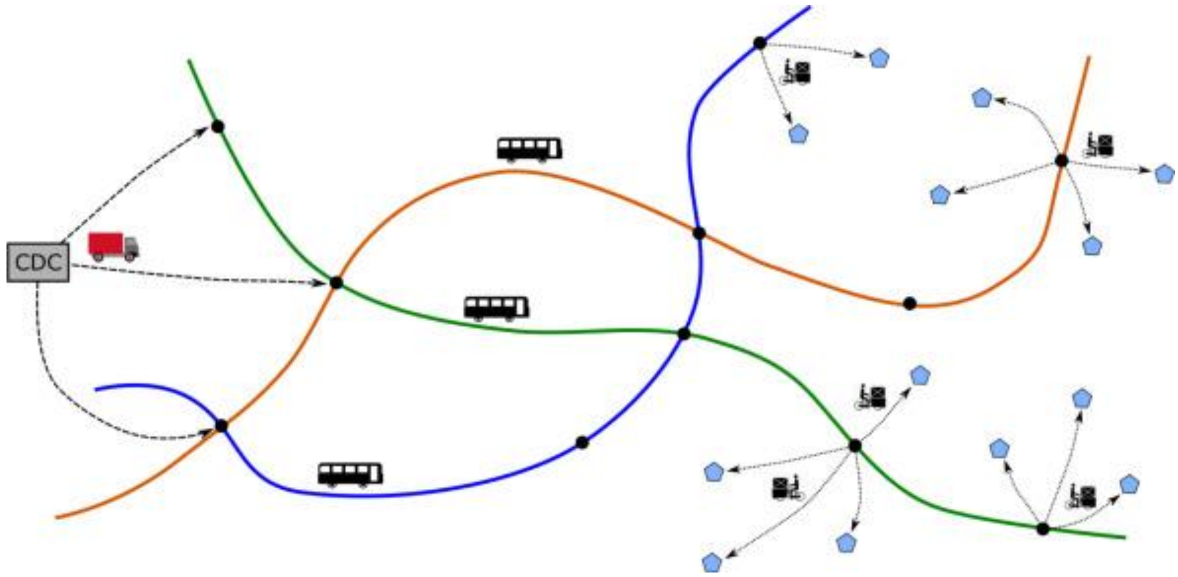

Fig. 2-2 Illustrative example of a FOT system [7]

The diagram (Fig. 2-2) illustrates a hierarchical logistics system, where high-capacity rail transport is combined with decentralised last-mile delivery. Such an approach enables consolidation of freight flows and reduction of delivery traffic in dense urban environments [7].

Further research analysing the integration of freight transport into public transport systems confirms that this approach can significantly reduce congestion, lower emissions, and improve the overall efficiency of urban logistics [6]. At the same time, metro systems are identified as particularly suitable for this purpose due to their high capacity, frequency, and independence from surface traffic.

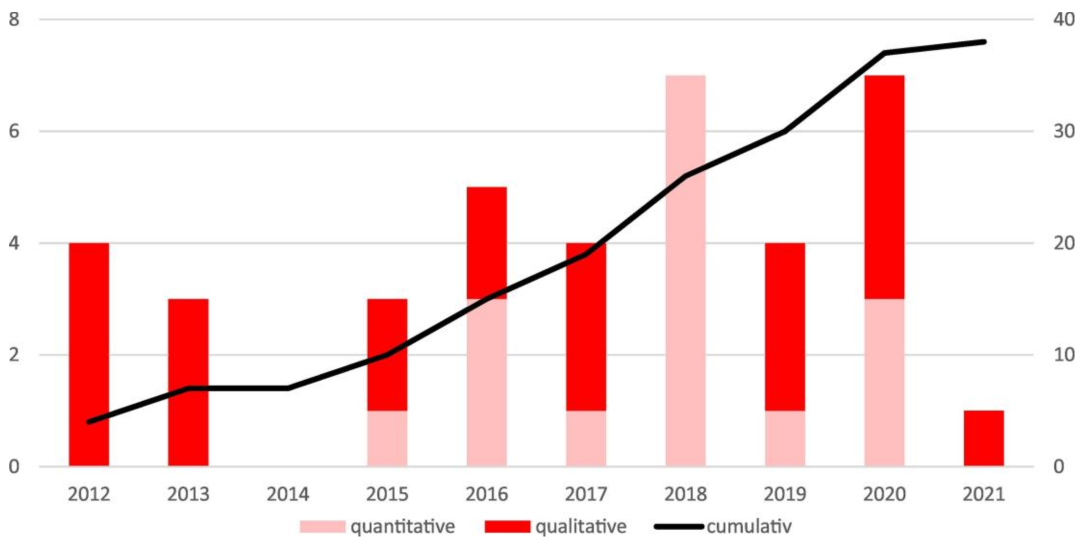

Fig. 2-3 Development of topic related publications over time [8]

The increasing number of scientific publications addressing this topic (Fig. 2-3) reflects a growing research interest in multimodal logistics systems and the integration of freight into public transport networks. The cumulative growth of publications over time indicates that this field represents an emerging and rapidly developing area of research [8].

A notable real-world example of this approach is the Monoprix logistics project in Paris, where rail-based transport was used to supply goods into the city centre, reducing the number of delivery vehicles and improving overall logistics efficiency [5]. This example demonstrates that the integration of freight into rail-based systems is technically feasible and can contribute to more sustainable urban logistics.

Despite these advantages, practical implementations and research studies reveal significant challenges associated with combining passenger transport and freight distribution within a single system. These challenges include conflicts between passenger comfort and cargo handling, safety concerns, hygiene requirements, and increased operational complexity.

From an operational perspective, mixed-use systems require precise coordination of loading and unloading processes alongside passenger flow, which may negatively affect dwell times and overall system efficiency. Additionally, the presence of goods within passenger spaces raises concerns related to security, potential damage, and user perception.

These limitations are also reflected in research literature, which suggests that while integration at the network level is feasible, the physical combination of passengers and freight within a single vehicle presents substantial design and operational difficulties [6].

2.2.2 E-commerce Growth and Last-Mile Economics

The rapid growth of e-commerce represents one of the most significant drivers of change in urban logistics systems. Global e-commerce sales have increased dramatically over the past decade and continue to grow, with billions of online transactions generated annually. This trend has been further accelerated by the COVID-19 pandemic, which fundamentally shifted consumer behaviour towards digital purchasing channels [9].

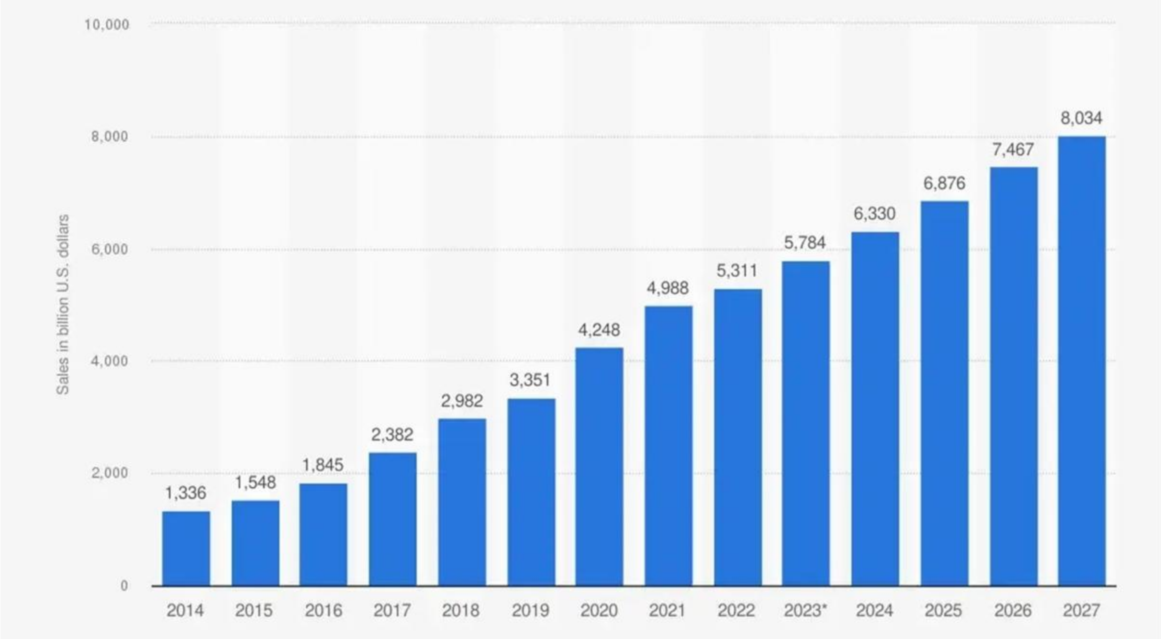

Fig. 2-4 Retail e-commerce sales worldwide from 2014 to 2027 [12]

Recent statistics confirm the strong upward trajectory of e-commerce, with continuous year-on-year growth and increasing market penetration across all regions. The expansion of online retail has led to a substantial rise in delivery demand, particularly in urban areas, where high population density intensifies logistical challenges [12].

As a direct consequence, urban logistics systems are experiencing a growing number of small, fragmented, and time-sensitive deliveries. Unlike traditional logistics models based on consolidated shipments, e-commerce requires flexible and highly responsive distribution networks capable of handling last-mile delivery under strict time constraints [6].

The last mile has consequently become the most complex and expensive segment of the supply chain. Studies indicate that last-mile delivery can account for up to 50% of total logistics costs, depending on the delivery model and urban environment [10]. This inefficiency is primarily driven by low delivery density, failed delivery attempts, and increasing congestion in urban areas.

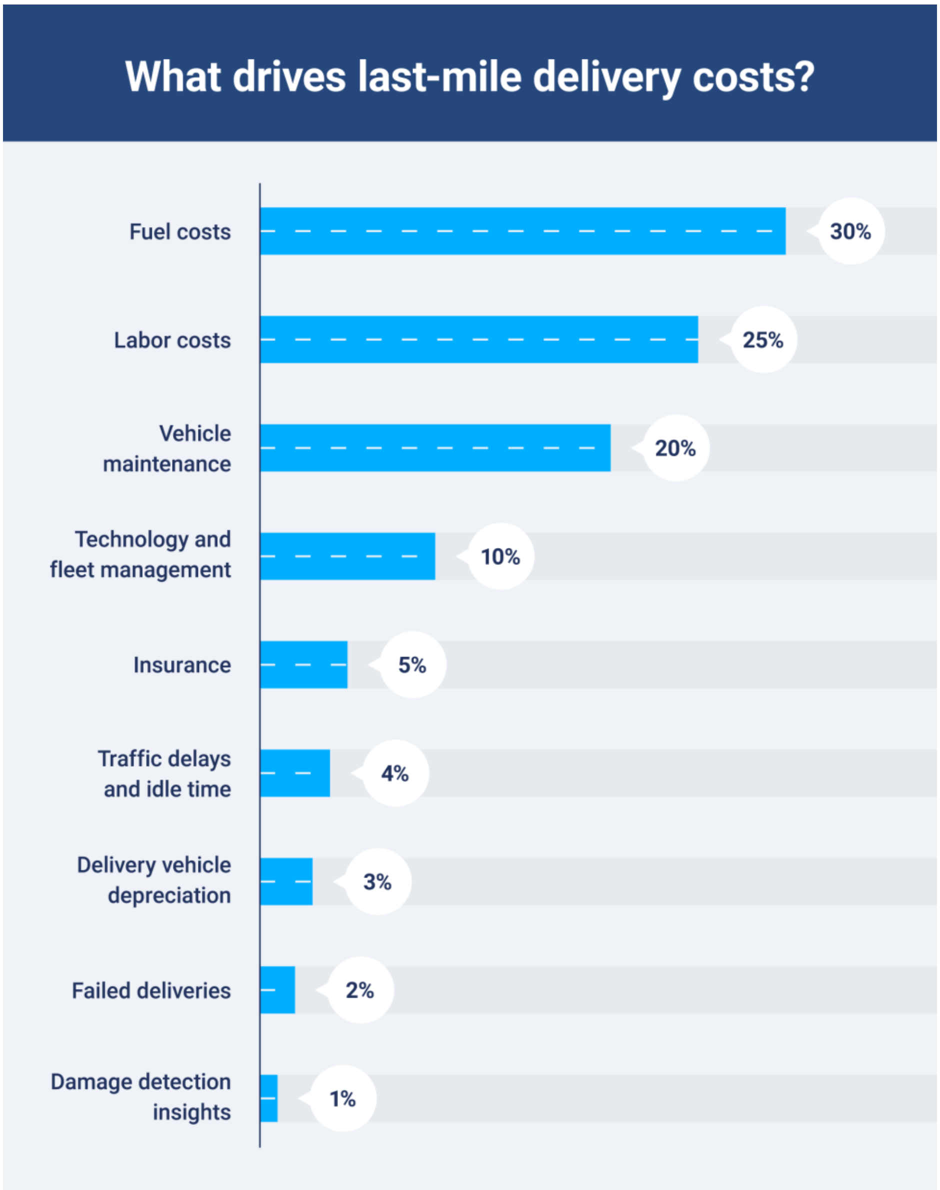

Fig. 2-5 Last-mile delivery costs [10]

Industry data further emphasize that last-mile delivery is not only the most expensive but also the least efficient part of the logistics chain, requiring continuous optimization and innovation [11]. The increasing demand for same-day and next-day delivery services further intensifies operational pressure on logistics providers.

At the same time, the growth of e-commerce contributes significantly to negative externalities such as traffic congestion, emissions, and noise. The rising number of delivery vehicles in cities exacerbates already strained urban transport systems, particularly in densely populated areas [8].

2.2.3 Urban Perspective on Freight Transport Challenges

Cities are increasingly adopting strategies aimed at creating more sustainable and liveable urban environments. The concept of the “green city” promotes the reduction of emissions, noise, and traffic through policies supporting low-emission mobility and limiting conventional vehicles in urban areas [13].

However, the growing volume of delivery traffic continues to place significant pressure on urban road networks. In cities such as New York, the rapid expansion of e-commerce has led to a visible increase in delivery vehicles, contributing to congestion and reduced street capacity [14].

Fig. 2-6 Morning New York street [14]

Another emerging issue is the growing number of parcel lockers and pick-up points, which contribute to visual clutter in public space. This phenomenon, often referred to as “visual smog”, reflects the increasing spatial impact of last-mile delivery infrastructure and its insufficient integration into urban environments [15].

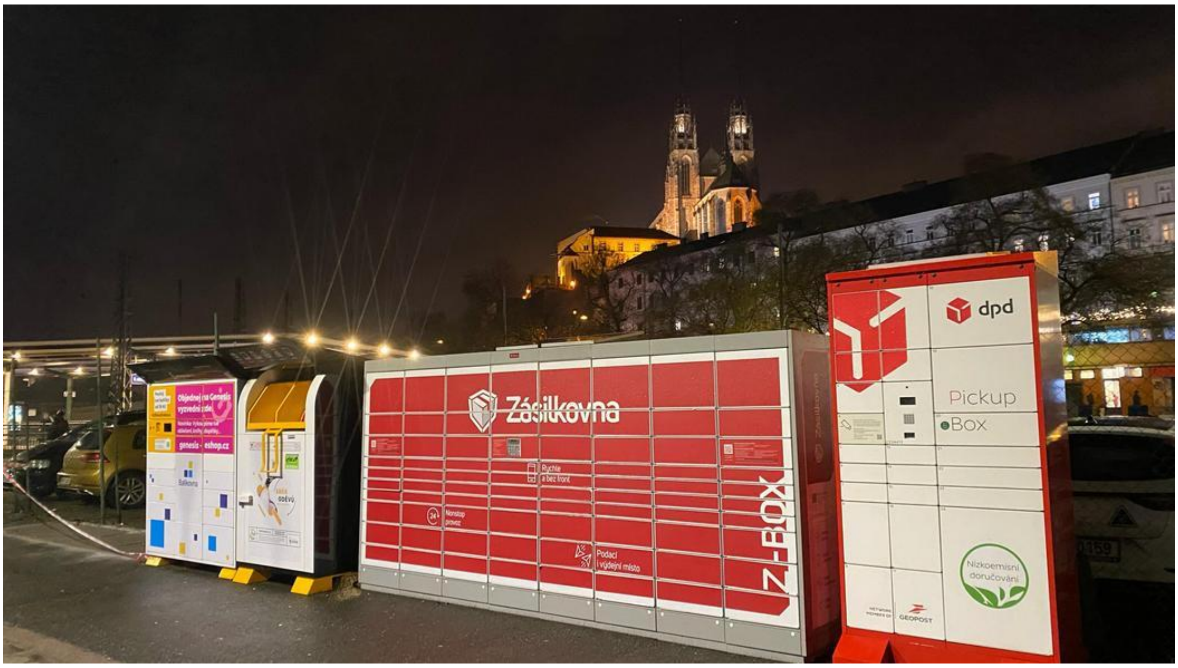

Fig. 2-7 Visual smog caused by pick-up boxes [15]

2.2.4 Summary of Constraints and Opportunity

The analysis of current trends reveals a fundamental mismatch between the increasing demand for urban logistics and the limitations of existing transport systems. While cities aim to reduce traffic, emissions, and spatial impact, the rapid growth of e-commerce continues to generate additional pressure on already saturated urban environments.

Although various solutions are being explored, including alternative delivery methods and the integration of freight into public transport, these approaches introduce significant operational and design challenges. In particular, the combination of passenger and freight transport within a single system presents substantial complexity in terms of safety, efficiency, and user experience [6].

These limitations highlight the need for new approaches that can utilize existing infrastructure while avoiding the conflicts associated with current solutions.

2.3 State of the Art Research

Based on the findings presented in the previous chapter, the design direction of this thesis was defined more precisely. Although the integration of freight into public transport systems offers clear environmental and operational potential, the analysis also showed that combining passenger and freight transport within a single vehicle introduces substantial spatial, operational, and safety-related conflicts. For this reason, the proposed unit is further developed as a dedicated cargo vehicle that does not transport passengers, while still making use of the existing metro infrastructure.

The following research is therefore focused on three main areas. The first examines existing and historical projects that attempt to integrate freight transport into public transport systems, including both real implementations and conceptual proposals. The second focuses on the exterior design language of autonomous rail vehicles. The third area addresses the technical principles of metro units and autonomous logistics systems, including key vehicle components, cargo-handling technologies, and logistical parameters relevant to the dimensional definition of the transported cargo.

2.3.1 Existing projects integrating cargo into public transport

This section presents a structured overview of selected projects that attempted to integrate public transport infrastructure such as underground railways, metro systems, and tram networks with urban freight transport or last-mile delivery. The aim of this review is to analyse real implementations, historical precedents, and conceptual proposals in order to identify operational patterns, limitations, and transferable principles relevant to the development of a dedicated autonomous cargo metro unit operating within existing metro infrastructure.

The selected cases represent a spectrum ranging from fully operational historical systems to pilot projects and design concepts. Each case is examined in terms of system structure, operational outcome, and relevance for the present thesis.

London Post Office Railway (Mail Rail)

The London Post Office Railway, commonly referred to as Mail Rail, operated between 1927 and 2003 as a fully automated underground railway dedicated exclusively to the transport of mail across central London [16]. The system connected major sorting offices via a narrow-gauge tunnel network and operated independently of passenger transport systems.

Fig. 2-8 Loading containers [16]

Mail Rail did not transport passengers at any point during its operational life. The system was purpose-built for freight and functioned autonomously, demonstrating early implementation of automated underground logistics. It was eventually closed due to restructuring of Royal Mail logistics operations and the high maintenance costs associated with the ageing infrastructure rather than due to technical failure [16].

Fig. 2-9 Train with special cowling, added in mid 1980s [16]

Mail Rail represents a historical precedent of a cargo-only underground transport system. The primary lesson lies in the clear spatial and operational separation between freight and passenger flows. The standardised loading interfaces and dedicated station nodes are particularly relevant for the design of a contemporary autonomous cargo metro unit.

Cargo Tram Dresden

The CarGoTram in Dresden operated from 2001 until 2020 as a freight tram service supplying Volkswagen's Transparent Factory located in the city centre [17]. The system used the existing tram network to transport vehicle components between a logistics hub and the production facility.

Fig. 2-10 CarGoTram in Dresden [17]

The project significantly reduced the number of truck deliveries in the urban core and demonstrated long-term technical and operational feasibility. Its termination was primarily linked to changes in Volkswagen's production strategy and restructuring of supply chains rather than intrinsic system failure [17].

The Dresden case confirms that existing public transport infrastructure can support freight transport if the logistics corridor is clearly defined and demand remains stable. The system functioned effectively due to its simplified hub-to-hub model, minimising interference with passenger transport. This supports the importance of clearly defined cargo space within existing metro infrastructure.

Zurich Cargo-Tram

The Zurich Cargo-Tram has been operating since 2003 as part of the city's waste and recycling management strategy [18]. Unlike Dresden, this system is used primarily for reverse logistics, collecting bulky waste and recyclable materials via tram infrastructure.

Fig. 2-11 Zurich Cargo-Tram [18]

The project demonstrates long-term viability within a municipal framework and operates without carrying passengers during freight operations. Its continued use reflects strong institutional support and integration into broader urban sustainability policies [18].

Zurich provides evidence that cargo-only operations within public transport infrastructure can function sustainably when clearly embedded within municipal objectives. The key insight lies in the design of secure loading processes and modular cargo containers compatible with existing platforms.

S-Ply

The S-Ply project, developed by students at UMPRUM in 2023, represents a conceptual design proposal integrating freight transport into public transport infrastructure [19]. The project explores the spatial and systemic possibilities of combining urban mobility networks with logistics functions.

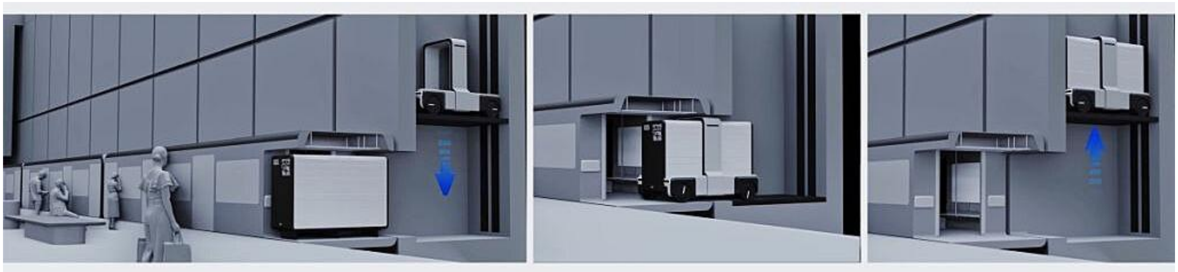

Fig. 2-12 S-ply [19]

As a conceptual design, S-Ply does not represent an operational system. However, it contributes valuable design thinking regarding modularity, vehicle adaptability, and the redefinition of urban transport roles.

Fig. 2-13 S-ply [19]

S-Ply provides a design-oriented precedent, emphasizing the role of vehicle architecture and modular cargo units. The project underlines the importance of spatial adaptability and systemic thinking. For the present thesis, the challenge lies in translating conceptual ideas into technically and operationally feasible parameters.

CargoCap

CargoCap is a German concept proposing a fully automated underground freight transport system using small-diameter tunnels and autonomous capsules [20]. The system is designed to connect logistics hubs through a dedicated subterranean infrastructure independent of passenger rail networks.

Fig. 2-14 CargoCap [20]

Unlike tram-based systems, CargoCap envisions a purpose-built underground logistics network. As of now, it remains a conceptual and developmental project without large-scale implementation.

Fig. 2-15 CargoCap [20]

CargoCap demonstrates the potential efficiency of fully automated underground freight systems. However, its reliance on dedicated infrastructure significantly increases implementation costs. The key insight is that leveraging existing metro infrastructure may provide a more economically viable alternative to constructing entirely new underground networks.

2.3.2 Exterior design language of autonomous rail vehicles

Although the proposed metro unit developed in this thesis is intended only for freight transport, it operates within the same infrastructural and urban context as conventional passenger metro systems. For this reason, it is essential to analyse existing autonomous metro vehicles, in order to understand the visual language, perception of such vehicles, and context in real-world environments.

Unlike traditional rolling stock, autonomous metro systems introduce significant changes in vehicle design, especially in the front section. The absence of a driver’s cabin allows for greater formal freedom, while simultaneously placing higher demands on visual communication, safety perception, and user trust. In many cases, passengers are positioned directly behind the front glazing, which fundamentally changes the way the vehicle is perceived.

The following section therefore examines selected metro systems from major manufacturers, focusing on their exterior design, front geometry, and overall visual expression. While these systems are designed for passenger transport, they provide an important reference framework for understanding how autonomous rail vehicles are shaped and perceived.

Siemens – Inspiro

The Siemens Inspiro represents one of the most widely implemented metro solutions, used in multiple cities worldwide including London, Bangkok or Sydney. Its design is based on a modular platform approach, allowing adaptation of the exterior form to different operational and cultural contexts [23][24].

Fig. 2-16 Simens – Inspiro [23]

From a design perspective, Inspiro demonstrates a rational and engineering-driven approach. The front geometry is typically smooth and enclosed, with a strong emphasis on continuity of surfaces and integration of lighting elements. The absence of a traditional driver’s cabin allows for a more symmetrical and simplified front design, often characterised by large, glazed areas.

A notable aspect of the design is the balance between technical clarity and user perception. The front of the vehicle is designed to appear approachable and safe, avoiding aggressive or overly futuristic forms. At the same time, integrated lighting elements act as a key communication tool, replacing traditional visual cues associated with human operators.

Across different implementations, the Inspiro shows a high degree of variability in exterior styling, while maintaining a consistent underlying design logic. This demonstrates how a single technical platform can support diverse visual identities without compromising functional coherence.

Fig. 2-17 Simens – Inspiro, London [23]

The Inspiro platform highlights the importance of modularity and adaptability in rail vehicle design. It also illustrates how the absence of a driver influences front geometry and visual communication, which is directly relevant for the design of an autonomous cargo unit.

Alstom – Metropolis

The Alstom Metropolis family represents a global benchmark in metro design, including fully autonomous systems deployed in cities such as Riyadh and Vancouver [25][26][27].

In contrast to the more restrained Siemens approach, Alstom vehicles often exhibit a more expressive and identity-driven design language. The front section is typically more sculpted, with pronounced curvature and a strong visual emphasis on the “face” of the vehicle. This is particularly evident in the Riyadh Metro, where the design integrates fluid surfaces and distinctive lighting signatures.

Fig. 2-18 Alstom – Metropolis [25]

The Vancouver SkyTrain units demonstrate a slightly different approach, combining functional clarity with a more conservative form language. Compared to Riyadh, the design is less expressive but still reflects contemporary trends such as smooth surface transitions and integrated lighting.

Fig. 2-19 Alstom – SkyTrain Vancouver [26]

A key characteristic across the Metropolis platform is the treatment of the front as a communicative element. With passengers positioned behind the front glazing, the design must balance openness and protection. The result is a controlled visual transparency that allows visibility while maintaining a sense of enclosure and safety.

Alstom’s approach demonstrates how autonomous metro vehicles can develop a strong visual identity while maintaining functional requirements. The emphasis on front design as a communicative interface is particularly relevant for defining the visual language of a non-passenger cargo unit.

Hitachi Rail – Driverless Metro Systems

Hitachi Rail has developed a series of fully autonomous metro systems implemented in cities such as Milan, Copenhagen, Thessaloniki, and Rome [28].

Fig. 2-20 Hitachi Rail, Rome [28]

Across these projects, a consistent design approach can be observed, characterised by minimalism and surface clarity. The vehicles typically feature clean, uninterrupted geometries with limited use of decorative elements. The front design is often defined by a simple combination of glazing and subtle lighting, resulting in a calm and neutral visual expression.

Fig. 2-21 Hitachi Rail, Thessaloniki [28]

Compared to other manufacturers, Hitachi’s approach places less emphasis on strong visual identity and more on functional legibility. The vehicles are designed to integrate seamlessly into the urban environment, avoiding overly expressive or dominant forms.

Fig. 2-22 Hitachi Rail, Milan [28]

The autonomous nature of these systems is reflected in the symmetrical and enclosed front sections, which lack the hierarchical structure associated with traditional driver-operated vehicles. This results in a more product-like appearance, where the vehicle is perceived as a system component rather than a machine operated by a human.

Fig. 2-23 Hitachi Rail, Copenhagen [28]

Hitachi’s design approach highlights the value of simplicity and visual neutrality. For a cargo-focused metro unit, such characteristics may be advantageous in reducing visual noise and ensuring clear functional communication.

Škoda Group - Metro Design Approach

Škoda Group represents the industrial partner of this thesis and provides an important reference in terms of real-world production and design constraints. The company’s metro solutions, such as the unit developed for Warszawa, reflect a pragmatic and engineering-oriented design approach [29].

Fig. 2-24 Škoda Group metro, Warszawa [29]

Unlike the previously discussed manufacturers, Škoda's metro vehicles are not primarily developed as fully autonomous systems. As a result, their design retains elements associated with traditional driver-operated vehicles, including a more defined front hierarchy and clearer separation of the driver's area.

From a design perspective, Škoda vehicles are characterised by robust proportions, clear structural logic, and restrained surface treatment. The emphasis is placed on manufacturability, durability, and integration into existing systems rather than on expressive or iconic design features.

Škoda Group provides a realistic framework for the implementation of the proposed design. While its current products do not fully reflect autonomous design trends, they highlight the importance of feasibility, production constraints, and system compatibility.

2.3.3 Technical research

Running Gear, Traction and Power Supply

The running gear of a metro vehicle forms the fundamental mechanical and electromechanical system enabling motion, stability, and energy transfer. It is primarily composed of bogies, which serve as the interface between the vehicle and the track. Modern metro vehicles typically utilise two bogies per car body, positioned near the vehicle ends, defining both the structural support and the spatial constraints of the unit [32].

A typical metro bogie consists of several key components, including the bogie frame, wheelsets, suspension systems, braking units, and traction equipment. The bogie frame, usually made of cast or welded steel, provides the primary structural support and connects all subcomponents into a single functional unit. Wheelsets, composed of solid steel axles and wheels, are mounted within the frame and allow guided movement along the rails. Suspension is typically divided into primary and secondary systems, where the primary suspension is located between the axle and the bogie frame, and the secondary suspension connects the bogie to the car body, ensuring ride stability and vibration damping [31].

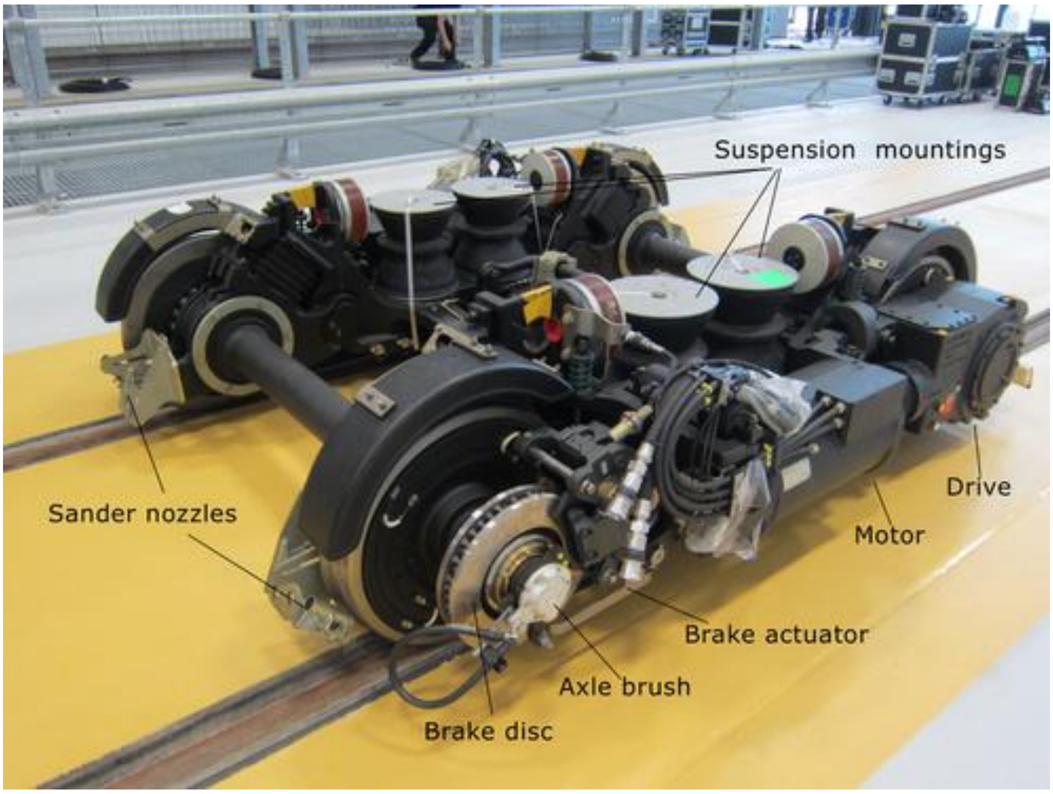

Fig. 2-25 Bogie scheme [31].

The structural and functional composition of a bogie is illustrated in Fig. 2-25, where the main elements such as the wheelset, bogie frame, suspension springs, and central pivot are visible. These components work together to distribute loads, absorb dynamic forces, and maintain stable contact between the vehicle and the track. Additional systems, such as braking beams and dampers, are integrated into the bogie to ensure safe operation under varying conditions.

Suspension plays a critical role in separating dynamic forces between the track and the vehicle body. The relationship between the primary and secondary suspension systems is illustrated in Fig. 2-26, where the primary suspension absorbs high-frequency vibrations directly at the wheel–rail interface, while the secondary suspension provides overall stability and comfort at the car body level [31].

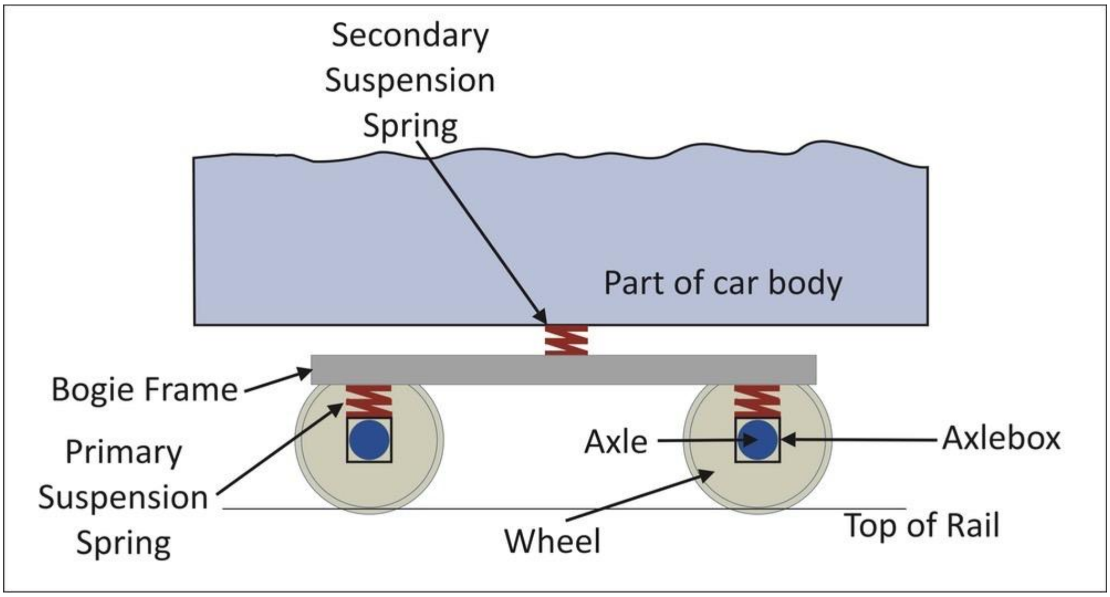

Fig. 2-26 Suspension systems [31]

From a traction perspective, modern metro vehicles commonly employ traction motors mounted directly on the bogie. As shown in Fig. 2-27, the motor is connected to the axle via a gearbox and flexible coupling, enabling efficient transmission of torque to the wheels. This configuration allows for compact integration of the propulsion system and minimises energy losses. The integration of traction equipment within the bogie defines a highly constrained mechanical zone, limiting the available space for other functions.

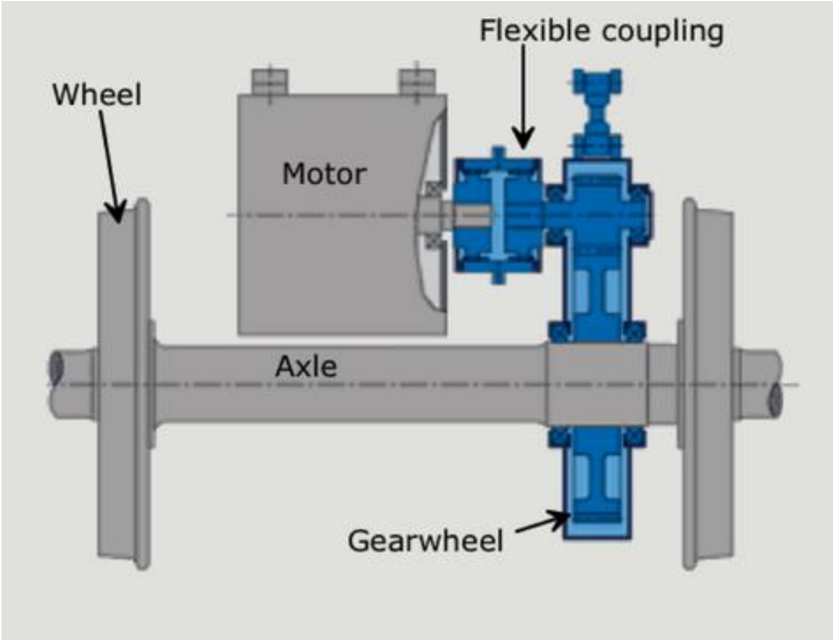

Fig. 2-27 Traction motors shcme [31].

The behaviour of bogies in curved track sections represents an important aspect of vehicle dynamics. As illustrated in Fig. 2-28, the wheelsets must align with the radius of curvature while maintaining stable guidance along the rails. The bogie structure allows a certain degree of rotational freedom relative to the car body, ensuring smooth passage through curves while reducing wear on both wheels and rails [31].

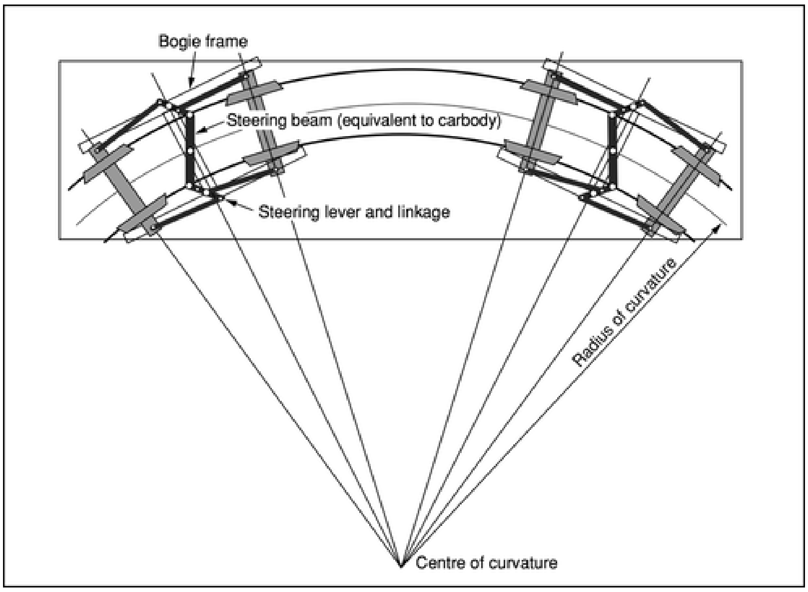

Fig. 2-28 Bogies in curved track sections [31]

Electrical power for metro vehicles is most commonly supplied via a third rail system. In modern implementations, current is collected through a contact shoe mounted on an insulated bracket attached to the bogie frame. This arrangement allows the collector to accurately follow the track geometry and maintain consistent contact with the third rail. The system configuration, including the position of the third rail and the type of contact, is illustrated in Fig. 2-29.

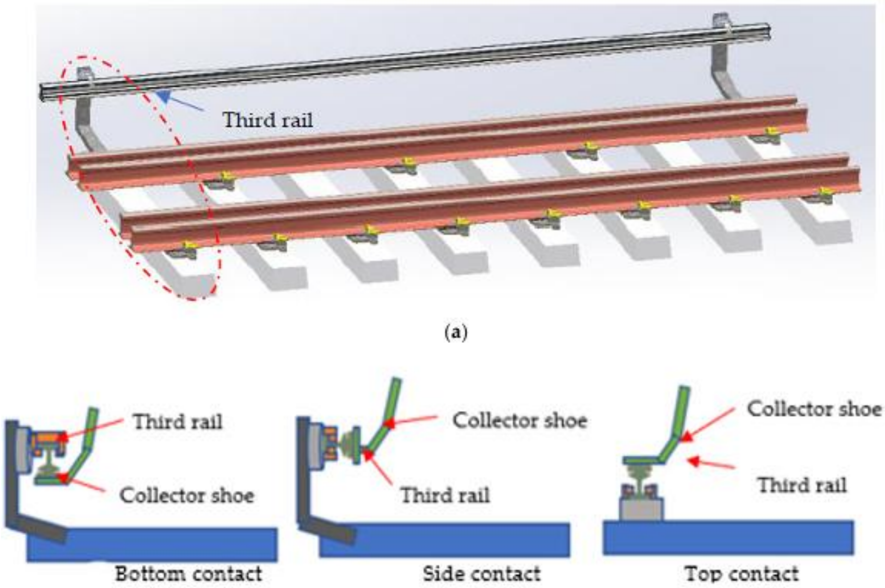

Fig. 2-29 Third rail, types of contact [31]

According to the analysed study, several types of contact systems exist, including top-contact, side-contact, and bottom-contact configurations. Contemporary metro systems predominantly utilise side-contact or bottom-contact solutions due to improved safety and reduced exposure to environmental influences such as snow, ice, or debris. The collected electrical energy is transferred to onboard systems, including traction converters and motors, which are distributed between the bogie and the underfloor equipment zones.

In addition to traction-related components, the underfloor area of metro vehicles accommodates a range of auxiliary systems. These include power converters, batteries, compressors, and control units, typically mounted between the bogies along the vehicle floor. While these systems are not part of the bogie itself, they form an integrated technical layer that significantly influences the internal layout of the vehicle.

Modern metro bogies, such as those developed by Alstom, are designed as modular systems optimised for specific operational requirements, including load capacity, speed, and energy efficiency. These bogies integrate mechanical robustness with compact traction solutions, enabling reliable operation in dense urban environments [32].

A real-world example of a metro bogie base is shown in Fig. 2-30, documented during a visit to Škoda Group production facilities. This image demonstrates the actual scale, complexity, and spatial occupation of the bogie and its associated components, reinforcing the constraints identified in the technical analysis.

Fig. 2-30 Škoda Group metro bogie

The concentration of mechanical and electrical systems within the bogie and underfloor areas creates clearly defined zones that cannot be utilised for cargo. This directly influences the spatial organisation of the vehicle, where usable cargo space must be positioned above or between the bogies. At the same time, the integration of traction systems within the bogie supports a modular vehicle architecture, which is beneficial for the development of a cargo-oriented metro unit.

Carbody Structure, Materials and Dimensional Constraints

The car body of a metro vehicle represents the primary structural shell that defines the external geometry, internal volume, and integration of all vehicle systems. Unlike the bogies, which concentrate mechanical and traction components, the car body provides the main usable space and acts as the load-bearing structure of the vehicle. It must withstand static loads, dynamic forces during operation, and stresses transferred from the bogies while maintaining structural integrity and safety.

Modern metro vehicles are typically designed as self-supporting welded structures. The car body consists of a system of longitudinal beams, transverse frames, and outer panels that together form a rigid shell. This structure distributes loads across the entire vehicle and ensures sufficient stiffness while minimising weight. The connection between the body and the bogies is realised through a central pivot and suspension system, allowing controlled relative movement and efficient load transfer.

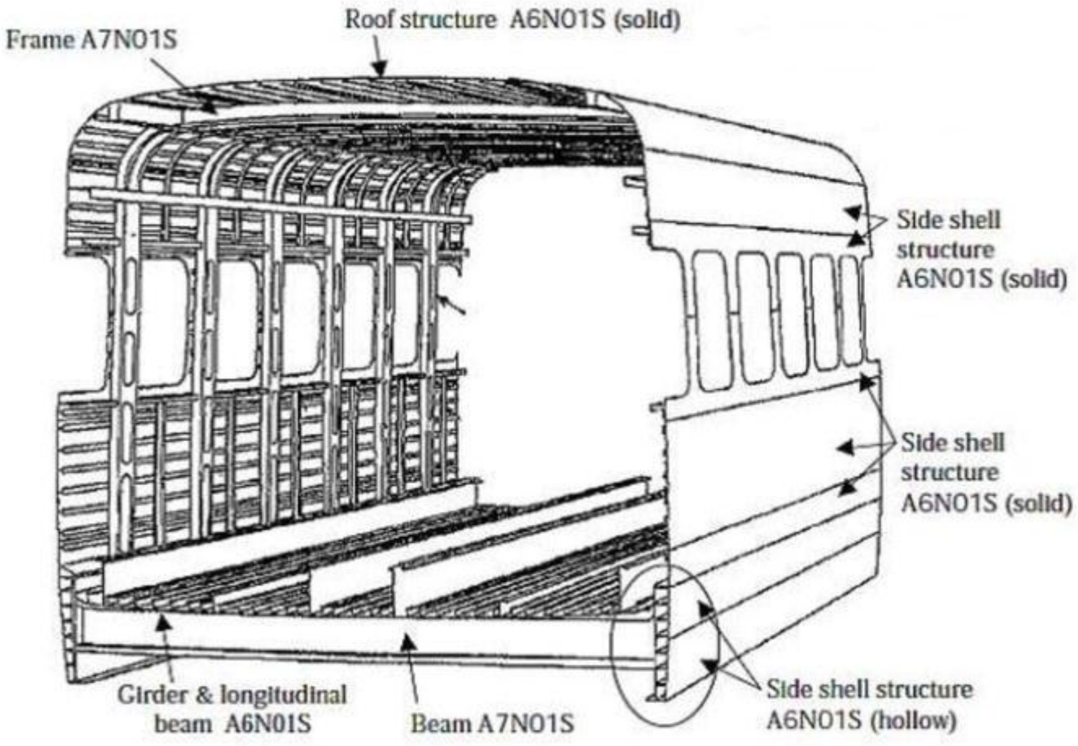

Fig. 2-31 Structural composition of metro car body [33]

The structural composition of the car body is illustrated in Fig. 2-31, where key elements such as longitudinal beams, side structures, and roof components are visible. These elements form a continuous load-bearing system, where forces are transferred along the length of the vehicle. The use of closed profiles and reinforced sections increases stiffness while maintaining a relatively low structural mass.

Material selection plays a critical role in car body design. Modern rolling stock increasingly utilises lightweight materials, particularly aluminium, due to its favourable strength-to-weight ratio, corrosion resistance, and contribution to reduced energy consumption. Lower structural weight leads to reduced traction energy demand and improved operational efficiency. Steel, on the other hand, remains widely used due to its higher structural robustness, lower cost, and well-established manufacturing processes [33].

Fig. 2-32 Metro car body structure [33]

The real-world car body structure shown in Fig. 2-32 demonstrates the application of these principles in practice. The use of aluminium profiles and welded panels enables the creation of a lightweight yet rigid structure. The modular nature of the construction also allows for efficient manufacturing and integration of internal systems.

A critical aspect of car body design is the integration of structural openings. In conventional passenger metro vehicles, these are primarily doors and windows, which must be carefully positioned to avoid weakening the structure. The size and placement of openings are limited by the need to maintain structural stiffness and ensure safety requirements such as crashworthiness. In the context of a cargo metro unit, these limitations become particularly important, as larger openings for loading may be required, directly affecting the structural behaviour of the vehicle.

The overall dimensions of the metro vehicle represent a fixed boundary condition defined by existing infrastructure. In this thesis, dimensional constraints are based on data provided by Škoda Group, ensuring compatibility with real metro systems and manufacturing processes.

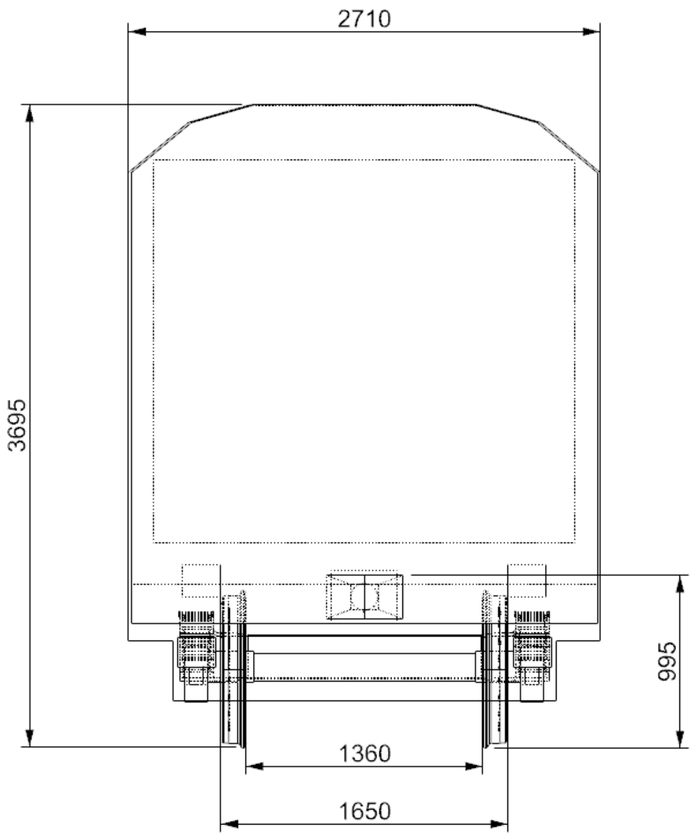

Fig. 2-33 Boundaries, front view

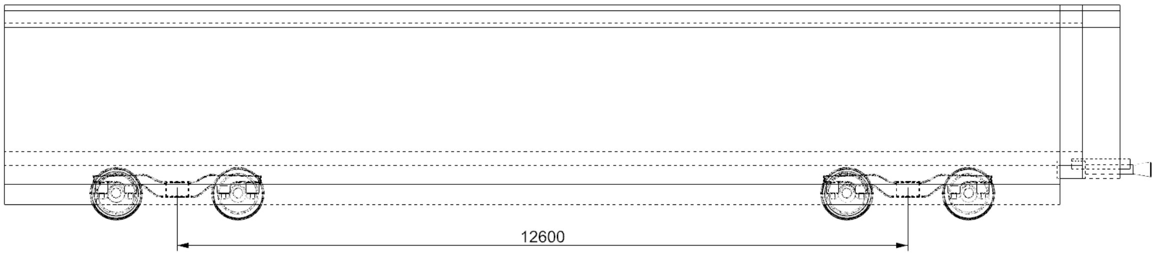

Fig. 2-34 Boundaries, Side view

The car body must also accommodate underfloor systems located between the bogies, including traction converters, batteries, and auxiliary equipment. This results in a layered spatial organisation, where technical components occupy the lower section of the vehicle, while the primary usable space is located above. Consequently, the effective cargo volume is defined not only by external dimensions but also by internal structural and technical constraints.

The car body defines the primary structural and spatial framework of the cargo metro unit. The use of lightweight materials such as aluminium supports energy efficiency and increased payload capacity, while structural constraints limit the size and placement of cargo openings. Combined with fixed dimensional parameters provided by Škoda Group, these factors establish the fundamental boundaries within which the cargo-oriented design must be developed.

Automation and Control Systems

Automation represents a fundamental shift in the operation of metro systems, transforming the vehicle from a driver-controlled machine into a fully autonomous system. The level of automation is defined using the Grades of Automation (GoA), which classify the extent to which train operation is controlled by onboard systems rather than a human operator.

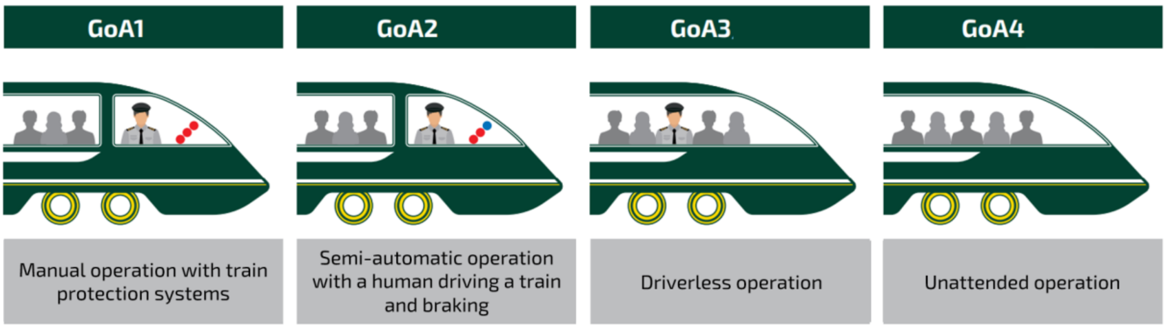

Fig. 2-35 Grades of Automation (GoA) [35]

As illustrated in Fig. 2-36, GoA1 corresponds to manual operation with driver assistance systems, while GoA2 introduces partial automation such as automatic acceleration and braking. GoA3 enables driverless operation with onboard staff supervision. The highest level, GoA4, represents fully unattended train operation (UTO), where no staff is required onboard the vehicle [35]. This level of automation is the basis for the proposed cargo metro system.

In GoA4 systems, all operational functions are controlled automatically, including train movement, door operation, and emergency response. The vehicle operates as part of a larger digital ecosystem, typically based on communication-based train control (CBTC), which continuously exchanges data between the vehicle and infrastructure. This enables precise control of speed, positioning, and safe distance between vehicles.

A key requirement of fully autonomous operation is the ability of the vehicle to perceive its surroundings. This is achieved through a combination of sensor systems integrated into the vehicle structure.

Fig. 2-36 Placement and types of sensors [34]

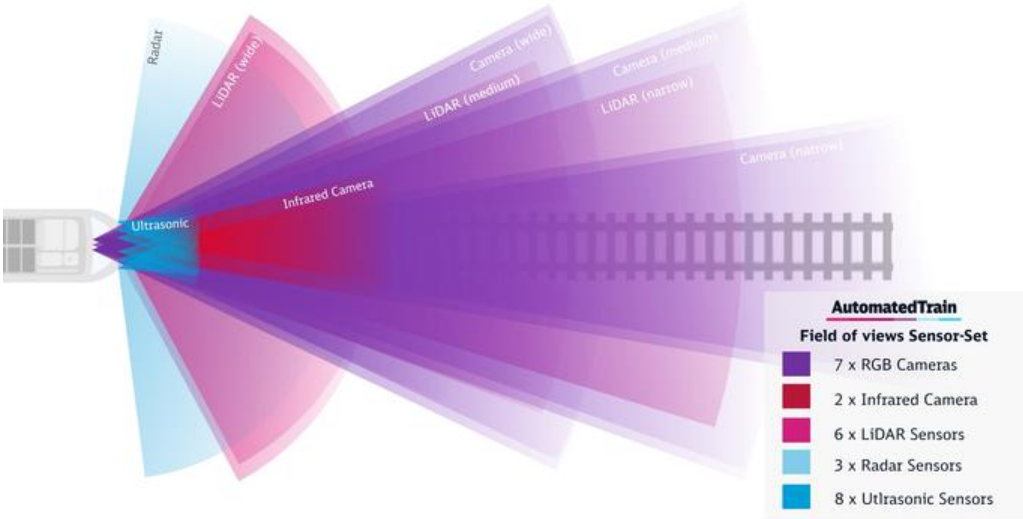

Fig. 2-37 Field of views Sensor set [34]

As shown in Fig. 2-37, autonomous rail vehicles utilise multiple types of sensors, including LiDAR, radar, cameras, and ultrasonic sensors. Each sensor type provides different information about the environment: LiDAR enables precise distance measurement and 3D mapping, radar performs reliably under adverse weather conditions, and cameras provide visual context for object recognition. The combination of these systems creates a redundant and robust perception system capable of detecting obstacles, monitoring the track environment, and ensuring safe operation [34].

The distribution of sensors across the vehicle is a critical design factor. Sensors are typically positioned on the front of the vehicle, where they provide forward-looking perception, as well as on the sides to monitor platform edges and surrounding space. This results in specific requirements for the vehicle exterior, including sensor integration, protection against damage, and unobstructed fields of view.

From a system perspective, autonomous metro operation relies on the integration of onboard sensing, real-time data processing, and continuous communication with infrastructure. The vehicle must be capable of interpreting sensor data, making decisions, and executing control actions without human intervention. This introduces new technical layers that significantly influence both the internal architecture and the exterior design of the vehicle.

The implementation of GoA4 automation fundamentally changes the design requirements of the metro unit. The absence of a driver removes the need for a traditional driver cabin, allowing for greater flexibility in the vehicle layout. At the same time, the integration of sensor systems introduces new constraints on the exterior design, particularly in the front area of the vehicle, where visibility and sensor placement are critical. These factors directly influence the form, functionality, and overall concept of the cargo metro unit.

2.4 Research summary

The conducted research confirms that the integration of freight transport into urban rail infrastructure represents an increasingly relevant topic within both academic research and real-world logistics development. Existing studies, historical examples, and contemporary pilot projects demonstrate that metro systems offer significant potential for reducing delivery traffic, emissions, and operational pressure on urban road networks. At the same time, the research also reveals substantial limitations related to combining passenger and freight transport within shared transport systems, particularly in terms of safety, operational complexity, spatial requirements, and user experience.

The analysis of existing projects such as Mail Rail [16], Cargo Tram Dresden [17], and Freight-on-Transit concepts [18] highlighted several transferable principles relevant to the development of the proposed system. These include the importance of standardized cargo units, separation between passenger and freight operations, use of existing infrastructure, and the implementation of clearly defined logistical nodes. The research further demonstrated that current urban logistics systems remain heavily dependent on road-based transportation and are increasingly challenged by the rapid growth of e-commerce and last mile delivery demand [4][7].

An important outcome of the research phase was also the realization that operational speed and minimal interaction with public space are critical factors for any future freight metro system. Existing studies and operational examples indicate that freight handling within metro infrastructure must remain extremely fast in order to avoid disruption of standard metro operation. For this reason, minimizing unloading time became one of the key principles of the proposed system, with the target of keeping station handling times approximately within the range of conventional passenger metro stopping times. The research additionally demonstrated that any unnecessary movement of cargo through public station spaces, elevators, or passenger circulation areas creates significant operational complications and negatively affects both efficiency and safety. As a result, the proposed concept attempts to minimize direct contact between cargo manipulation and public passenger environments as much as possible.

From a design perspective, the research identified a gap between existing public transport systems and the emerging needs of autonomous urban logistics. While contemporary metro systems are progressively adopting automation, modularity, and advanced operational technologies, relatively little attention has been devoted to the industrial design and functional integration of dedicated freight-oriented metro units.

Based on these findings, the direction of the thesis was defined more precisely. The proposed solution therefore focuses on the development of a dedicated autonomous cargo metro unit that does not transport passengers but instead utilizes existing metro infrastructure for urban freight distribution. Emphasis is placed on modular cargo handling, operational flexibility, compatibility with future autonomous systems, and the reduction of negative environmental and spatial impacts associated with conventional last mile delivery.

The research phase therefore established both the theoretical foundation and the primary development objectives for the subsequent conceptual and design stages of the project.

3 THESIS OBJECTIVES

This chapter analyses the problem context that forms the basis of the design project and defines the objectives of the thesis. The first part of the chapter focuses on broader challenges related to urban environments and contemporary logistics, identifying the key reasons why alternative freight transport solutions are increasingly required in dense city centres. The second part addresses a more specific layer of the problem, examining the challenges associated with integrating a freight-oriented product into existing metro infrastructure, including operational, infrastructural, and systemic constraints. Based on these two levels of analysis, the chapter formulates the main objective of the thesis and outlines the partial goals that guide the subsequent design development.

3.1 Definition of problems

3.1.1 Urban logistics as a growing challenge in city centres

Urban logistics has become an increasingly visible and influential factor in the functioning of contemporary city centres. The growth of e-commerce, combined with rising expectations for fast and flexible delivery, has led to a substantial increase in the volume of goods transported into dense urban areas. This development places significant demands on public space, infrastructure, and urban mobility systems, which were not originally designed to accommodate such intensive freight activity [37].

One of the most critical aspects of this transformation is the pressure exerted by last-mile delivery operations. Delivery vehicles frequently compete with pedestrians, cyclists, and public transport for limited street space, contributing to congestion and reduced spatial quality. As a result, urban logistics is no longer solely a transport-related issue but has become a broader urban challenge affecting the everyday experience of city environments [38].

Beyond traffic and environmental impacts, the expansion of urban logistics has also introduced a pronounced visual dimension to the problem. The rapid deployment of parcel lockers and pickup boxes in public and semi-public spaces has significantly altered the visual character of many city centres. These installations are often placed opportunistically, without sufficient integration into their architectural or urban context, leading to visual clutter and the fragmentation of public space [39].

From an urban design perspective, such elements contribute to visual pollution by disrupting established spatial hierarchies, obstructing sightlines, and weakening the visual coherence of streetscapes and public squares [40].

The accumulation of logistics-related objects in the urban environment highlights a growing conflict between functional efficiency and spatial quality. While pickup boxes improve delivery convenience, their widespread and uncoordinated implementation raises questions regarding long-term urban aesthetics, identity, and the management of shared public space. This tension underscores the need to reconsider how freight transport systems are integrated into cities, not only from a logistical or technological standpoint, but also from a design and spatial perspective [41].

3.1.2 Limits of current urban freight transport models

Current urban freight transport is predominantly based on road-based delivery systems that have gradually evolved in response to increasing demand. Delivery vans, cargo bicycles, and decentralised pickup points represent the most commonly used models in contemporary city centres. While these approaches offer operational flexibility, their effectiveness is fundamentally constrained by the spatial and infrastructural limitations of dense urban environments.

Delivery vehicles remain dependent on surface-level street networks, where they directly compete with private cars, public transport, cyclists, and pedestrians. As delivery volumes increase, this competition intensifies, resulting in congestion, reduced reliability, and growing pressure on public space. Rather than resolving structural inefficiencies, these models redistribute logistical complexity across already saturated urban streets.

Alternative solutions such as cargo bikes and micro-distribution hubs address some of these challenges at a local scale, particularly in terms of emissions and vehicle size. However, their limited range and carrying capacity restrict their applicability across entire metropolitan areas. As a result, such solutions often rely on additional handling stages and supporting infrastructure, which reduces overall system efficiency.

Pickup boxes and parcel lockers further externalise logistics into public and semi-public space. Although they increase delivery convenience, they do not reduce the overall volume of freight entering cities. Instead, they shift the final stage of delivery onto users and service personnel, without addressing upstream transport inefficiencies or spatial impacts.

Overall, existing urban freight transport models lack scalability, systemic integration, and long-term sustainability. Their reliance on road-based infrastructure highlights the need to explore alternative transport systems capable of operating independently from congested urban streets and offering higher capacity at a systemic level [42].

3.1.3 Challenges of integrating freight transport into metro systems

The design of a dedicated metro unit for non-passenger use forms the central focus of this thesis. Within this context, urban logistics is considered as a specific application domain, in which metro infrastructure represents a potential alternative for freight transport. From a design perspective, an essential requirement is to propose a solution that can be implemented within existing metro systems, while remaining adaptable to future developments and newly emerging transport infrastructures. This dual requirement introduces specific constraints, as the designed unit must respect current operational, infrastructural, and regulatory conditions, while simultaneously allowing for scalability and long-term system evolution.

Although metro networks offer high capacity, energy efficiency, and operational stability, they are primarily designed for passenger service. Any incorporation of freight-oriented transport must therefore function without compromising the reliability, safety, or performance of regular passenger operations. This necessitates careful consideration of ompatibility with established timetables, network capacity, and operational priorities.

Further challenges are related to infrastructure and operational time constraints. Platforms, depots, and service facilities are primarily designed for passenger transportation and therefore do not naturally support freight handling operations. In addition, metro systems already operate at very high frequencies, with standard station stopping times typically ranging between approximately 20–40 seconds depending on the system and operational conditions. This creates extremely limited time windows for any freight manipulation process. As a result, unloading operations within the proposed system must be designed to function within timeframes comparable to conventional passenger metro stops in order to avoid disruption of regular metro traffic and maintain operational flow of the metro network.

These constraints demonstrate that integrating freight transport into metro systems is not merely a technical task, but a systemic challenge requiring coordination between infrastructure, operations, and vehicle design. By addressing these challenges through the design of a dedicated metro unit, the project will explore how freight transport can be integrated into current metro networks while simultaneously offering extended potential for future transport systems and evolving urban logistics models [43].

3.2 Definition of the Customer and the End User

The design of a metro unit is inherently shaped by the requirements and constraints of multiple stakeholders operating at different levels of the transport system. In the context of this thesis, the design process is developed in cooperation with Škoda Group, whose expertise in the development and production of rail vehicles provides an important industrial framework for the project. This collaboration influences both the definition of the customer and the practical boundaries within which the proposed design solution is developed.

The primary customer of the designed metro unit is represented by public transport authorities and city administrations responsible for the operation and procurement of metro systems. These entities act as decision-makers in relation to vehicle acquisition, system integration, and long-term operation. Their requirements focus primarily on reliability, safety, economic efficiency, compliance with regulations, and compatibility with existing infrastructure. In addition, municipalities play a key role in ensuring that such systems align with broader urban strategies, including sustainability objectives, traffic reduction, and the management of public space.

The end users of the proposed metro unit differ significantly from those of conventional passenger rolling stock. In this case, end users primarily include professional operators responsible for loading, unloading, supervision, and maintenance of the vehicle. Their interaction with the unit is functional and task-oriented, placing emphasis on ergonomics, intuitive interfaces, operational clarity, and safe handling of cargo. In certain scenarios, end users may also include logistics personnel operating within depots or distribution hubs connected to the metro network.

3.3 Development Objectives

3.3.1 Product Name and Classification

The product developed within this thesis is an autonomous metro unit designed for the transportation of urban freight within metro systems. It is conceived as a specialised industrial product intended for repeated and long-term use within a controlled transport environment. The unit belongs to the category of special-purpose rail vehicles with situational demand, as its deployment is closely linked to specific urban, infrastructural, and logistical conditions rather than continuous mass-market consumption.

3.3.2 Main Development Objectives

The main objective of this thesis is to develop a concept of an urban freight transport system utilizing existing metro infrastructure as part of future last mile delivery logistics. The proposed system is intended to operate within realistic operational conditions of contemporary metro networks while responding to the growing pressure placed on urban logistics by the rapid expansion of e-commerce and high-frequency delivery services. A key objective of the project is the minimization of direct interaction between freight transport and public passenger space while maintaining extremely fast loading and unloading operations compatible with the strict time constraints of metro traffic. The proposal therefore focuses on creating a flexible logistical framework capable of integrating existing and emerging autonomous technologies related to cargo handling, warehouse automation, autonomous delivery vehicles, and urban logistics systems.

The second primary objective of the thesis is the development of an autonomous metro freight unit specifically designed for the proposed logistical system. The unit is intended to transport last mile delivery freight while supporting rapid manipulation, operational efficiency, and compatibility with possibly both manual and autonomous unloading processes. At the same time, the design of the vehicle aims to visually communicate its technological, autonomous, and logistical purpose through its shape and graphical identity. The proposed metro unit is therefore developed not only as a transportation vehicle itself, but as a functional component of a larger future-oriented urban logistics system.

3.3.3 Partial Development Objectives

The partial development objectives of the project focus primarily on the operational, ergonomic, and visual aspects of the proposed metro freight system. Particular attention is given to the development of efficient loading and unloading scenarios capable of functioning within the strict spatial and time limitations of metro infrastructure. The proposal also explores the relationship between autonomous and manual freight handling approaches together with the integration of future urban logistics technologies potentially connected to the system.

An additional objective of the project is the creation of a coherent visual and formal identity for the proposed metro unit. The design aims to communicate the autonomous, technical, and highly functional character of the system while partially referencing the contemporary visual language associated with Škoda Group railway vehicles. At the same time, the proposal attempts to maintain realistic construction logic and manufacturing principles appropriate for contemporary railway vehicle production.

4 CONCEPTUAL DESIGN

This chapter presents a set of conceptual design variants developed in response to the findings of the preceding analytical and research phases. The proposed concepts are based on insights derived from technical, design, and ergonomic analysis, as well as from considerations related to operation and system integration. Emphasis is placed on translating the defined development objectives into distinct conceptual approaches while responding to the key constraints of the project.

The chapter introduces three individual approaches and design variants and examines their specific characteristics, advantages, and limitations in relation to the defined goals. Based on a comparative evaluation of these variants, the concepts are subsequently assessed and synthesised to identify the most suitable solution, or a combination of solutions, that provides the most effective foundation for the further development of the proposed metro unit.

4.1 Variants

The conceptual design variants presented in this chapter differ in their approach to vehicle configuration, cargo handling, and system integration. The only shared assumption across all variants is the definition of metro depots as the primary loading and dispatch locations for the proposed metro unit. This assumption is derived from the research phase and is applied consistently to all variants to establish a common point of departure.

Metro depots are typically located at the periphery of urban areas and are predominantly situated above ground, which makes them well suited for freight-related operations. They provide controlled environments with sufficient spatial capacity, direct access to the metro network, and established operational procedures. Defining depots as the loading point allows freight handling to take place outside dense city centres, thereby minimising interference with passenger flows and public space.

By fixing this single operational condition, the individual variants can be compared while remaining otherwise conceptually independent. Each variant explores a distinct design strategy within this shared logistical premise, allowing differences in vehicle layout, handling principles, and system interaction to be evaluated without altering the fundamental starting conditions.

4.1.1 Variant one

The first conceptual variant explores a structurally minimal approach to freight transport within the metro system, in which the vehicle functions primarily as a supporting shell for the transported cargo. Rather than fully enclosing the freight, the unit provides a partial protective structure designed to ensure sufficient stability and guidance during transport while avoiding unnecessary structural complexity.

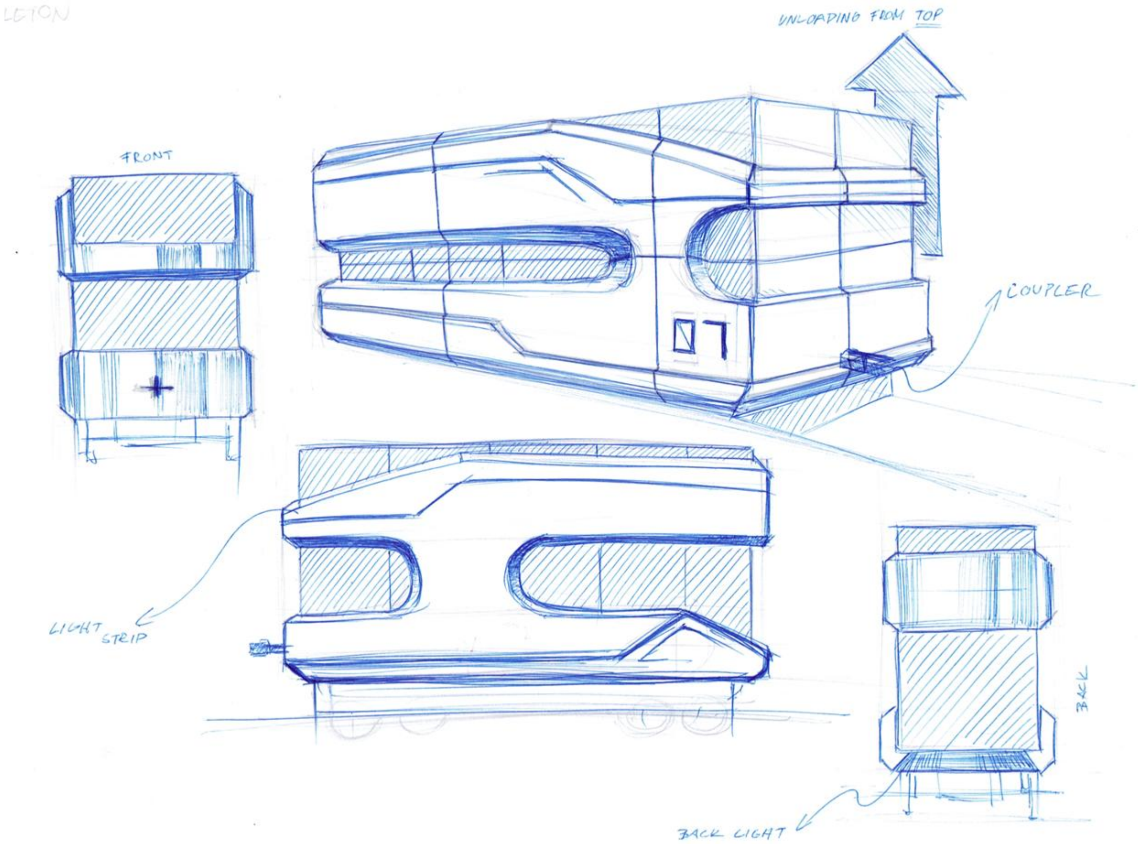

Fig. 4-1 Variant 1 sketches

A defining characteristic of this variant is the use of top-loading and top-unloading principles. Cargo is handled vertically, allowing insertion and removal from above the vehicle. This approach eliminates the need for side-opening mechanisms and simplifies the interface between the freight and the metro unit, while remaining compatible with depot-based loading processes.

From a logistical perspective, this variant assumes that direct human interaction with the cargo occurs only outside the underground metro environment. After transport within the metro network, the freight is transferred to a depot house located above the metro station, where further manual handling and redistribution take place. By limiting human involvement within underground sections of the system, this concept aims to reduce operational complexity and potential safety conflicts within the metro infrastructure.

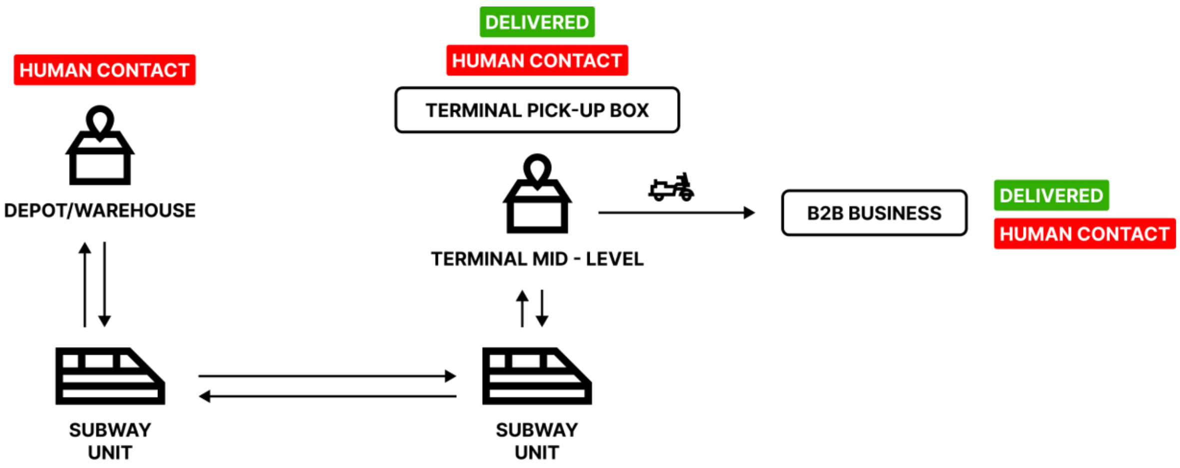

Fig. 4-2 Variant 1 scheme

Through its open-shell configuration and vertically oriented handling strategy, this variant investigates the feasibility of a lightweight, functionally restrained solution that prioritises simplicity, clarity of operation, and separation between automated transport and human-led logistics processes. The concept establishes a baseline against which more enclosed or functionally integrated variants can be evaluated.

Fig. 4-3 Variant 1 3D sketch

Fig. 4-4 Variant 1 3D sketch

4.1.2 Variant two

The second conceptual variant investigates a modular approach to the design of the metro unit, in which the overall length and functional capacity of the vehicle are determined by the type and size of the transported load. Unlike the first variant, this concept is based on a flexible vehicle configuration that can be adapted to different operational requirements rather than a fixed vehicle body.

The central principle of this variant is a modular unit inserted between two bogies. The distance between the bogies can be increased or reduced depending on the dimensions of the inserted module, allowing the effective length of the vehicle to change accordingly. This configuration enables the transport of a wide range of cargo types without relying on multiple dedicated vehicle designs.

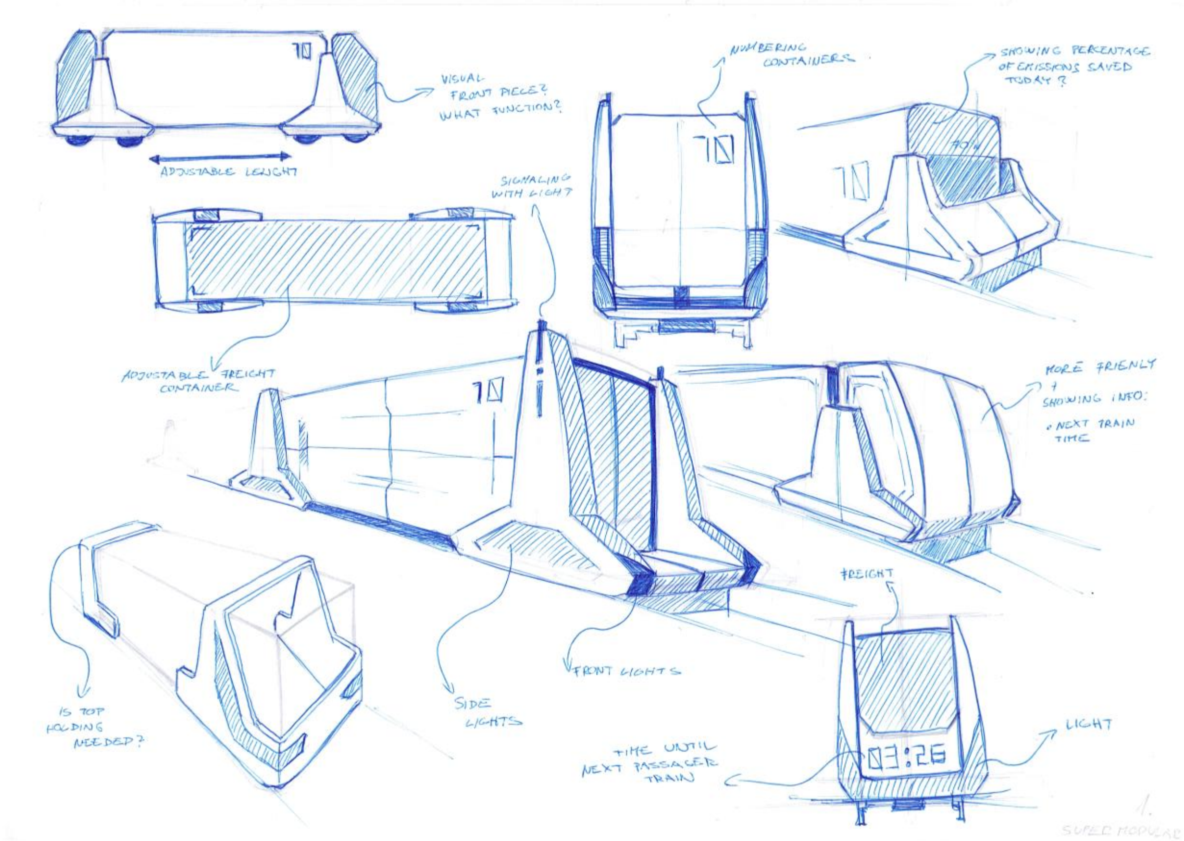

Fig. 4-5 Variant 2 sketches

From a functional perspective, the modular system extends beyond standardised freight units and explores the potential to carry non-standard or oversized loads, such as construction materials. In a broader exploratory context, the variant also considers whether similar modular principles could be adapted for alternative uses, including the transport of people or mixed-use applications. These considerations position the concept as an investigation into the upper limits of flexibility within metro-based transport systems.

In terms of logistics, this variant follows a distribution logic comparable to the first concept. Human interaction with the cargo is assumed to occur only outside the underground metro environment. After arrival at the destination station, freight is transferred to an above-ground facility, from which the final stage of distribution is handled by additional autonomous technologies. This approach maintains a clear separation between automated underground transport and surface-level logistics operations.

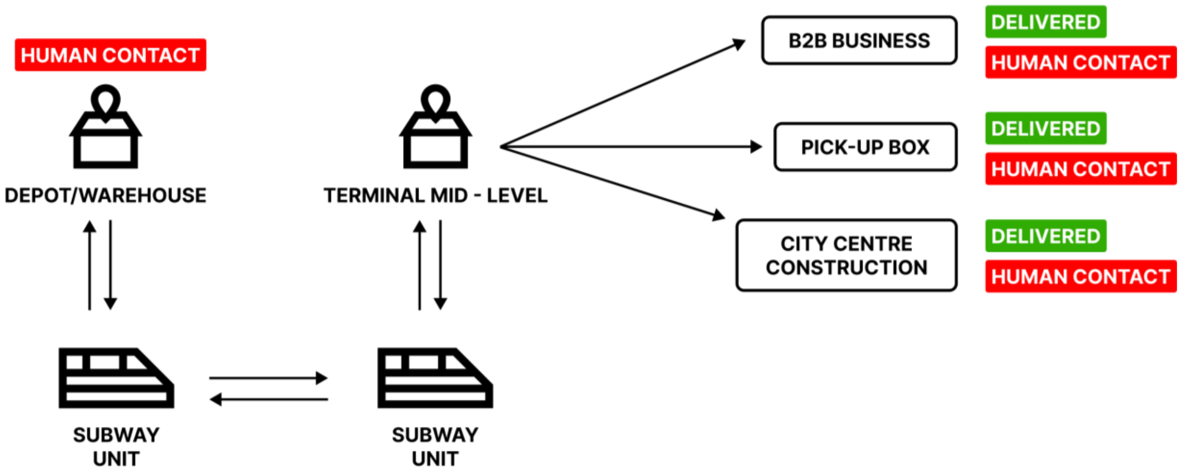

Fig. 4-6 Variant 2 scheme

By transferring variability to the vehicle architecture rather than to handling processes, this variant explores the trade-off between increased structural complexity and expanded operational versatility. It serves as a conceptual counterpoint to the more restrained first variant and provides a basis for evaluating the benefits and limitations of modular adaptability within metro freight systems.

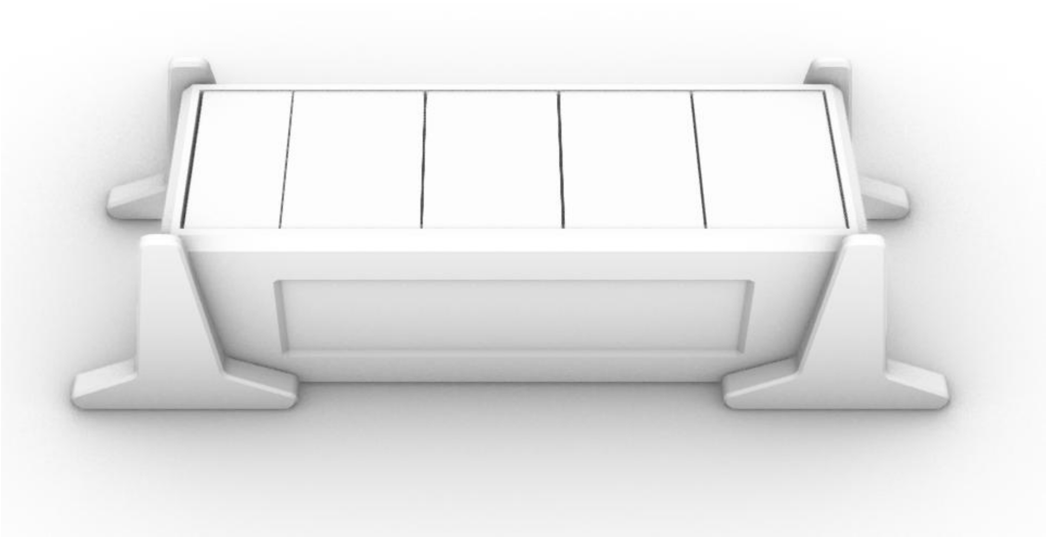

Fig. 4-7 Variant 2 3D sketch

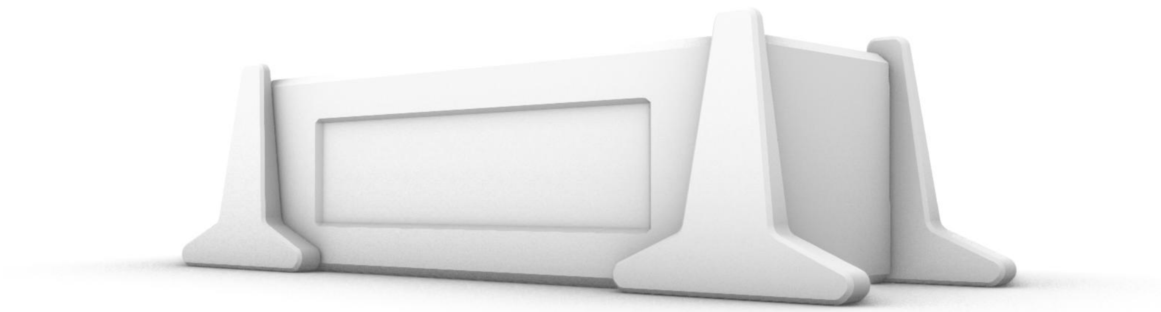

Fig. 4-8 Variant 2 3D sketch

4.1.3 Variant three

The third conceptual variant explores a more direct interaction between the metro unit and human operators by introducing manual side access to the transported cargo. In contrast to the previous variants, this concept is based on lateral loading and unloading, allowing the freight to be extracted from the side of the vehicle using human force.

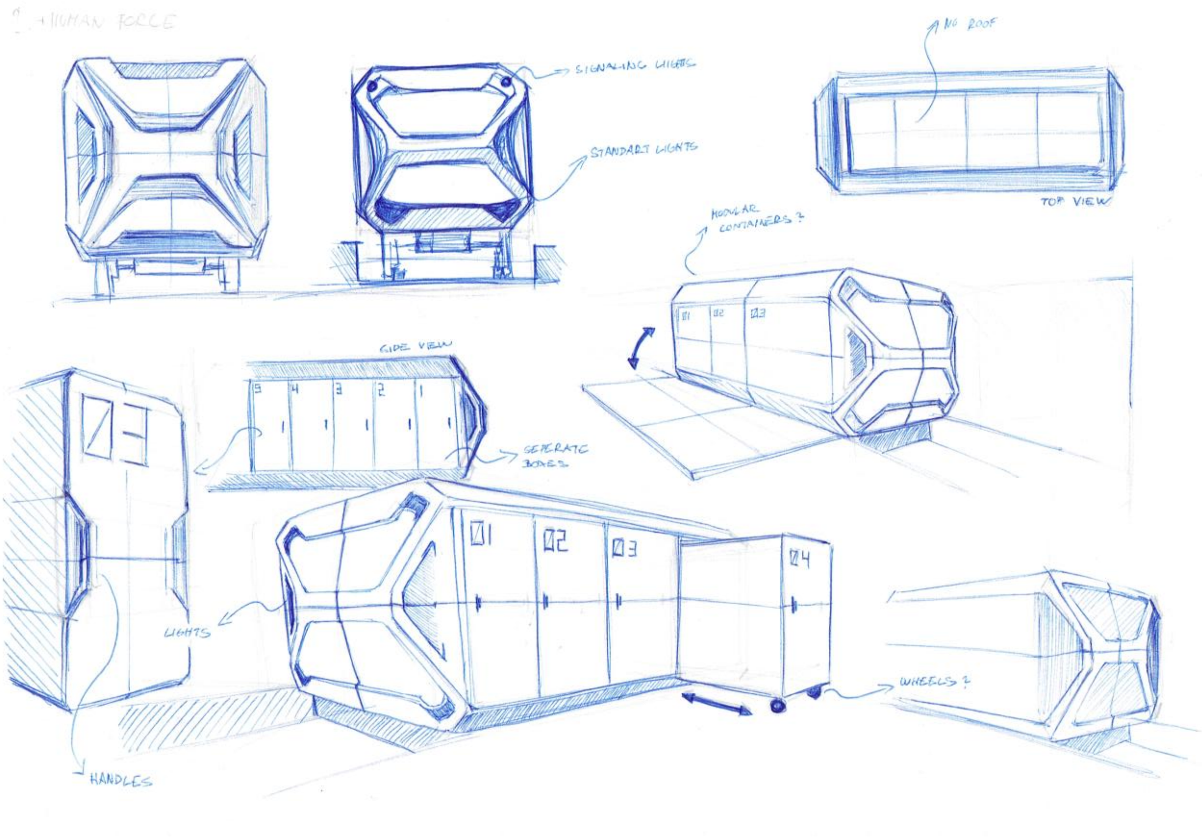

Fig. 4-9 Variant 3 sketches

The vehicle configuration in this variant prioritises accessibility and immediacy of handling over automation and separation. Side openings are designed to enable direct physical interaction with the cargo, reducing the need for additional lifting mechanisms or transfer systems. This approach simplifies the technical complexity of the vehicle while increasing reliance on manual labour during the handling process.

From a logistical perspective, this variant assumes that the first point of contact between the freight and human operators occurs directly at the metro platform. Cargo is unloaded at station level and subsequently distributed through surface-level logistics processes. As a result, freight handling becomes closely integrated with passenger infrastructure, introducing new considerations related to safety, spatial organisation, and the coexistence of logistics activities with regular metro operations.

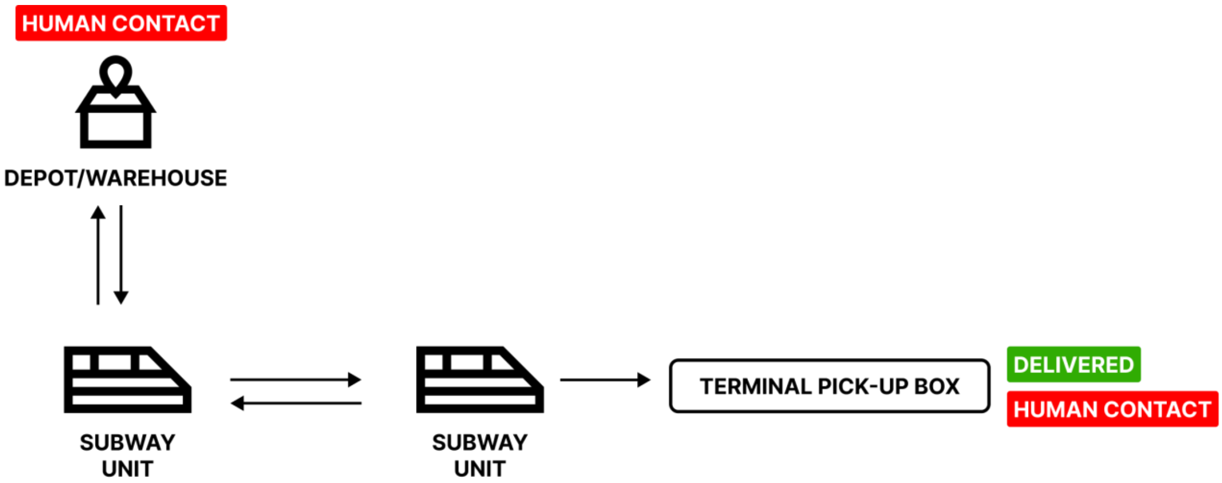

Fig. 4-10 Variant 3 scheme

By placing human interaction at the earliest stage of unloading, this variant investigates the trade-offs between operational simplicity and increased demands on station environments. It serves as a contrasting concept that highlights the implications of manual handling and platform-based logistics, providing a valuable reference point for evaluating the role of automation and separation in metro-based freight transport systems.

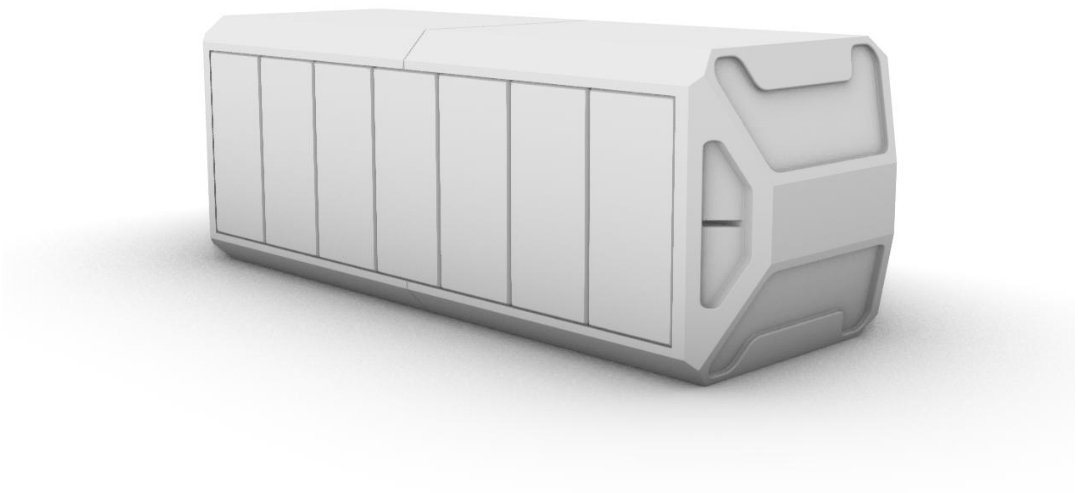

Fig. 4-11 Variant 3 3D sketch

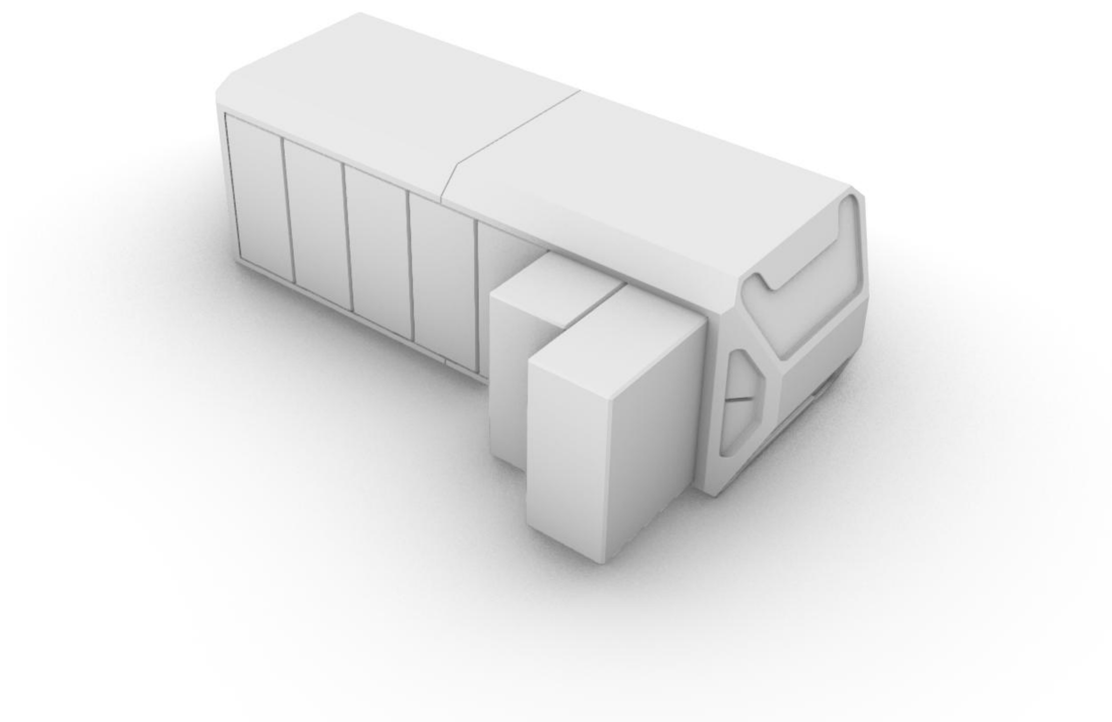

Fig. 4-12 Variant 3 3D sketch

4.2 Evaluation

The conceptual variants were evaluated using a multi-criteria assessment framework focusing on key aspects relevant to the integration of freight transport into metro systems. The evaluation criteria included integrability into existing infrastructure, cost, operational speed, financial and environmental benefits, impact on urban space, degree of intervention into existing infrastructure, flexibility, maintenance requirements, and visual coherence. Each variant was assessed against these criteria and assigned a numerical score, allowing for a structured comparison of their respective strengths and limitations.

Kritérium hodnocení	Varianta 1	Varianta 2	Varianta 3
Integrovatelnost	6	5	9
Cena	8	6	9
Rychlost	9	8	2
Přínos (finanční)	8	9	4
Přínos (životní prostředí)	8	9	6
Přínos (prostor měst)	8	7	9
Zásah do prostředí (infrastruktury)	6	3	9
Flexibilita	8	9	4
Cena oprav a údržba	7	8	7
Vizuální ucelenost	7	3	9
Součet bodů	**75**	**67**	**68**

Tab. 4-1 Table of variant evaluation (in Czech language)

The results of the evaluation indicate that no single variant performs optimally across all criteria. While the first variant achieves a balanced overall score due to its simplicity and operational efficiency, the second variant demonstrates strong potential in terms of flexibility and adaptability. The third variant performs well in aspects related to integrability and urban impact but shows limitations in operational speed and logistical efficiency. Based on the scoring results, it becomes evident that the most effective design approach does not lie in selecting one variant exclusively, but rather in combining selected aspects from multiple variants. This synthesis provides a more robust foundation for the subsequent design development, allowing the strengths of individual concepts to be integrated while mitigating their respective weaknesses.

5 PRELIMINARY DESIGN

The preliminary design is based on a synthesis of the previously evaluated concept variants, drawing primarily from those aspects that demonstrated the highest potential in terms of system integration, operational efficiency, and spatial impact. Rather than directly adopting a single variant, the preliminary proposal combines selected principles from multiple concepts to create a more balanced and robust design solution.

The resulting design reflects the strengths identified during the evaluation phase, particularly regarding compatibility with existing metro infrastructure, clarity of operation, and suitability for urban logistics applications. At the same time, the preliminary design establishes a foundation that allows for further technical refinement and development in subsequent stages of the project, while remaining aligned with contemporary requirements for autonomous transport systems and future-oriented urban mobility.

5.1 The system

The pre-final proposed system is based on a combination of manual and autonomous unloading strategies within the metro network. This approach allows the system to respond to different logistical requirements while remaining compatible with existing infrastructure and operational conditions.

Manual unloading represents the simplest and most easily implementable solution. It requires minimal additional infrastructure, involves lower investment costs, and can be integrated into current metro operations with limited technical intervention. For these reasons, manual unloading is considered the primary and initial mode of system implementation. It is particularly suitable for parcel-based distribution, such as e-commerce deliveries, where flexibility and human interaction remain essential.

Autonomous unloading, by contrast, is designed as a more advanced and efficient solution. It enables higher throughput, reduced handling time, and greater operational consistency, particularly for regular supply chains such as deliveries to restaurants, commercial centres, or large-scale urban facilities. However, this approach requires dedicated infrastructure, advanced control systems, and higher initial investment. As a result, autonomous unloading is intended for a limited number of selected central stations and represents a future-oriented extension of the system rather than its initial deployment stage.

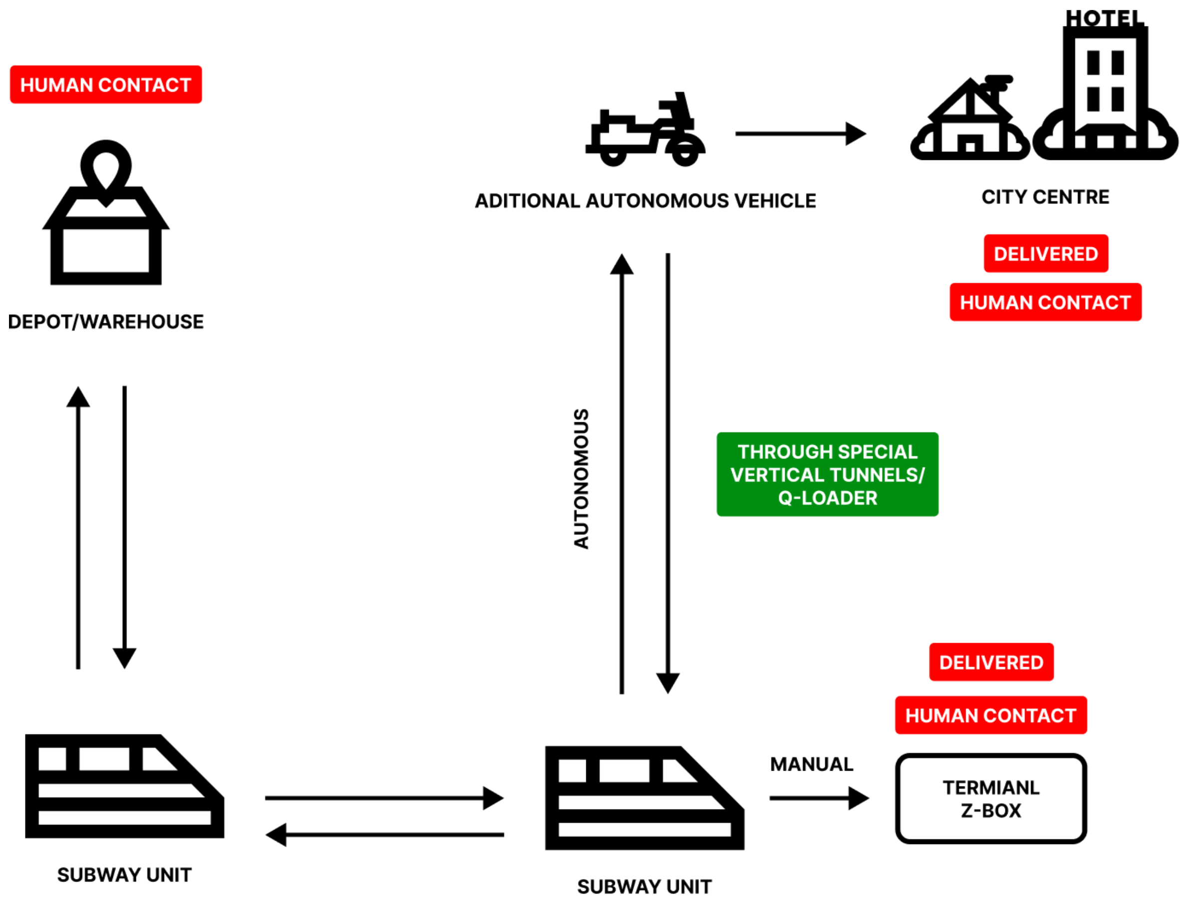

Fig. 5-1 Final logistics scheme

By combining manual and autonomous unloading within a single framework, the system supports gradual implementation and technological development. This structure allows immediate deployment through manual processes while providing a clear pathway towards increased automation as operational experience, infrastructure, and economic conditions evolve. The unit design stays the same for both options.

5.2 Functionality

The functional design of the system is directly influenced by the combination of manual and autonomous unloading strategies. In order to support both approaches within a single vehicle configuration, the cargo boxes are designed to be extracted from the side of the metro unit. Side-based extraction is essential for manual unloading at station platforms, where human operators require direct and unobstructed access to the cargo without additional lifting equipment.

Autonomous unloading is based on principles already applied in contemporary automated logistics systems. A relevant reference can be found in automated truck loading and unloading solutions, such as the Q-loader system, which enables horizontal transfer of standardized cargo units between a vehicle and a handling platform through guided and controlled motion. This approach eliminates the need for vertical lifting and allows reliable, repeatable unloading operations within constrained spatial conditions [44]. In the context of the proposed system, a similar principle is applied to transfer cargo boxes from the metro unit to surface-level automated infrastructure located above selected stations.

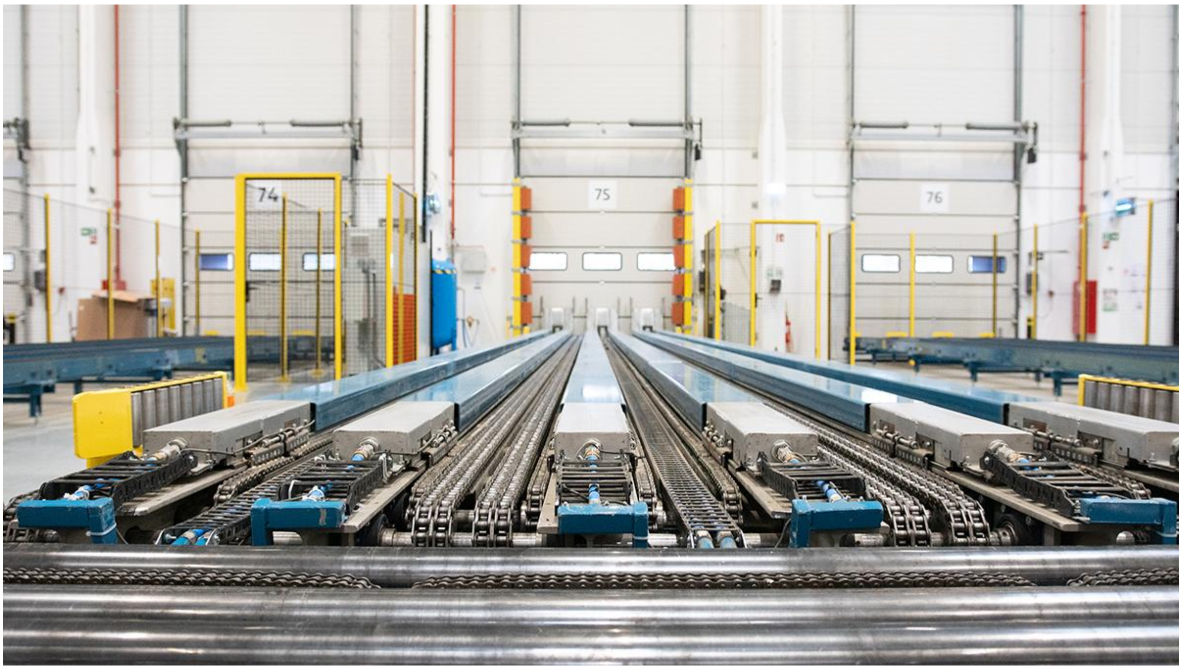

Fig. 5-2 The Q-loader [44]

Inside the metro unit, the cargo is organised into a set of standardised boxes with uniform dimensions. The system is designed to accommodate approximately twelve cargo boxes per unit, a number and size determined through earlier research into handling efficiency, spatial constraints, and operational feasibility. This configuration is further supported by the high operational frequency of the metro-based transport system, which enables more frequent deliveries compared to conventional last-mile freight transport and therefore allows individual cargo boxes to be smaller in size. To support manual unloading, each cargo box is equipped with integrated wheels, allowing safe and efficient manipulation by human operators at platform level.

In autonomous unloading scenarios, the cargo boxes are transferred from the metro unit to a designated surface-level platform located above the station. From this point, the boxes are handled by an auxiliary autonomous vehicle responsible for short-distance distribution over the final segment of the delivery route. This last stage typically covers several tens of metres and enables direct delivery to destinations such as shopping centres, restaurants, or service facilities without human intervention.

Fig. 5-3 AGV robots [22]

By combining side-extractable standardized cargo boxes with both manual and autonomous handling processes, the system achieves a high degree of functional flexibility. Manual unloading enables immediate and cost-effective implementation within existing metro infrastructure, while autonomous unloading provides a scalable and future-oriented solution for high-volume and repetitive supply scenarios. Together, these functional principles form a coherent system capable of supporting diverse urban logistics operations within the metro network.

5.3 Shape and visuals

The overall shape of the proposed metro unit is derived from the principles established in the third conceptual variant, particularly in relation to side-based cargo handling and direct interaction with station environments. This variant provided the most suitable formal foundation for the final design, as its configuration responds directly to the operational requirements of manual unloading while maintaining a clear and legible vehicle geometry.

The visual expression of the unit is closely linked to the principle of side unloading. The longitudinal form emphasises accessibility along the sides of the vehicle, while the front section is designed to remain visually compact and clearly defined. In autonomous unloading scenarios, the metro unit stops before the station platform and does not enter passenger areas. As a result, passengers waiting at stations primarily perceive the front of the vehicle, making the design of the front section a key element of visual communication.

Fig. 5-4 Moodboard

Despite its primary function as a freight vehicle, the visual design of the unit remains an important aspect of the overall system. In some cities, metro lines operate partially above ground, increasing the visibility of the vehicle within the urban environment. In addition, the introduction of a dedicated freight unit represents a new element within the metro system, making visual clarity and recognisability essential. The design must therefore avoid evoking uncertainty or discomfort, particularly in relation to autonomous operation.

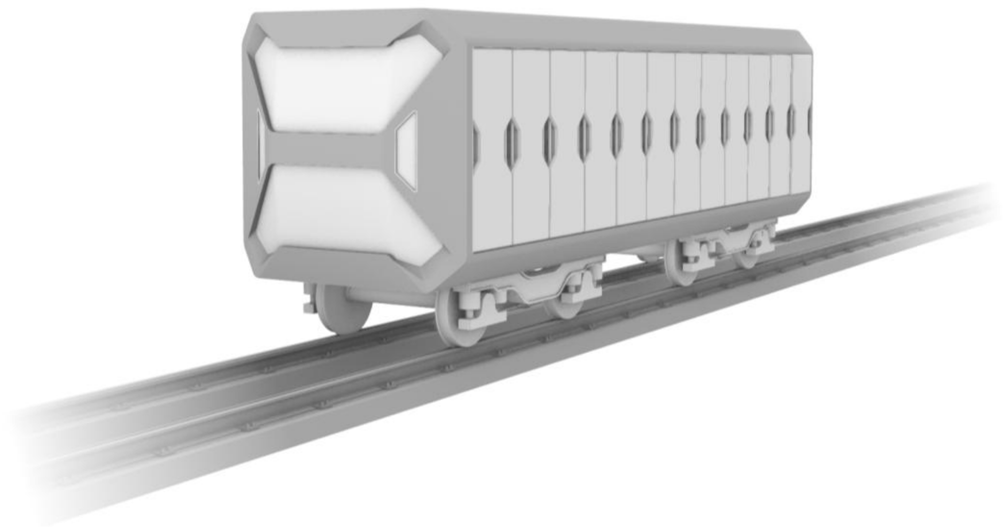

Fig. 5-5 3D concept model of the unit

At the same time, the visual language of the unit is intended to clearly distinguish it from passenger rolling stock. The absence of a driver, higher operational speed, and the exclusive transport of cargo require a form that communicates autonomy and functional purpose. The design aims to convey a dynamic and forward-looking character, reflecting the technological nature of the system, while maintaining a friendly and approachable appearance. Through this balance, the shape of the metro unit supports both operational clarity and public acceptance, reinforcing its role as a safe, autonomous, and integral component of the urban transport infrastructure.

The colour strategy of the proposed metro unit is intentionally restrained and focused on clarity and immediate legibility. The primary goal of the colour design is to communicate the function of the unit at first glance and to clearly distinguish it from passenger rolling stock. A limited and neutral colour palette is used to ensure visual calm and coherence within the complex environment of metro infrastructure, while avoiding unnecessary visual noise.

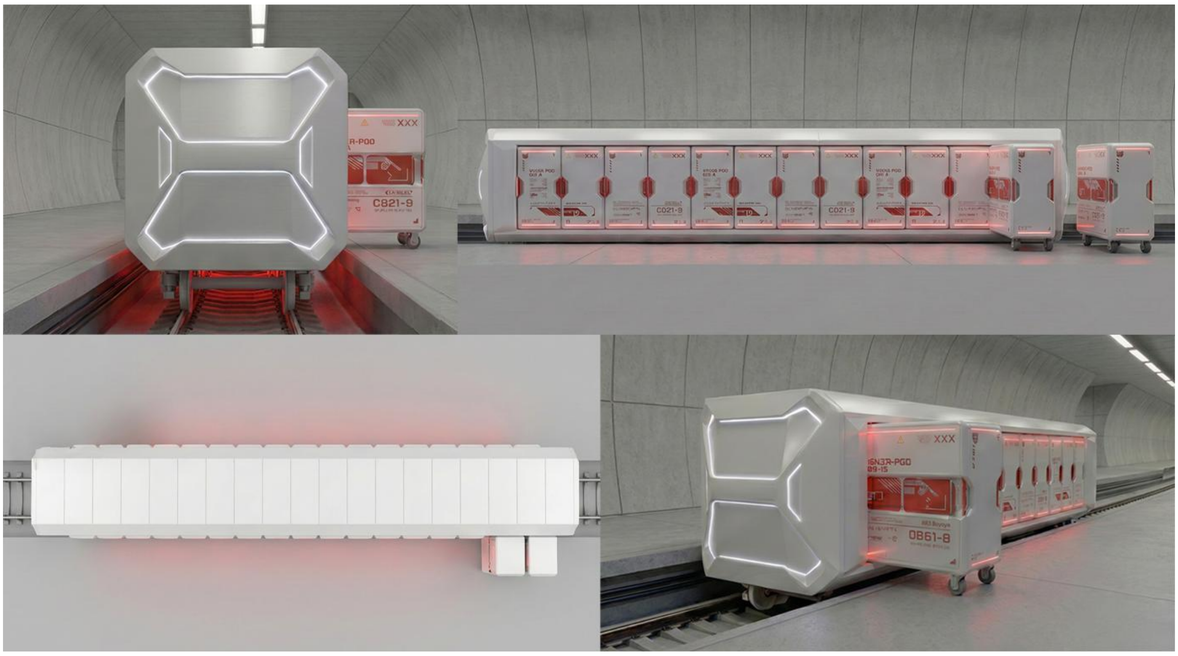

Fig. 5-6 Visualization of the possible colour variation (generated with Google Gemini)

Accent colours are applied selectively to highlight functional elements related to cargo handling and unloading. This approach supports intuitive understanding of what the unit transports and how it operates, without reliance on textual information. At the same time, the simplified colour scheme contributes to a trustworthy and approachable appearance, which is particularly important for an autonomous vehicle operating in proximity to passengers. Through this balance, the colour design reinforces the perception of the unit as a functional, autonomous, and clearly purpose-driven element of the metro system.

5.4 Dimensions

The dimensional definition of the proposed metro unit is primarily driven by functional requirements related to cargo capacity and handling. In addition to cargo-related requirements, the dimensional limits of the vehicle are defined by standardised clearance envelopes used in metro vehicle design. These envelopes specify maximum allowable dimensions to ensure safe operation within tunnels, stations, depots, and maintenance facilities. The dimensional approach therefore balances internal cargo capacity with strict external constraints imposed by existing metro infrastructure.

5.4.1 The unit

The overall dimensions of the metro unit are derived from the internal arrangement of standardized cargo boxes. The longitudinal length of the unit corresponds to the required number of boxes and their individual volume, ensuring efficient use of internal space while supporting side-based loading and unloading. This cargo-driven approach establishes the fundamental proportions of the vehicle.

The external dimensions of the unit are further constrained by predefined clearance envelopes provided in cooperation with Škoda Transportation. These envelopes define the maximum allowable width and height of the vehicle body and ensure compatibility with existing metro infrastructure. By adhering to these dimensional limits, the proposed unit can be integrated into current metro networks without requiring structural modifications to tunnels, platforms, or depots.

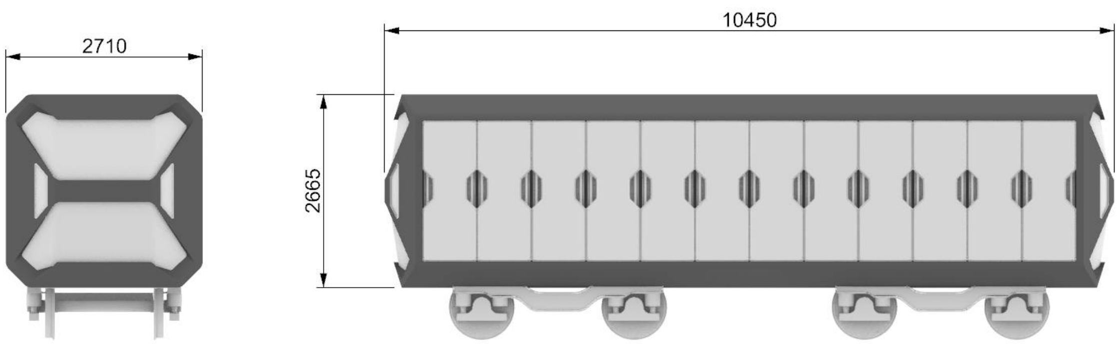

Fig. 5-7 Main dimensions of the unit (in millimetres)

5.4.2 The cargo containers

The dimensions of the cargo containers are primarily defined by the requirements of the transported goods and the intended logistics scenarios. Based on earlier research and design development, the containers are sized to accommodate typical urban freight, such as parcels, supplies for retail and gastronomy, and similar last-mile cargo types. The selected volume represents a balance between sufficient carrying capacity and the need for efficient handling within the metro environment.

In addition to cargo-related requirements, the dimensions of the containers are significantly influenced by ergonomic considerations. The height, width, and depth of the containers are adjusted to allow safe and intuitive manual handling by a single operator at platform level. The working height corresponds to natural reach zones, reducing the need for excessive bending or lifting. To further support manual unloading, each container is equipped with integrated wheels, enabling smooth horizontal movement and minimising physical strain during manipulation.

The container proportions are also adapted to the spatial constraints of the metro unit and side-based extraction system. Their geometry allows straightforward insertion and removal from the vehicle while maintaining stability during transport. Through the combination of cargo-driven sizing and ergonomic optimisation, the containers function as a key interface between automated transport and human-operated last-mile distribution.

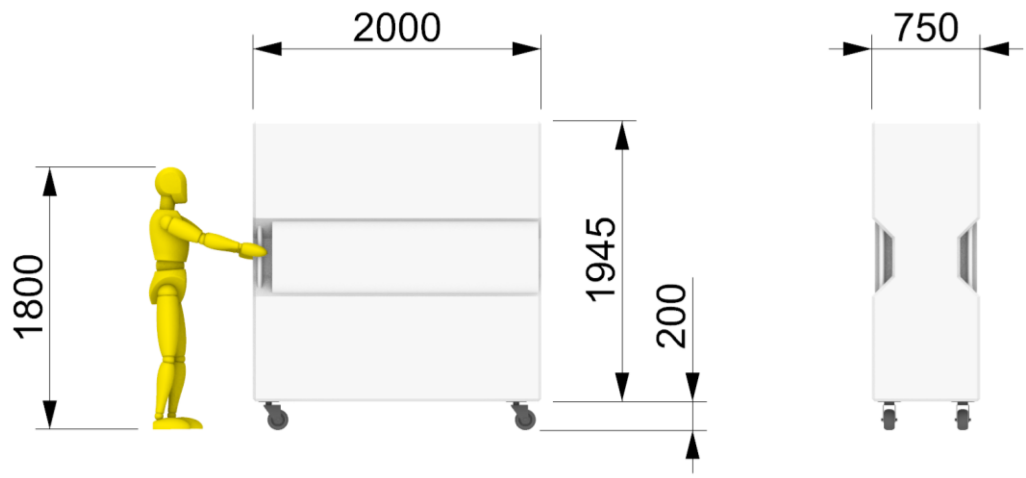

Fig. 5-8 Main dimensions of the cargo container (in millimetres)

5.5 Materials and production

The material and production strategy of the proposed system is based on established manufacturing practices used in contemporary rail vehicle production. The design intentionally relies on proven materials and joining technologies in order to ensure feasibility, durability, and compatibility with existing industrial processes. The approach reflects standard production methods applied in metro vehicle manufacturing and aligns with procedures commonly used by industrial rail vehicle manufacturers.

5.5.1 The unit

The metro unit is conceived as a welded structural assembly designed to meet the mechanical and safety requirements of rail operation. The primary load-bearing structure is based on steel or aluminium profiles, selected according to strength, weight, and fatigue resistance requirements. Welding is the dominant joining method for the main structural frame, ensuring high rigidity and long-term durability under dynamic loads typical of metro operation.

Secondary structural and exterior elements, such as body panels and access interfaces, are designed as modular components. These parts are attached using a combination of adhesive bonding, bolted joints, and riveting, depending on accessibility, maintenance requirements, and material combinations. This multi-method approach reflects standard rail vehicle production practice, where permanent joints are used for structural elements and reversible joints are applied for serviceable or replaceable components.

Surface finishes and protective coatings are selected to withstand intensive operational use and frequent cleaning, reflecting the freight-oriented nature of the unit. Compared to passenger rolling stock, interior finishes are simplified, prioritising durability and ease of maintenance over comfort-related features. The overall production concept allows the unit to be integrated into existing manufacturing workflows without requiring fundamentally new technologies or tooling.

5.5.2 The Cargo Containers

The cargo containers are designed as independent modular units optimised for repeated handling and manual manipulation. Their structural shells are primarily conceived from lightweight metal sheets or composite panels, supported by an internal frame that ensures sufficient stiffness while minimising overall weight. Material selection prioritises impact resistance, durability, and ease of cleaning, reflecting the diverse nature of transported goods.

Manufacturing of the cargo containers is based on straightforward industrial processes such as sheet metal forming, bending, and welding, combined with mechanical fastening for functional components. Adhesive bonding may be used for non-load-bearing panels to reduce weight and improve surface quality. Integrated wheels and handling elements are attached using bolted connections, allowing for replacement and maintenance over the container’s service life.

By separating container production from the main vehicle structure, the system allows containers to be manufactured, serviced, or replaced independently of the metro unit itself. This modular production approach supports scalability and flexibility, enabling adaptation of container materials or configurations to specific logistics needs without affecting the core vehicle design.

5.6 Estimated Manufacturing Costs and Production Volume

5.6.1 Cost

Exact manufacturing costs of rail vehicles are generally subject to commercial confidentiality and are not publicly disclosed by manufacturers. The cost estimation presented in this thesis is therefore based on publicly available information, including results of completed procurement procedures and tenders for metro and special-purpose rolling stock, as well as on comparisons with similar vehicle typologies. The presented values should be understood as indicative estimates reflecting typical cost structures in rail vehicle production rather than precise pricing data.

The total estimated manufacturing cost of approximately 42 million CZK per unit corresponds to a small-series, specialised metro vehicle equipped with traction systems, bogies, and an autonomous sensor package. Given the limited expected production volume - typically several units to a few dozen units per network - such cost levels are consistent with publicly reported tender outcomes for comparable rail vehicles. This estimation supports the feasibility of gradual system deployment through pilot projects and phased implementation, aligning with standard practices in contemporary metro system development.

Komponenty	Cena
Karoserie + rám + kompozitní opláštění	12 000 000 Kč
Podvozky (2×) + brzdové a tlumicí systémy	7 000 000 Kč
Trakční a elektrické systémy (měniče, výzbroj, kabeláž)	9 000 000 Kč
Autonomní senzorový paket (LiDAR, radar, kamery) + výpočetní jednotka	4 000 000 Kč
Interiér + úchyty pro boxy + podlahové moduly	3 000 000 Kč
Nákladní boxy (12 ks) – hliník + plasty + zámky	1 200 000 Kč
Integrace, montáž, testování, validace, certifikace	6 000 000 Kč
Cena celkem (výrobní)	**42 200 000 Kč**

Tab. 5-1 Table of approximate cost per unit (in CZK)

5.6.2 Production

Given the specialised nature of a metro-based freight unit and the fact that deployment would most likely proceed through pilot operation and gradual scaling, the expected production volume can be characterised as small-series manufacturing rather than mass production. A realistic estimate is that production would range from approximately 5–20 units per year for a single project or city network, depending on the level of system adoption and infrastructure readiness. In an expanded scenario involving multiple cities or parallel contracts, overall annual output at the manufacturer level could reach several dozen units per year, while still remaining within a low-volume rail-vehicle production model typical for specialised rolling stock.

6 FINAL DESIGN

The final design builds upon the previously developed preliminary proposal and further refines it into a more detailed and coherent solution. Based on the conclusions established during the research, concept development, and evaluation stages, the proposal is expanded through detailed consideration of the system structure, vehicle design, ergonomics, construction principles, graphical identity, and operational functionality. The following chapter therefore presents the final proposed system and its individual components in their developed form.

6.1 The system

The proposed freight transport system is based on the utilisation of existing metro infrastructure as a logistics network operating independently from conventional road-based urban freight transport. The system is designed around autonomous metro units transporting standardized cargo boxes between metro depots located at the periphery of the city and selected metro stations within the urban centre. The stations are either the final destination of the freight, or the freight is further redistributed through autonomous delivery system. The proposed solution therefore introduces a new logistical layer into the existing metro infrastructure without requiring the construction of a dedicated underground freight network.

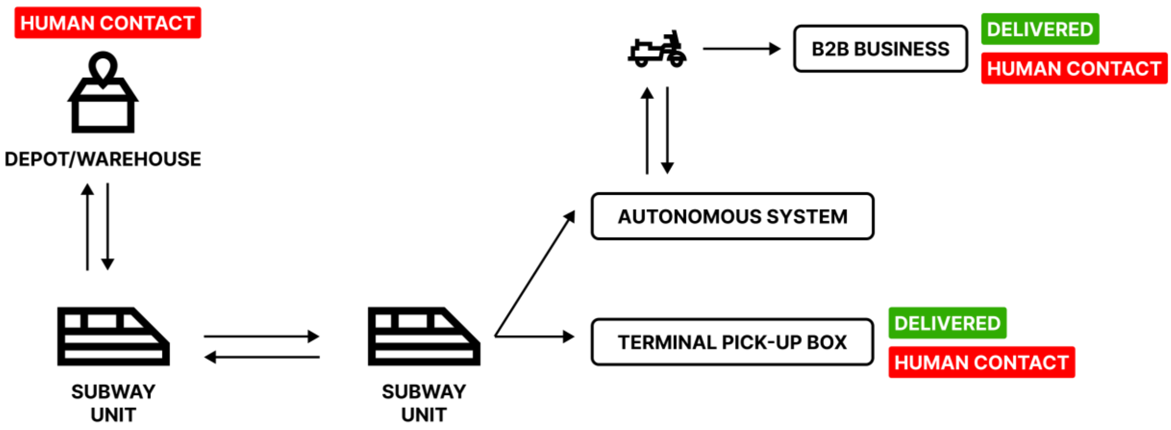

Fig. 6-1 Flow chart

The operational cycle of the system begins within existing metro depots. These depots are not conceived as newly built logistics facilities, but rather as current metro maintenance and storage depots already integrated into the metro network. In many cities, such depots are located near existing industrial zones, warehouses, and large-scale logistics centres situated at the outskirts of urban areas. This spatial relationship creates favourable conditions for future integration with urban freight transport systems.

Within the long-term vision of the proposed system, metro depots could gradually evolve into multimodal logistics nodes directly connected to regional freight infrastructure. However, the proposed system does not solely depend on such future transformation. Its primary advantage lies in the ability to operate using the existing depot infrastructure already present within contemporary metro systems.

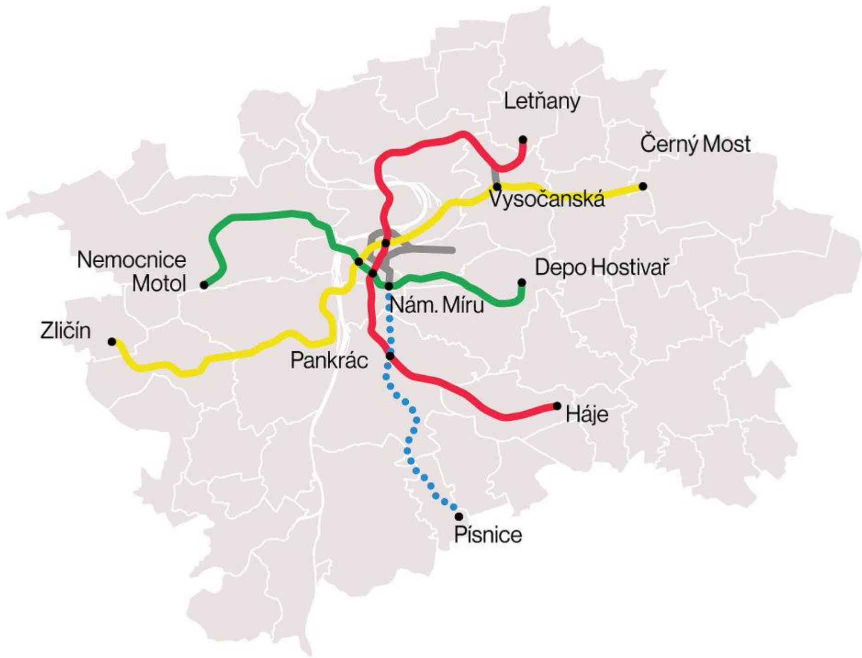

Fig. 6-2 Metro depots in Prague [45]

After loading, the autonomous metro units enter the standard metro network and operate using existing metro tracks and stations. The system does not require dedicated freight-only stations. Instead, the freight units utilize existing metro stations as their final delivery points, allowing integration into current urban transport systems with minimal infrastructural intervention. In the case of autonomous unloading, however, an additional handling zone would need to be implemented either before or after the station platform. This dedicated area would allow the integration of autonomous unloading technologies without interfering with passenger movement or regular station operation. The principles of autonomous unloading are further described in Chapter 6.1.1 Autonomous Unloading.

The proposed metro unit is designed to transport twelve standardized cargo boxes, arranged in two groups of six boxes positioned along both sides of the vehicle body. Each side contains two sections consisting of three cargo boxes. This bilateral configuration is necessary because the accessible side of the metro unit changes depending on the direction of travel and the platform configuration of individual metro stations. The symmetrical arrangement therefore ensures that unloading operations can be performed regardless of which side of the vehicle is aligned with the station platform. These cargo boxes represent the primary logistical element of the entire transport system and function as independent modular freight units. Their dimensions, handling logic, and ergonomic principles are further described in Chapter 6.4 Ergonomics. The number of transported boxes was determined through earlier research focused on the required freight volume within medium-sized Central European metro systems, where the average number of stations per metro line is approximately twenty. Within this operational framework, two loaded metro units are considered sufficient to service an entire metro line during one circulation cycle. For example, Prague Metro Line C currently consists of twenty stations, which corresponds to the assumed operational model of the proposed system.

At the same time, the system allows the implementation of longer metro units with increased cargo capacity. A secondary vehicle configuration transporting eighteen cargo boxes is therefore considered as an alternative solution for cities operating longer metro lines or requiring increased freight capacity. This alternative configuration is further described in Chapter 6.1.3 Alternative Solutions.

The operational circulation of the system is based on alternating intervals between loaded and empty metro units. During one operational interval, a loaded unit arrives at the station and delivers cargo boxes intended for unloading. During the following interval, an empty collection unit arrives and receives empty cargo boxes, return shipments, or reverse-logistics cargo generated during the unloading process. At the end of each circulation cycle, the originally loaded unit becomes the empty collection unit, while the previously empty unit returns to the depot carrying empty cargo boxes intended for refilling and redistribution. This circulation principle establishes a continuous logistical loop connecting metro depots with the urban station network while maintaining uninterrupted freight operation throughout the metro system.

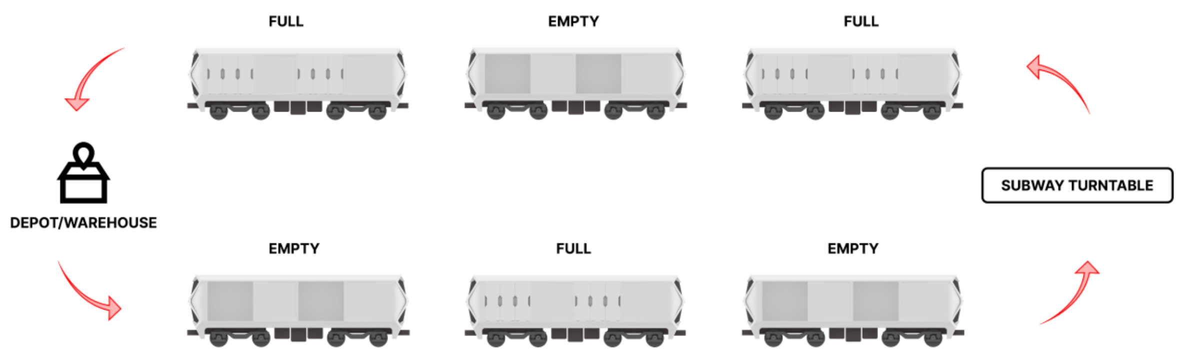

Fig. 6-3 Flow scheme of collecting and delivering units

Two different unloading principles are proposed within the system framework. The first unloading method is based on manual handling directly at existing station platforms and is intended for B2C parcel distribution only. In this scenario, the metro unit stops at a conventional passenger platform, where operators manually extract individual cargo boxes from the side of the vehicle. For each platform there will be only one box at a time. The contents of these boxes are subsequently transferred into parcel lockers or pickup boxes integrated directly into the station environment. Within this model, the metro station effectively becomes the final delivery point of the shipment. The system is particularly suited for e-commerce logistics services such as Alza, Amazon, Zásilkovna, and similar parcel-based distribution models. The principles of manual unloading are further described in Chapter 6.1.2 Manual Operation.

The second unloading method is based on autonomous cargo handling intended primarily for larger-scale and repetitive logistics operations. In this scenario, unloading takes place outside the passenger platform area within a dedicated handling zone positioned either before or after the station. This additional infrastructural space allows the implementation of automated unloading technologies. Multiple cargo boxes can therefore be unloaded simultaneously without direct human interaction. The cargo is subsequently transferred to additional autonomous delivery systems responsible for the final stage of urban distribution. Compared to manual unloading, this approach enables significantly higher operational efficiency and reduced station handling times but requires additional infrastructural integration within selected metro stations. The autonomous unloading process is further described in Chapter 6.1.1 Autonomous Operation.

By combining existing metro infrastructure with interval-based autonomous freight circulation and two complementary unloading strategies, the proposed system establishes a scalable framework capable of supporting both current and future urban logistics requirements. The system allows immediate implementation through manually operated logistics processes while simultaneously creating conditions for the gradual introduction of increasingly autonomous freight transport technologies within contemporary metropolitan environments.

6.1.1 The autonomous option

The autonomous unloading principle represents the most technologically advanced operational mode of the proposed freight transport system. This system is designed for fully automated cargo transfer without direct human interaction within the metro infrastructure. The autonomous unloading mode is primarily intended for repetitive and high-volume B2B logistics operations, such as supplying restaurants, retail facilities, shopping centres, hotels, or other urban service infrastructure requiring regular freight distribution.

The proposed autonomous operation is primarily intended for off-peak and night-time metro operation. During these periods, metro systems typically operate with lower passenger density and increased network capacity, creating more favourable conditions for autonomous freight circulation and automated unloading procedures. Night-time operation also aligns with the logistical requirements of B2B supply chains, where deliveries often take place before opening hours to avoid interference with daytime customer activity and urban traffic.

Unlike the manual unloading system operating directly at passenger platforms, autonomous unloading requires the implementation of a dedicated handling zone positioned either before or after the station. This additional infrastructural space allows the unloading process to operate independently from passenger circulation and standard station activities. The metro unit therefore does not unload directly at the passenger platform but instead enters a controlled autonomous unloading section integrated into the station infrastructure.

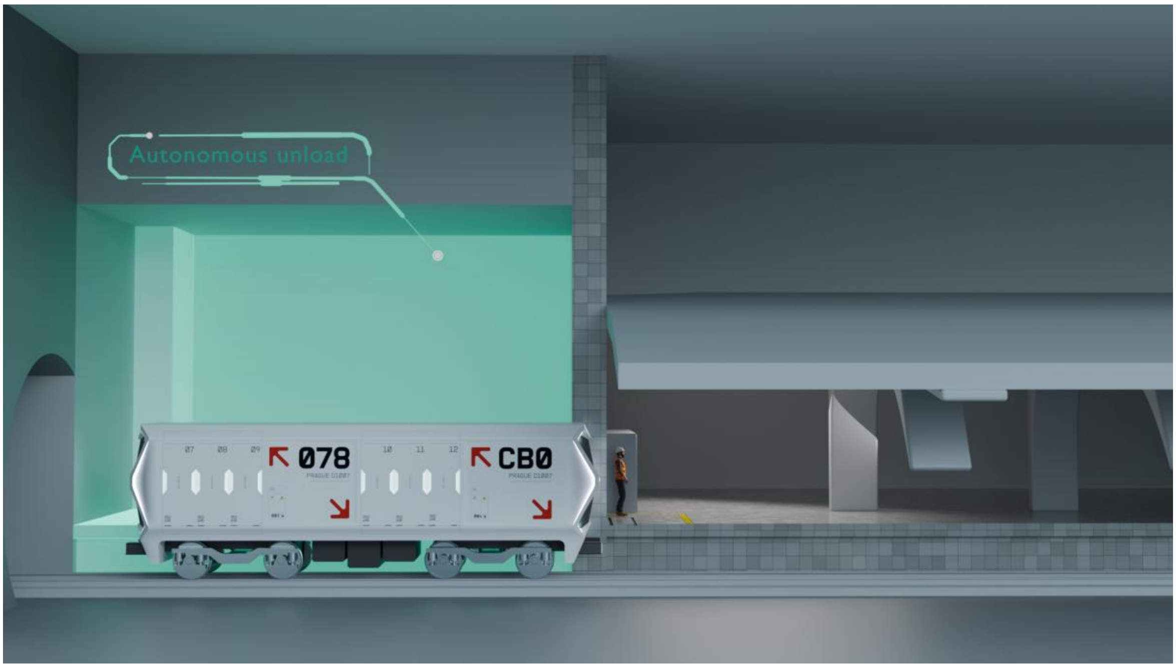

Fig. 6-4 Autonomous unloading zone before/after station

The unloading process is based on principles derived from automated warehouse logistics and autonomous truck-loading systems, particularly technologies like the previously referenced Q-loader [44] system discussed in Chapter 5 Preliminary design. Rather than relying on manual extraction, cargo boxes are transferred automatically between the metro unit and the station logistics infrastructure using guided horizontal handling systems.

Inside the metro unit, the cargo boxes are arranged along both sides of the vehicle body in groups of three. These groups do not form fixed structural modules, as each cargo box remains an independent unit. The grouping principle instead reflects the operational logic of the autonomous unloading system and the intended scale of urban B2B logistics operations.

The autonomous unloading system can handle one, two, or three cargo boxes depending on the specific delivery requirements of an individual station. Three boxes represent the maximum unloading capacity intended for a single autonomous unloading cycle. This capacity was defined based on earlier logistical research, where three cargo boxes were considered an appropriate volume for supplying a single urban business operation, such as a restaurant, café, or retail unit, during one delivery interval.

The arrangement of boxes into groups of three additionally improves unloading efficiency. The autonomous handling process requires approximately the same operational time regardless of whether one or three cargo boxes are extracted. The grouped configuration therefore increases the transported freight volume without significantly increasing unloading time.

All cargo boxes are equipped with integrated wheels. These wheels primarily serve manual manipulation during depot loading procedures and manual unloading scenarios described in Chapter 6.1.2 Manual Operation. During autonomous unloading, however, the boxes are not moved on their wheels. Instead, the wheel system is designed to temporarily retract into the body of the cargo box to allow interaction with the automated unloading mechanism.

The autonomous transfer process begins once the metro unit enters the unloading zone and stops in its designated unloading position. Integrated flaps positioned both above and below the cargo boxes subsequently open, creating access channels for the autonomous handling mechanism. From the station infrastructure, a set of loading rails or shuttle platforms extends beneath the cargo boxes similarly to warehouse pallet-handling systems.

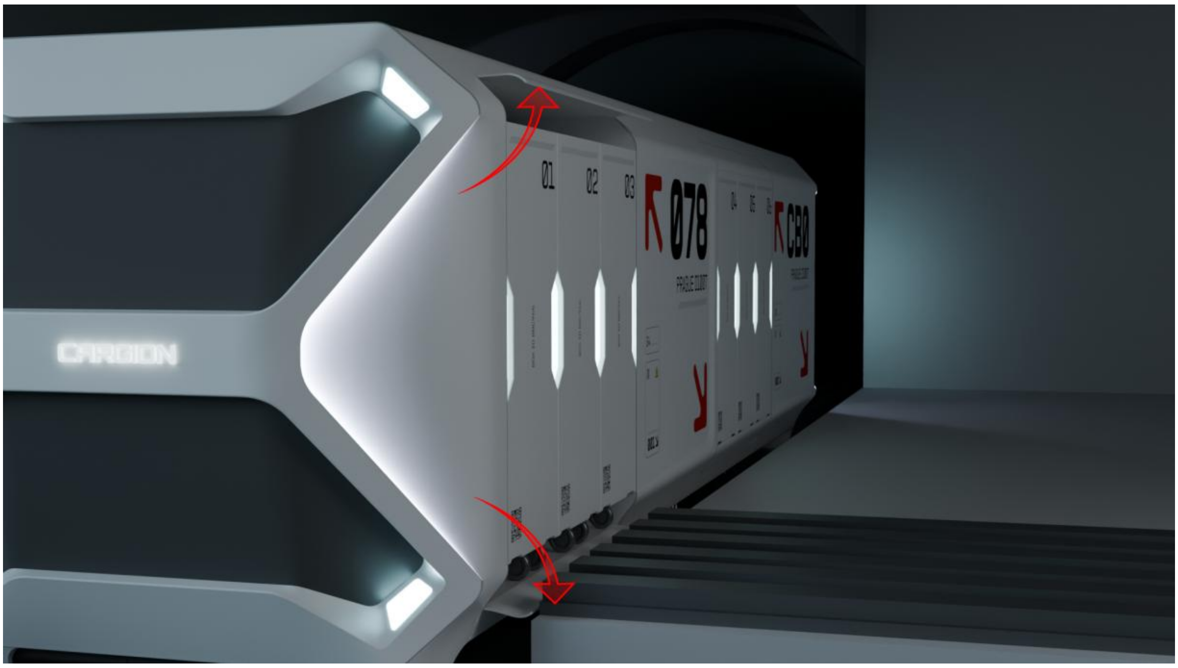

Fig. 6-5 Flaps opening

As the rails move underneath the cargo boxes, they mechanically press against the first set of integrated wheels. This pressure activates the retractable wheel mechanism, causing the wheels to fold into the internal structure of the cargo box. The movement of the first wheel pair subsequently triggers the retraction of the second wheel pair, allowing the entire cargo box to transition from rolling support into a stable transfer position.

Fig. 6-6 Q-loader rails moving underneath the cargo boxes

Once the wheels are retracted, the loading rails slightly elevate the cargo box above the vehicle floor. The box can then be horizontally transferred using conveyor-based or guided shuttle movement directly into the autonomous station logistics infrastructure. This approach allows highly controlled cargo manipulation while minimizing vertical movement inside the metro environment.

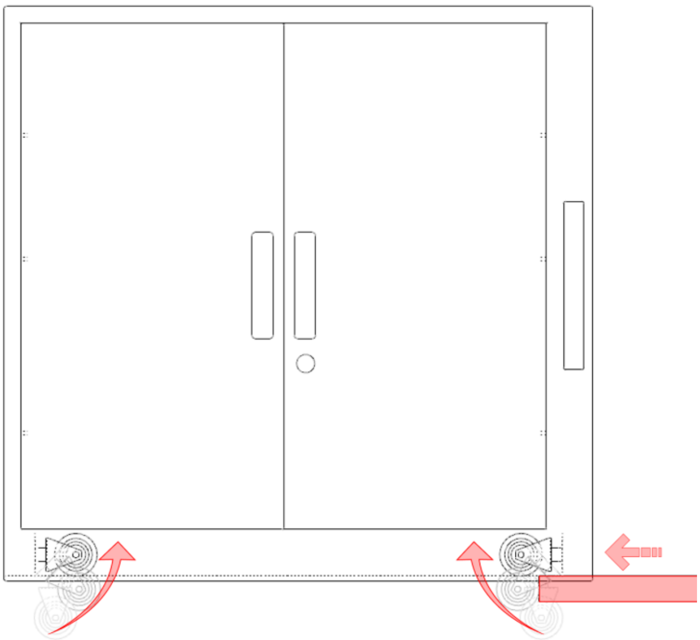

Fig. 6-7 Cargo box wheel mechanism

After extraction from the metro unit, the cargo boxes enter a secondary autonomous logistics layer operating similarly to contemporary automated warehouse systems. Inside this infrastructure, the boxes can be repositioned, sorted, buffered, or prepared for further transport using automated handling technologies derived from industrial storage and retrieval systems.

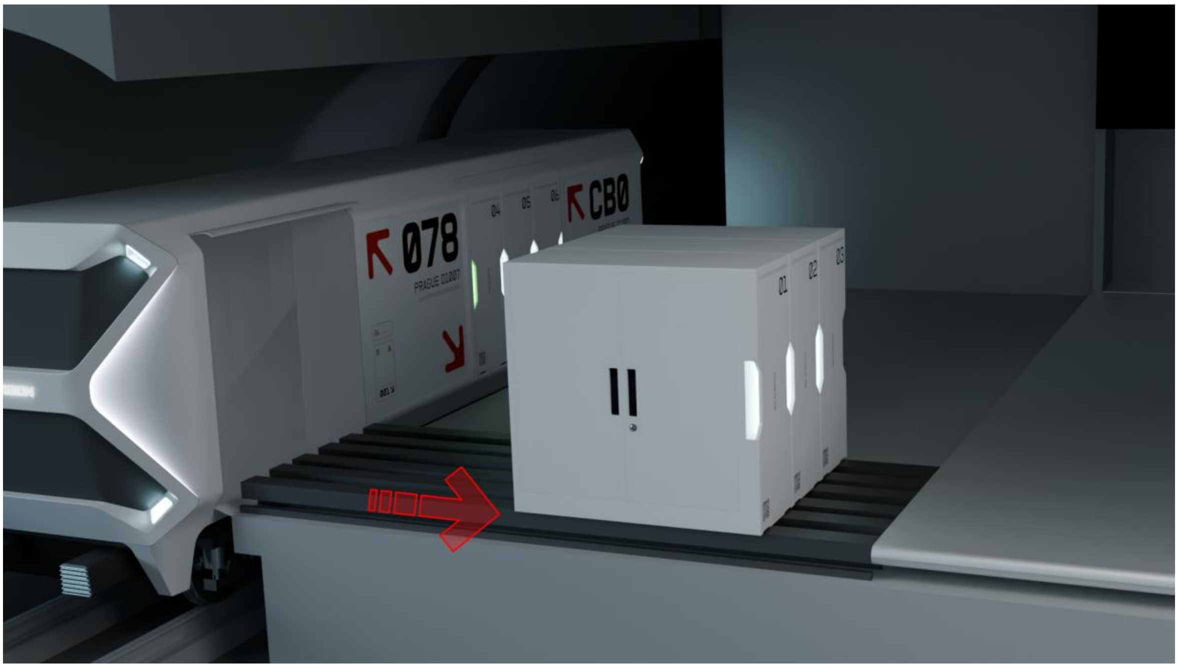

Fig. 6-8 Automated handling of the cargo boxes

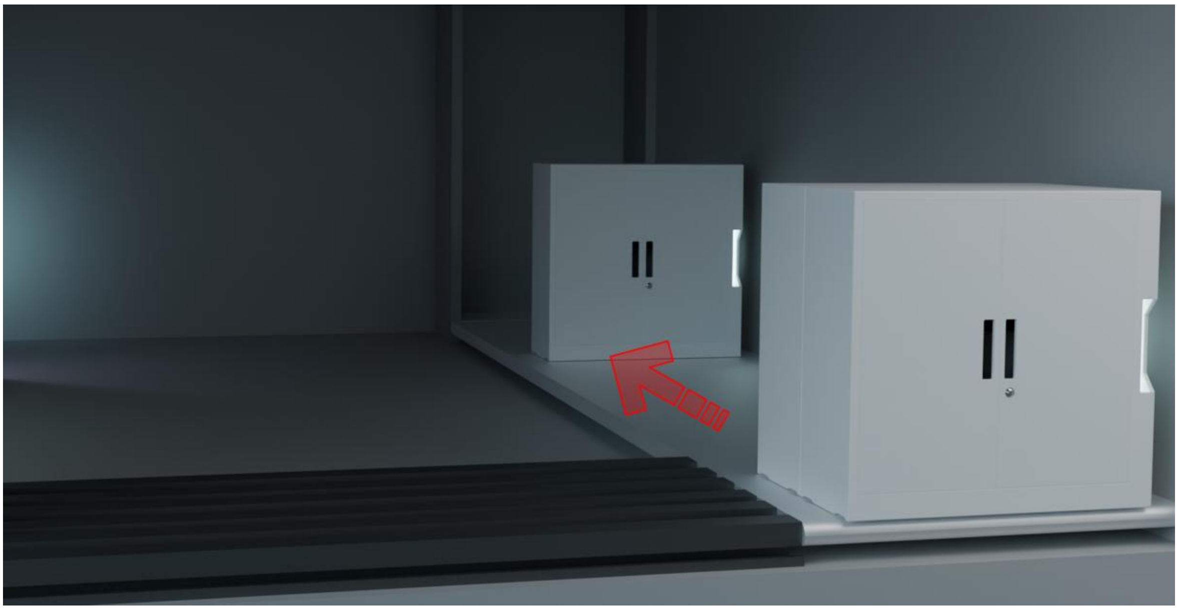

Fig. 6-9 Automated handling of the cargo boxes

An important aspect of the system is its ability to manipulate cargo both horizontally and vertically. Following unloading, the cargo boxes are transported through automated lift platforms or vertical shaft systems connecting the underground metro level with the urban surface. This allows the metro infrastructure to function as a fully integrated underground logistics layer directly connected to surface-level autonomous distribution.

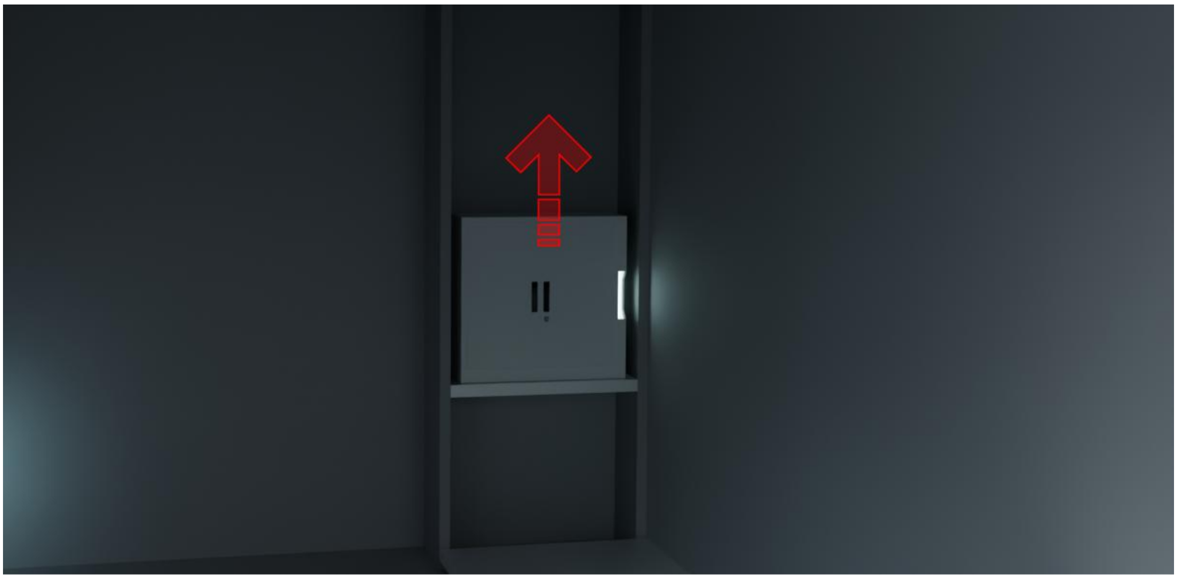

Fig. 6-10 Vertical cargo lift from metro level to surface

Once transported to the surface, the cargo boxes are transferred onto smaller autonomous delivery vehicles responsible for the final stage of the logistics chain. These vehicles operate similarly to existing AGV and autonomous last-mile delivery systems and provide short-distance freight distribution between the metro infrastructure and the final urban destination.

Fig. 6-11 Concept of autonomous last-mile delivery vehicle

Through the combination of autonomous metro transport, warehouse-based unloading technologies, vertical cargo transfer systems, and autonomous last-mile delivery vehicles, the proposed system establishes a fully autonomous urban logistics chain operating independently from conventional road-based freight transport. The system simultaneously minimizes the need for human interaction, reduces surface-level delivery traffic, and increases the operational efficiency of urban freight distribution within dense metropolitan environments.

6.1.2 The manual option

The manual unloading principle represents the simplest and most immediately implementable operational mode of the proposed freight transport system. Unlike the autonomous unloading approach described in Chapter 6.1.1 The autonomous option, this method does not require dedicated underground logistics infrastructure or autonomous unloading zones positioned outside the station. The unloading process takes place directly within existing metro stations and is therefore primarily intended as the first realistic implementation stage of the proposed freight transport system.

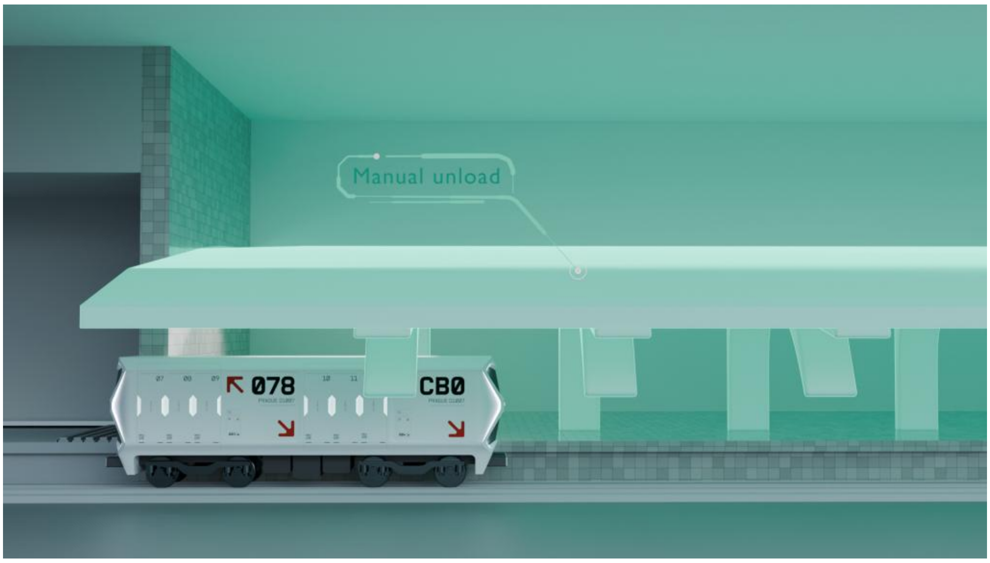

Fig. 6-12 Metro station

The manual unloading mode is primarily designed for B2C logistics operations associated with parcel distribution services such as Alza, Amazon, Zásilkovna, and similar e-commerce delivery providers. Within this operational model, metro stations function as final pickup points where shipments are manually transferred into parcel lockers or pickup boxes integrated directly into the station environment.

The unloading process is based on a simplified rail-guiding system positioned at the beginning of the station platform. During arrival, the autonomous metro unit automatically aligns itself with these unloading rails so that the selected cargo box is positioned precisely against the unloading interface.

Fig. 6-13 Metro unit aligned with platform unloading rails

Once the vehicle stops, the lower flap integrated beneath the cargo box opens and creates a small bridging surface between the metro unit and the station platform. Unlike the autonomous unloading system, where both upper and lower flaps are required for the insertion of autonomous loading rails, the manual unloading mode utilizes only the lower flap. This flap simultaneously uncovers the wheels of the cargo box and creates a continuous transition surface allowing the wheels to smoothly enter the platform rail system.

Fig. 6-14 Lower flap opening

The cargo box is subsequently pulled manually by the operator directly into the guiding rails integrated into the platform. Immediately after the cargo box is extracted, the metro unit is free to continue towards the next station, significantly reducing stationary time within the metro network and improving operational efficiency.

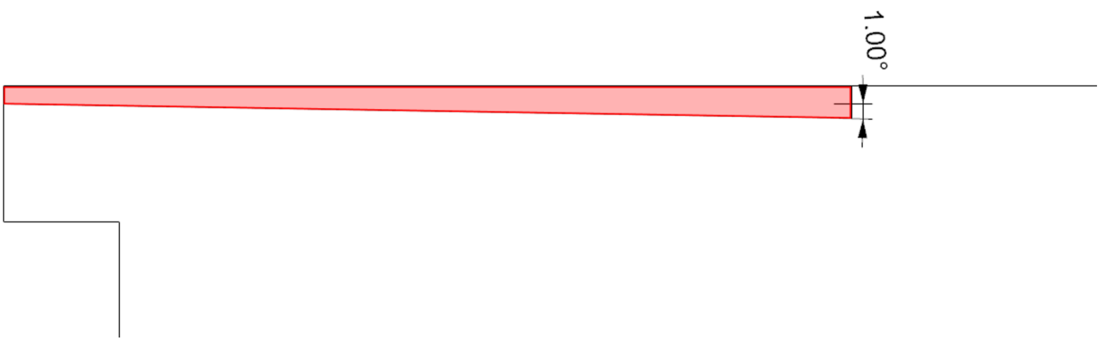

Fig. 6-15 Inclined unloading rail, side view

The unloading rails positioned on the platform are intentionally designed with a slight incline of approximately one degree directed towards the platform interior. This inclination serves both ergonomic and safety-related purposes. When the cargo box is fully loaded, its higher weight naturally stabilizes the box inside the rail system and reduces the risk of unintended movement back towards the metro track area. The inclined rails therefore create passive mechanical resistance preventing accidental rolling or uncontrolled motion of the cargo box.

At the same time, once the cargo box has been emptied, its significantly lower weight allows the operator to easily push the box back against the slight incline into the arriving empty collection unit during the following operational interval. The inclined rail system therefore simultaneously improves handling safety and reduces physical strain during reinsertion of empty cargo boxes.

Fig. 6-16 Manual unloading operation at metro platform

Throughout the entire unloading procedure, the cargo box remains guided within the rail system, meaning the operator performs only a controlled pulling and pushing motion along a single axis. The handling process therefore avoids lifting, rotation, or multidirectional manipulation, significantly improving ergonomics and operational simplicity.

After extraction from the metro unit, the cargo box remains positioned within the unloading rails while its contents are manually redistributed into parcel lockers or pickup boxes located directly on the station platform. Once emptied, the cargo box remains inside the guiding system until an empty collection unit arrives during the next operational interval.

An important aspect of the manual unloading system is passenger safety and operational separation from public movement within the station environment. The unloading zone is visually distinguished from the rest of the platform through floor markings, warning graphics, and safety communication elements preventing passengers from occupying the unloading area during operation.

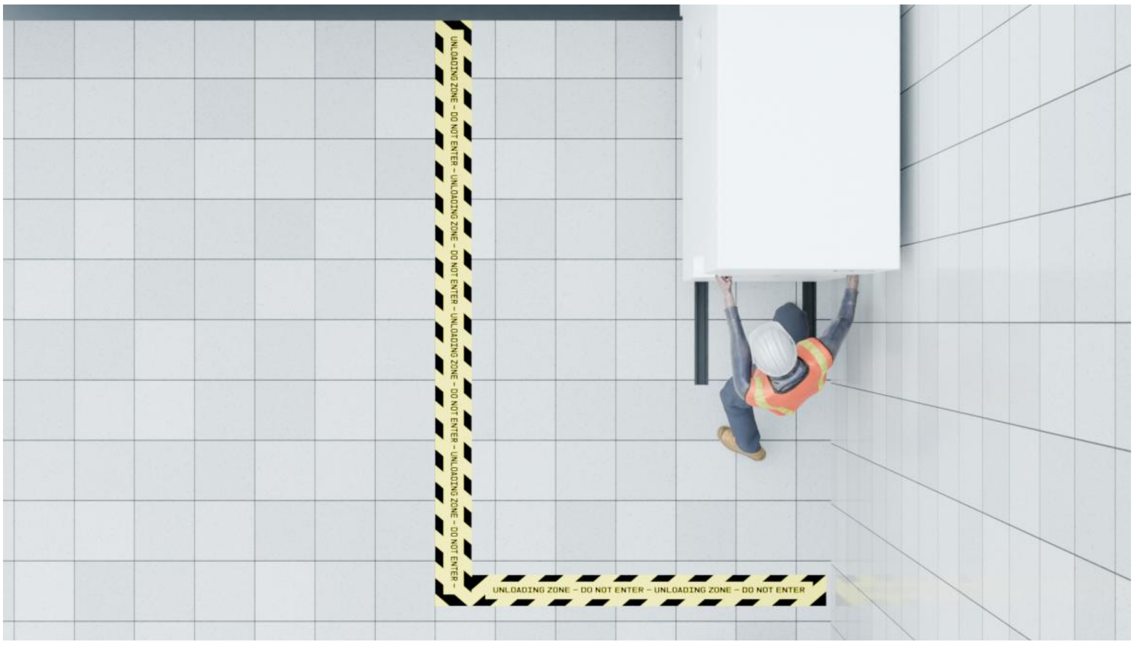

Fig. 6-17 Unloading zone graphics

In addition, the proposed system assumes the use of platform screen doors similarly to those already implemented in many contemporary metro systems. These doors remain closed during standard station operation and open only during the unloading procedure. Once the metro unit arrives, the platform doors open exclusively at the unloading interface, allowing the operator to extract the cargo box. Immediately after extraction and departure of the metro unit, the doors close again.

Fig. 6-18 Platform screen door opening during unloading

Fig. 6-19 Platform screen door closing after unloading

This system prevents passengers from entering the track area, eliminates direct physical access to the autonomous freight unit, and significantly increases operational safety within the station environment. At the same time, the controlled unloading interface improves public acceptance of autonomous freight transport within existing metro infrastructure by clearly separating passenger and logistics operations.

The manual unloading principle establishes a realistic, economically achievable, and operationally simple first implementation stage for the proposed freight transport system. By relying on existing metro infrastructure, minimizing technological complexity, and simplifying operator interaction, the system creates a scalable logistical framework capable of immediate integration into contemporary metropolitan environments. More detailed information regarding the construction and functionality of the unloading associated mechanisms is further described in Chapter 6.2.2 Functional Parts.

6.1.3 Alternative solutions

In addition to the primary operational scenarios described in the previous chapters, the proposed freight transport system also allows several alternative development directions and future system extensions. These alternatives are not considered part of the current final design solution but represent potential adaptations of the system responding to different infrastructural, operational, or technological conditions. The flexibility of the proposed metro unit and the modular logic of the freight transport system make such future modifications technically achievable without fundamentally changing the core system architecture.

Extended Metro Unit Configurations

One of the most significant scalable aspects of the proposed system is the possibility of modifying the overall length of the metro unit and the number of transported cargo boxes. The current final proposal is based on a configuration transporting twelve standardized cargo boxes, which was identified as the most suitable balance between vehicle dimensions, operational efficiency, and compatibility with typical Central European metro systems.

However, the vehicle architecture allows the implementation of longer metro units with increased freight capacity. Such extended variants may become advantageous in cities operating larger metro networks, longer metro lines, or significantly higher freight volumes. Within this logic, the number of cargo boxes should ideally remain divisible by three due to the unloading principles described in Chapter 6.1.1 Autonomous Operation. The grouping of cargo boxes into sets of three corresponds to the operational logic of autonomous unloading cycles and typical B2B freight distribution volumes.

Fig. 6-20 Extended unit

For example, an extended metro unit transporting eighteen cargo boxes represents a realistic alternative configuration for future implementation scenarios. The modularity of the proposed vehicle architecture therefore enables the system to adapt to different metropolitan conditions without requiring the development of entirely new vehicle concepts.

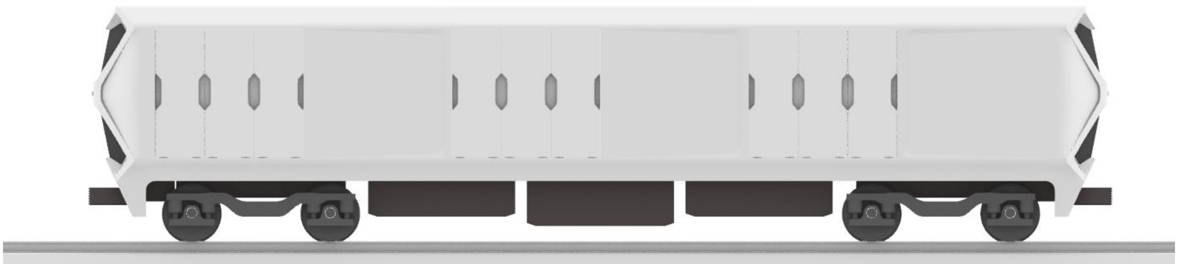

Fig. 6-21 Extended unit, side view

Dedicated Autonomous Freight Track

A significantly more futuristic development scenario involves the implementation of a dedicated metro track intended exclusively for autonomous freight operation. In this configuration, the freight transport system would no longer share operational capacity with conventional passenger metro traffic but would instead function as a partially independent underground logistics layer integrated alongside the existing metro infrastructure.

This additional track could be positioned parallel to existing metro lines and would operate entirely autonomously without direct interaction with passenger transport systems. Such an approach would allow uninterrupted freight circulation, higher transport frequency, and fully autonomous unloading procedures without operational limitations caused by passenger service schedules.

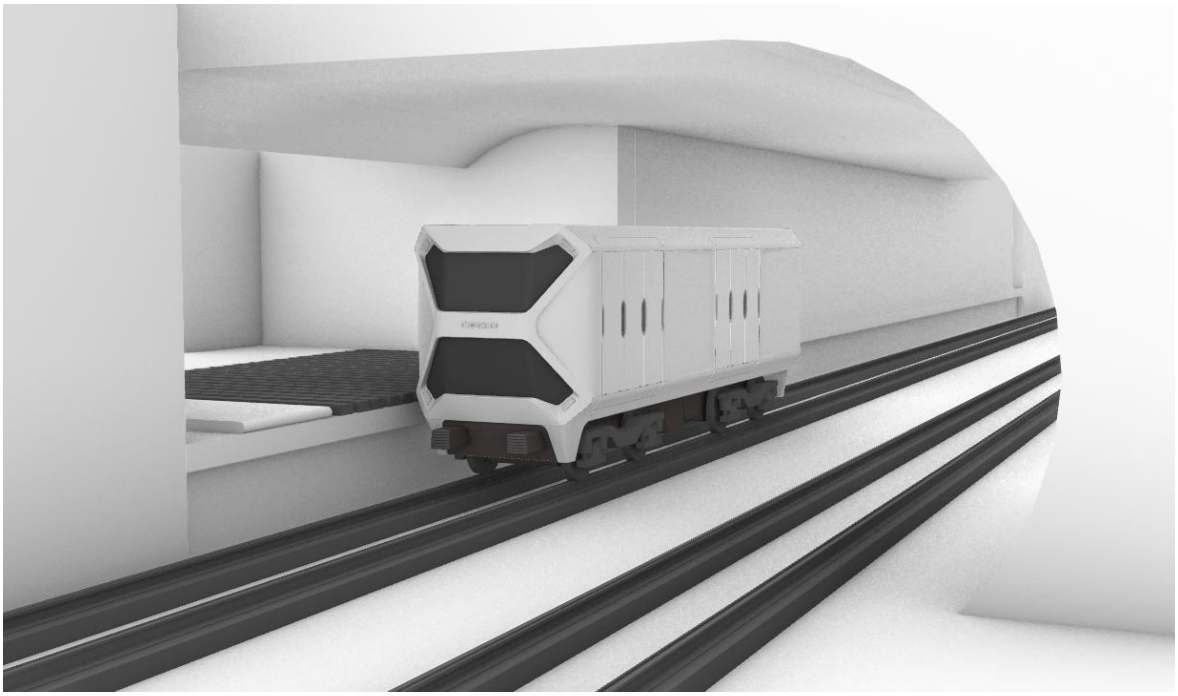

Fig. 6-22 Concept of dedicated freight metro track

Although this scenario would require substantial infrastructural investment and is therefore not considered part of the current proposal, it illustrates the long-term scalability potential of the system. The concept demonstrates how the proposed freight transport framework could gradually evolve from a shared metro infrastructure solution into a fully autonomous urban logistics network operating independently from conventional passenger transport.

Indirect B2C Loading Infrastructure

Another potential intermediate solution concerns the handling of B2C parcel distribution within metro stations. In the current proposal, manual unloading takes place directly at the station platform, where cargo boxes are manually emptied into parcel lockers positioned within the terminal environment.

An alternative approach could relocate the loading process outside the passenger platform area while preserving standard user interaction inside the station. In this scenario, the pickup boxes would remain accessible from the terminal interior for end users, but their rear service side would extend into a separate logistics corridor positioned behind the station wall or within a dedicated technical space adjacent to the platform.

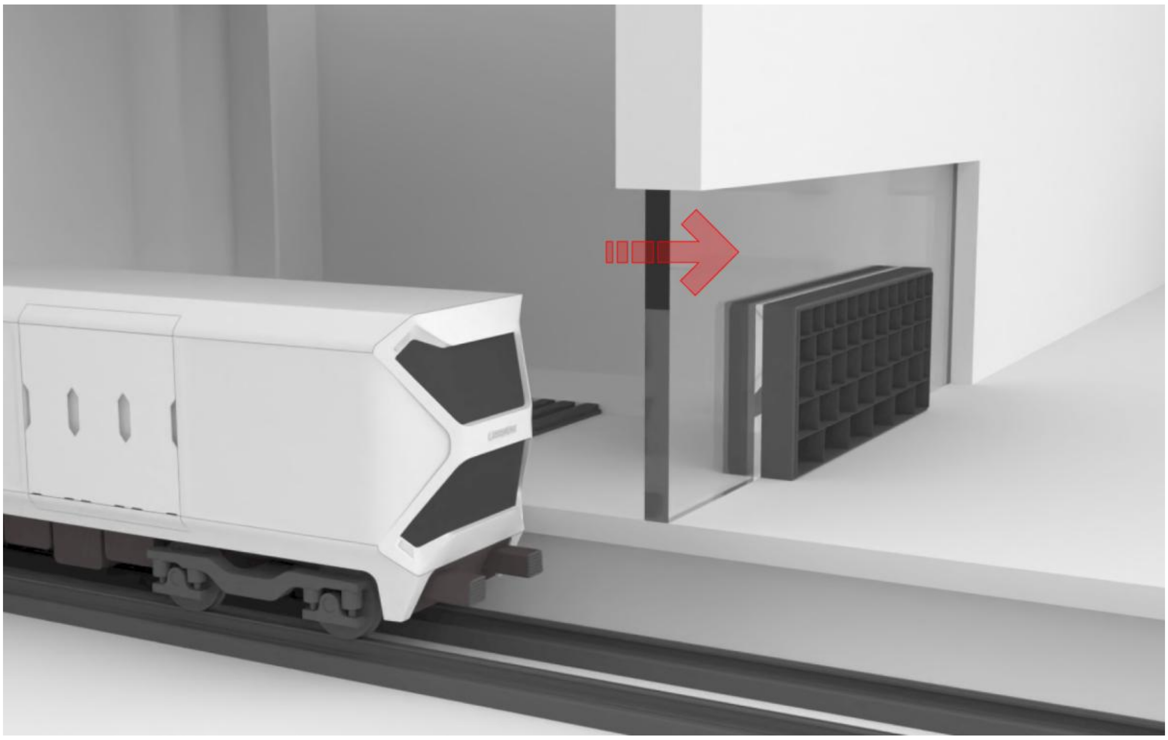

Fig. 6-23 Rear-loaded pickup box system integrated into station wall

Cargo boxes delivered by the metro unit would therefore be unloaded within this separated logistical area rather than directly on the passenger platform. Operators or autonomous systems could refill the pickup boxes from the rear side without interfering with passenger circulation inside the terminal. From the perspective of end users, the pickup process would remain identical to contemporary parcel locker systems, while the logistical operations themselves would become spatially separated from public station areas.

This intermediate solution represents a potential transition stage between fully manual unloading and fully autonomous freight operation. It simultaneously improves passenger safety, reduces visual and operational interference within the station environment, and creates more favourable conditions for future automation of B2C logistics processes.

6.2 Shape design

The final shape design of the proposed metro unit is based on a combination of functional requirements, autonomous operation, and the visual language of contemporary rail vehicles. The design was developed in cooperation with Škoda Group and partially follows the form language currently used in the company's transportation products. This influence can be seen mainly in the use of sharper geometric transitions, faceted surfaces, and a relatively simple overall surface treatment. The final form combines technically defined geometry with visually clean surfaces, creating a shape language close to contemporary industrial rail vehicle design.

Fig. 6-24 Perspective view of the metro unit

The overall shape of the unit is directly derived from its function. Unlike conventional metro vehicles, the proposed unit is not designed for passenger transport but exclusively for the transportation of cargo boxes. The form therefore reflects its technical and logistical purpose. The proportions of the body, side surfaces, and overall geometry are defined primarily by the arrangement and unloading of the cargo boxes described in previous chapters.

The final design intentionally communicates the character of an autonomous and highly efficient transport system. The unit does not visually invite passengers to enter or interact with it as with a conventional metro vehicle. Instead, the design creates the impression of a functional autonomous machine operating continuously in the background of the city infrastructure. The visual language communicates efficiency, precision, and reliability, showing passengers that this system represents the reason why their deliveries and online orders arrive quickly and on time.

At the same time, the unit still operates within public urban space and existing passenger metro infrastructure. For this reason, the design avoids an overly aggressive industrial appearance despite its technical purpose. The front geometry and surface treatment maintain a controlled and visually approachable character suitable for operation within human-centred environments.

An important aspect of the shaping process was also the futuristic nature of the proposed transport concept itself. Autonomous freight transport integrated into metro infrastructure represents a future-oriented logistics scenario, and this is reflected in the final design. Simplified surfaces, integrated transitions, reduced visual complexity, and the absence of traditional passenger-related elements create a visual identity positioned between contemporary rail vehicle production and speculative future urban transport systems.

The resulting shape therefore functions as a combination of technical railway design, autonomous logistics infrastructure, and future-oriented urban mobility.

Fig. 6-25 Perspective view of the metro unit

6.2.1 Face design

The front face is primarily formed by two darker plastic surfaces positioned in the upper and lower sections of the unit. The upper surface partially reflects the typical position and proportion of a front windshield commonly found on conventional non-autonomous metro vehicles. This reference creates a subtle visual connection to traditional railway vehicle architecture and communicates the origin of the vehicle typology from which the proposed unit is derived. The same shape is then symmetrically mirrored into the lower section of the front face. This symmetry removes the visual hierarchy typically associated with driver-operated vehicles and gives the unit a more autonomous and machine-like appearance. Through this approach, the front design visually communicates that the vehicle no longer relies on a human driver while still remaining connected to familiar railway design principles.

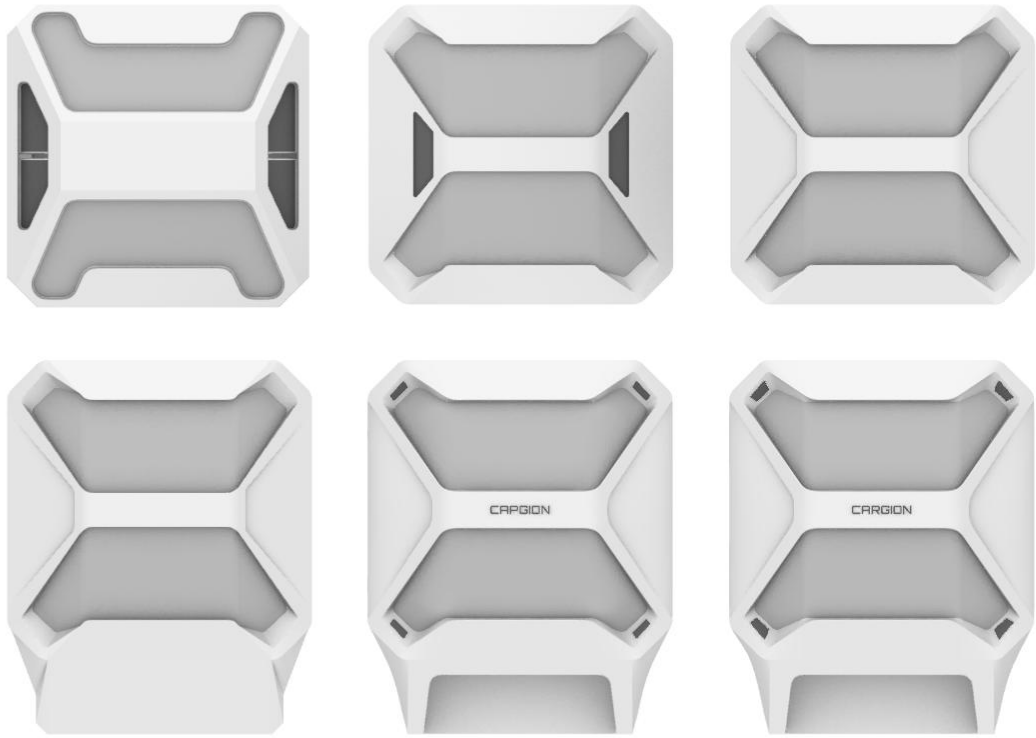

Fig. 6-26 The evolution of the front shape

The shaping of these darker front surfaces simultaneously creates a larger cross-shaped composition across the face of the unit. This cross motif references structural patterns commonly visible on historical freight train wagons as well as on contemporary luggage, transport cases, and products intended for the protection and transportation of cargo.

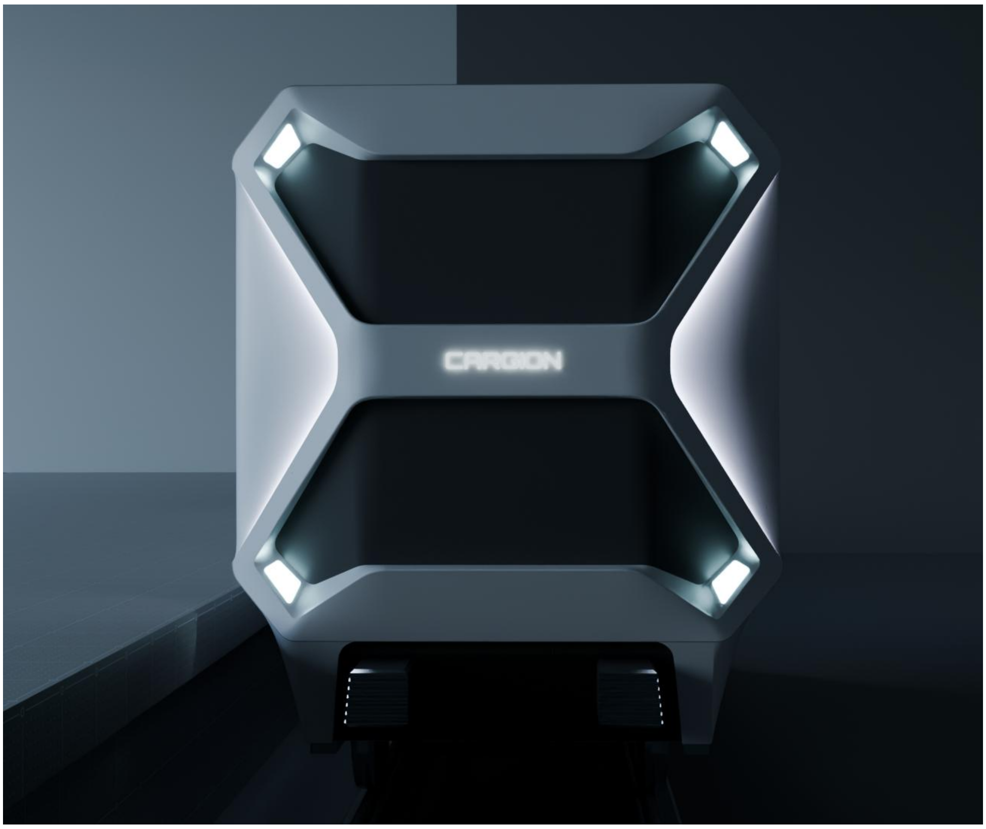

Fig. 6-27 Final face design

Fig. 6-28 Final face design

The visual effect of this cross-shaped geometry creates the impression that the transported cargo is being compressed, secured, and structurally held together by the vehicle body itself. The form therefore visually communicates stability, protection, and secure fixation of the transported freight. This relationship between shape and perceived structural strength reinforces the technical and cargo-oriented identity of the unit.

Fig. 6-29 Face design cross motif

An important part of the face design is also the transition between the front and side surfaces of the vehicle. Rather than creating a sharp separation between the two planes, the geometry smoothly transforms from the angled front surfaces into slightly chamfered rectangular side volumes. This transition creates a highly visible arrow-like shape extending along the sides of the unit. The arrow motif becomes one of the dominant visual elements of the overall design language. It directly communicates movement, speed, frequency, and efficiency, which represent some of the key operational values of the proposed freight transport system. Since the system is based on high-frequency autonomous logistics circulation within the metro infrastructure, the arrow-shaped side transition visually reinforces the idea of continuous movement and rapid freight distribution.

Fig. 6-30 Arrow motif from the side

Together, the symmetrical face composition, cross-shaped structural motif, and arrow-like side transitions create a front design that combines references to traditional freight transport with a contemporary autonomous character. The resulting form visually communicates the primary role of the unit as an efficient autonomous cargo transport system operating continuously within the urban logistics network.

6.2.2 Lights

The lighting design of the proposed metro unit combines functional railway lighting with integrated visual communication elements supporting the autonomous and technological character of the vehicle. The lighting system is intentionally minimal and fully integrated into the overall shape language of the unit.

Fig. 6-31 Front design in darkness

The primary lighting elements are four main lights positioned at the outer corners of the front face. These lights represent the main operational lighting of the metro unit and define the primary visual signature of the vehicle during movement through the metro infrastructure. Their placement emphasizes the width and stable geometry of the front face while simultaneously reinforcing the symmetrical autonomous character of the unit.

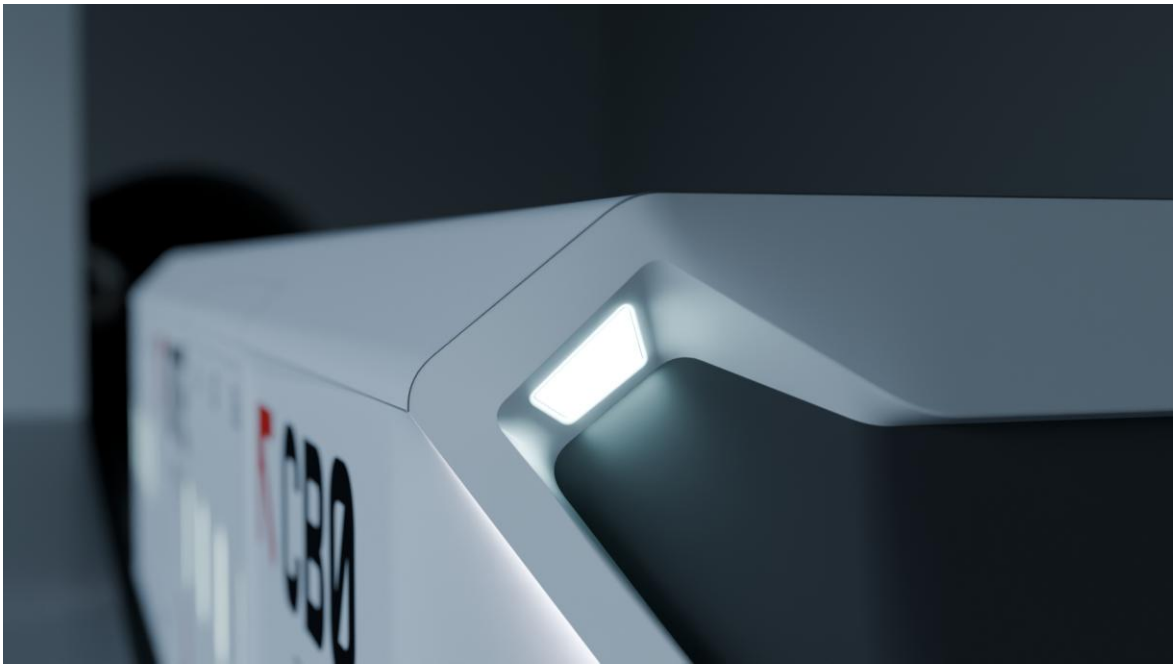

Fig. 6-32 Main front lights integrated into face geometry

The shape of the headlights is directly derived from the overall geometry of the front face. Their positioning strengthens the visual impact of the face design and highlights the outer structural edges of the vehicle. Together with the cross-shaped composition of the front surfaces described in Chapter 6.2.1 Face Design, the lights help visually define the overall proportions and technical character of the unit.

A secondary illuminated element is the “CARGION” logo positioned in the centre of the front face. This illuminated branding element functions both as identification and as part of the visual communication of the vehicle. The central placement additionally strengthens the symmetrical composition of the front design.

Integrated accent lighting is also positioned within the side transitions connecting the front face and side surfaces of the vehicle. These lighting elements are located inside the chamfered side sections and visually highlight the smooth geometric transition between the front and side parts of the unit described in Chapter 6.2.1 Face Design. The continuous curved transition between these surfaces allows the light to spread smoothly across the geometry without being interrupted by sharp edges. This creates a softer and more integrated lighting effect emphasizing the arrow-shaped side geometry and reinforcing the visual impression of movement, speed, and operational flow.

Fig. 6-33 Side accent lighting and surface transition

Additional ambient lighting is integrated directly into the cargo boxes, specifically within the handling areas around the box handles. These lights improve visibility during manual manipulation and unloading operations while simultaneously visually distinguishing the interaction zones of the cargo boxes. The ergonomic and functional role of this lighting is further described in Chapter 6.4 Ergonomics.

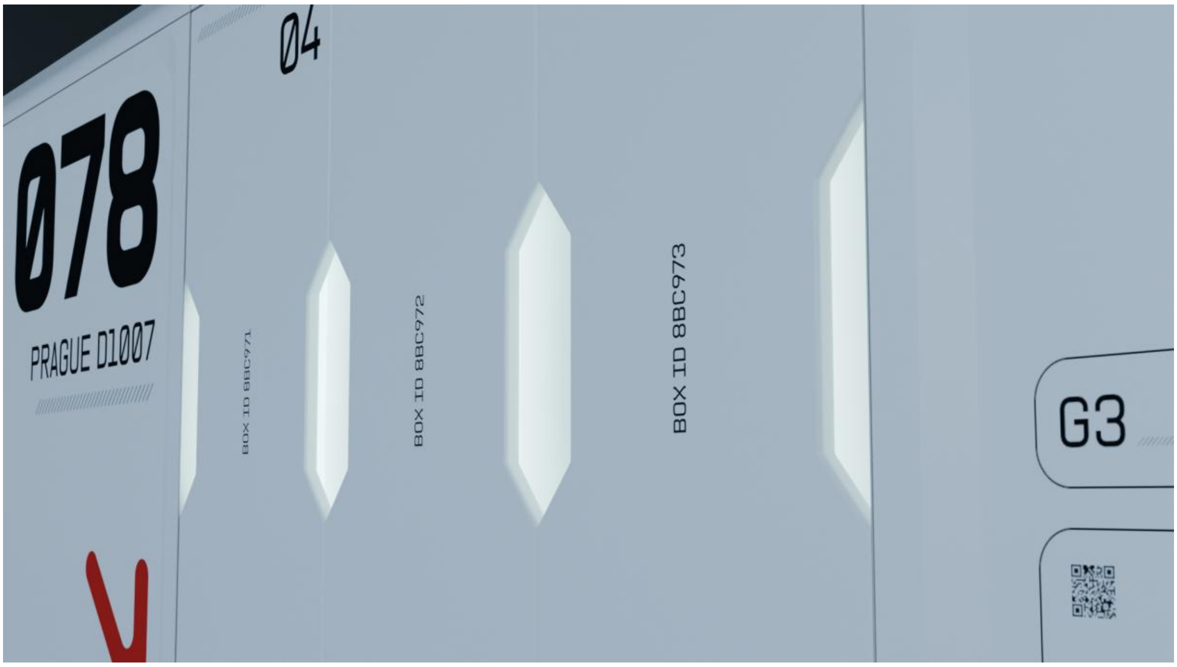

Fig. 6-34 Ambient cargo box handle lighting

6.2.3 Cargo boxes

The cargo boxes represent one of the most functional parts of the entire proposed system. For this reason, their shape design is intentionally kept simple and technically efficient. The overall form of the boxes is derived primarily from functional requirements related to handling, storage, unloading, and transportation, while the visual design itself plays a secondary role.

The shape of the cargo boxes is therefore based mainly on practical operational constraints and the need for efficient integration into both the metro unit and the unloading systems described in previous chapters. Simple surfaces and reduced geometric complexity additionally support manufacturability, durability, and ease of maintenance.

Fig. 6-35 Cargo box design

Although the cargo boxes are primarily function-driven components, selected elements of the overall design language of the metro unit are still reflected within their form. This is visible mainly in the shaping of the handling areas used for manual manipulation and extraction of the boxes. These areas partially adopt the sharper geometric transitions and simplified faceted surfaces used throughout the overall vehicle design.

An important aspect of the cargo box design is that the boxes were not designed as isolated standalone objects, but rather in the visual and operational context of neighbouring boxes. Since the system consistently operates with groups of three cargo boxes positioned next to one another, the proportions of the handles were developed to function visually as part of a larger grouped composition.

The inside/storage logic of the cargo boxes is described in more detail in Chapter 6.4 Ergonomics. The visual identity of the cargo boxes is further supported through graphical elements which are described in more detail in Chapter 6.5 Graphical Design.

Fig. 6-36 Inside view of the cargo box

6.3 Construction

This chapter describes the main construction elements of the proposed metro unit, their technical solution, materials, manufacturing principles, and role within the overall transport system. The following subchapters focus on the cargo boxes, unloading interfaces, coupling system, bumpers, bogies, and the material distribution of the individual components.

The dimensional and material solution of the proposed metro unit was developed based on technical documentation, dimensional constraints, and consultations provided by Škoda Group. An important part of the development process was also a visit to the company's rail vehicle production facilities in Pilsen, where existing manufacturing processes, vehicle structures, and construction principles of contemporary metro and railway vehicles were analysed directly in a real industrial environment.

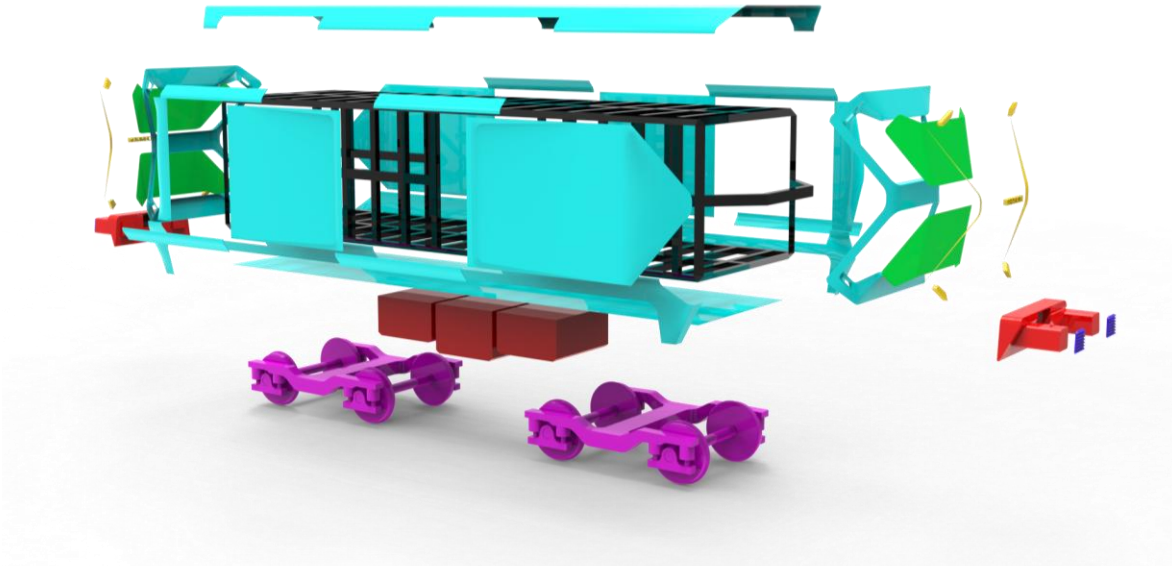

Fig. 6-37 Exploded view of the metro unit

The exploded view shown above illustrates the basic structural organization of the metro unit and serves as a visual reference for the following construction chapters.

6.3.1 The unit

The main body structure of the proposed metro unit is based on a welded aluminium frame similarly to contemporary metro and railway vehicle construction. The use of aluminium significantly reduces the overall weight of the vehicle while still providing sufficient structural rigidity for autonomous freight operation within metro infrastructure. Lower vehicle weight additionally reduces energy consumption and improves operational efficiency during frequent acceleration and braking cycles typical for metro systems.

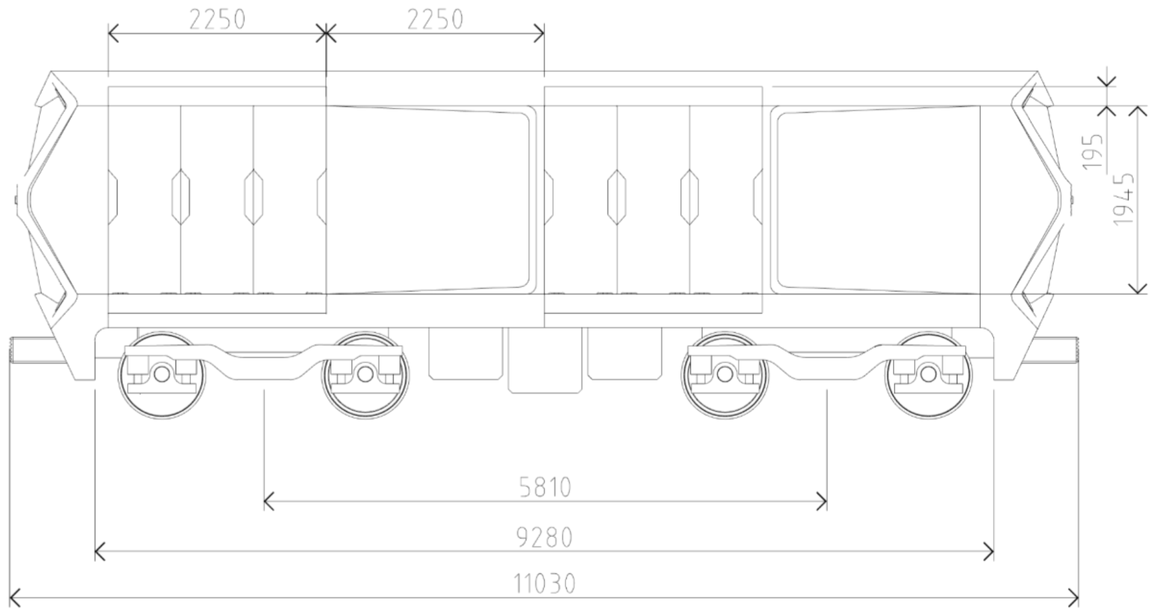

Fig. 6-38 Main dimensions of the unit, side view (in millimetres)

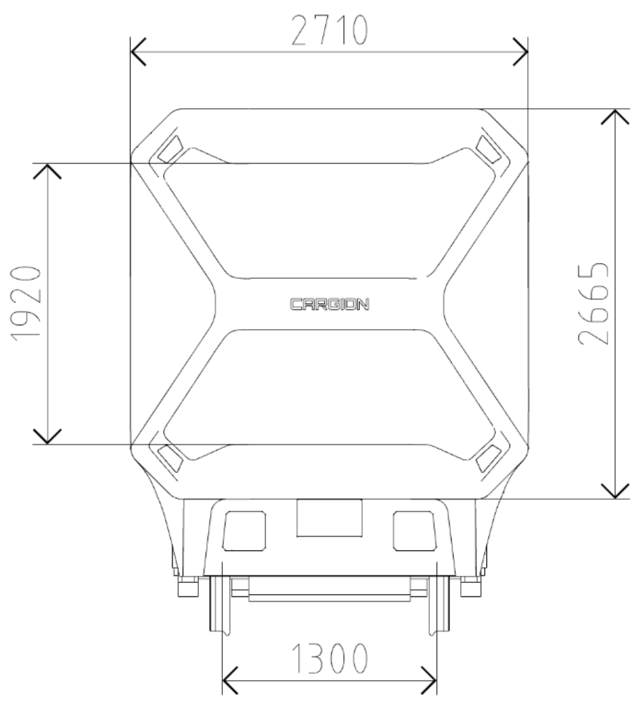

Fig. 6-39 Main dimensions of the unit, front view (in millimetres)

The exterior body panels are mounted directly onto the aluminium structural frame and form the final visible surfaces of the vehicle. These panels are also assumed to be manufactured from aluminium sheets due to their low weight, corrosion resistance, and compatibility with contemporary railway manufacturing technologies. The sharper geometric surfaces of the final design are particularly suitable for production using CNC bending and manual forming processes.

Although the proposed system may eventually require a larger production volume than conventional custom-built metro vehicles, the manufacturing process would still remain relatively low-volume compared to automotive mass production. For this reason, the construction approach assumes a significant amount of manual manufacturing and assembly work. Individual panels would be manually adjusted, welded, and fitted onto the structure before final surface treatment.

An important aspect of the manufacturing process is the final surface finishing required to achieve the clean continuous geometry of the proposed design. After assembly and welding, the body panels would undergo manual grinding, filling, and sanding in order to create smooth transitions between the individual exterior parts and maintain the sharp but visually continuous surface language of the vehicle.

6.3.2 Cargo boxes

The cargo boxes represent the primary transport and handling element of the entire proposed system. Their construction is designed mainly around functionality, repeated manipulation, low weight, and compatibility with both manual and autonomous unloading systems described in previous chapters.

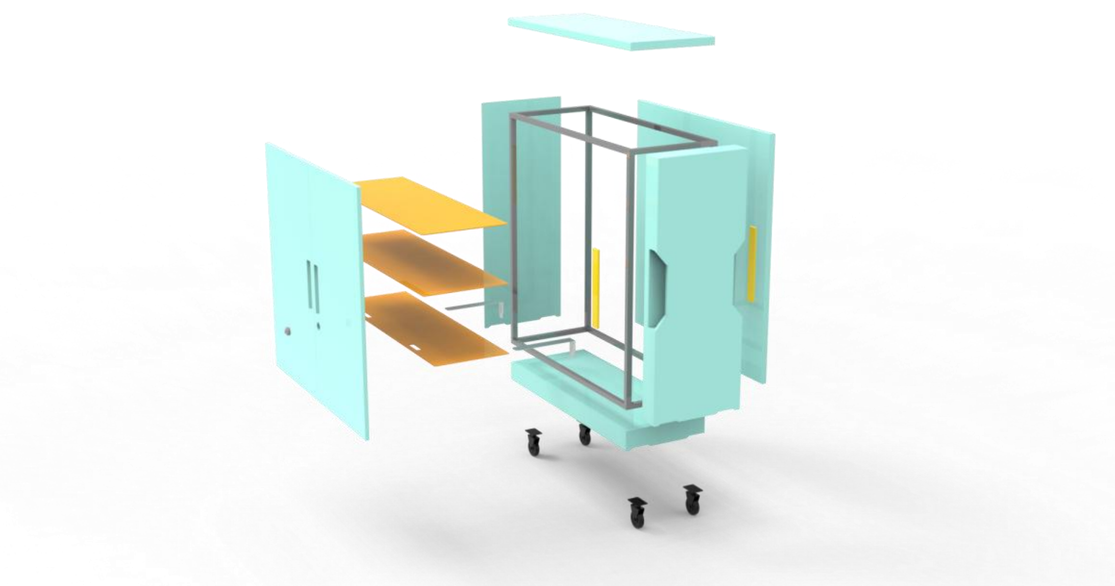

Fig. 6-40 Exploded view of cargo box

The main structure of the cargo box is based on a lightweight aluminium frame combined with durable plastic outer panels. This combination provides sufficient structural rigidity while maintaining relatively low overall weight and good resistance against repeated handling and operational wear. The interior shelving system is assumed to use lightweight plastic panels or composite shelves to further reduce weight while maintaining sufficient durability for parcel distribution.

All cargo boxes are equipped with integrated non-rotating wheels designed primarily for linear movement during loading and unloading operations. Since the movement of the boxes is always constrained to a single axis, rotating caster wheels are not necessary. The wheel construction is assumed to use a metal core combined with hardened rubber or polyurethane contact surfaces to reduce vibration, noise, and material wear during repeated operation.

An important aspect of the cargo box construction is the retractable wheel mechanism required for autonomous unloading. During autonomous operation, the wheels temporarily retract into the lower reinforced section of the cargo box, allowing the autonomous loading rails described in Chapter 6.1.1 Autonomous Operation to move underneath the box and slightly elevate it during transfer.

The cargo boxes are secured inside the metro unit using a bottom locking pin system inspired by aircraft cargo restraint mechanisms [46]. Each box contains reinforced positioning holes integrated into its lower structural section, which also accommodates the retractable wheel mechanism. After the box is inserted into the unit, mechanical stops define its final position so that the outer surface of the box remains flush with the side surface of the vehicle. Once the box reaches this position, locking pins extend from the vehicle floor into the reinforced holes of the cargo box, preventing movement during acceleration, braking, and vibration. Before unloading, the pins retract and the box can be manually or autonomously transferred out of the unit.

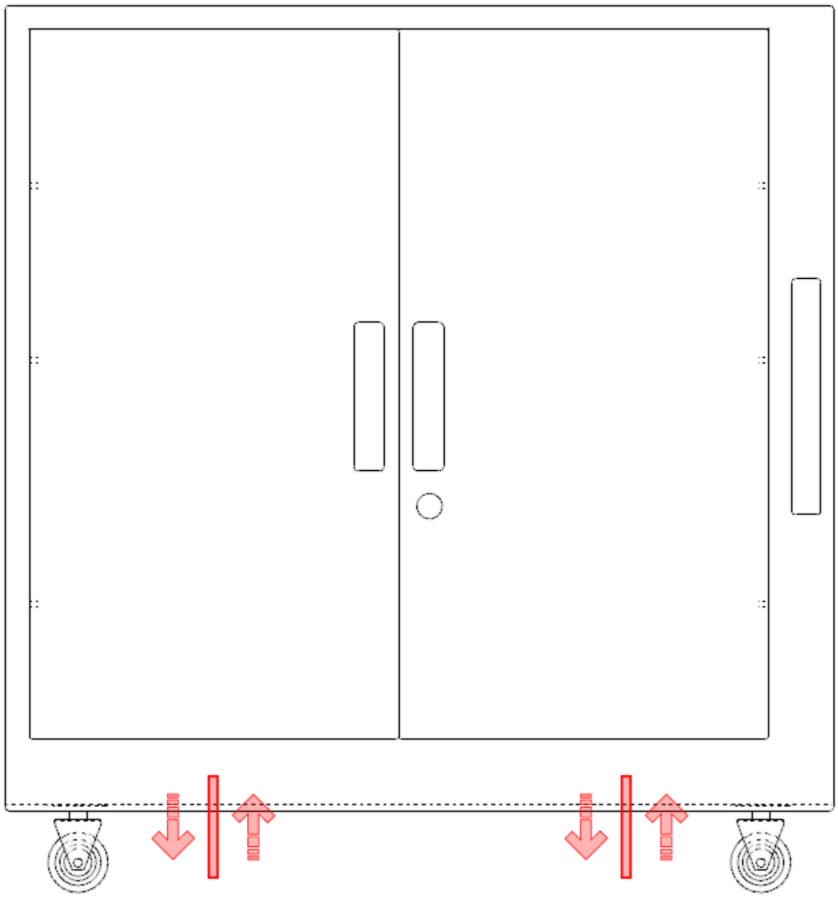

Fig. 6-41 Bottom locking pin system

The loading and unloading interface is additionally supported by a flap system integrated into the metro unit. During manual unloading, only the lower flap opens and creates a small bridge between the unit and the station platform, allowing the cargo box wheels to smoothly enter the unloading rails positioned on the platform.

In autonomous unloading mode, both the lower and upper flaps open simultaneously. This creates sufficient space for the autonomous loading rails to move underneath the cargo box and elevate it during the transfer process. The functionality of the flaps is illustrated in chapters 6.1.1. Autonomous option and 6.1.2 Manual option.

The unloading rails integrated into the station platform are designed as simple aluminium guiding rails embedded directly into the platform surface. Their implementation would require only minimal modification of the existing platform structure. The rails are positioned with an approximate inclination of five degrees towards the platform interior. This slight incline improves operational safety by preventing unintended movement of loaded cargo boxes back towards the metro track area while simultaneously making it easier to return emptied boxes into the arriving collection unit.

6.3.3 Lights

The design of the front headlights is based on contemporary LED technologies currently used in modern rail vehicles. Unlike older lighting systems, modern LED modules no longer require large illuminated surfaces to achieve high luminous intensity. The total illuminated surface area of the four front headlights is approximately 704 cm^2, with each individual headlight occupying approximately 176 cm^2.

This size is fully sufficient for metro operation, as current LED technology combined with optical systems and integrated lenses allows very high luminous intensity even within relatively compact lighting elements. Depending on the selected LED modules and optical configuration, each headlight could realistically achieve luminous intensity values in the range of approximately 30 000 to 60 000 cd. The complete front lighting system therefore provides sufficient illumination of the tunnel environment ahead of the vehicle while supporting safe autonomous operation and obstacle detection systems.

The lighting units are assumed to use railway lighting components similar to systems currently supplied by manufacturers such as FORVIA HELLA. The headlights combine aluminium rear housings for thermal management with polycarbonate front lenses and injection-moulded technical plastic mounting components. Although the proposed headlight geometry represents a custom design solution rather than an existing catalogue component, the overall construction principle remains based on currently available railway lighting technologies.

Additional lighting elements integrated into the metro unit, including the illuminated “CARGION” front logo, the side accent lighting integrated into the front-to-side transition surfaces, and the ambient lighting positioned behind the cargo box handles, are all based on integrated LED lighting technology. These lighting elements primarily serve visual communication, orientation, and operational visibility functions while reinforcing the overall visual identity of the proposed autonomous freight system.

6.3.4 Coupler

The proposed metro unit is equipped with a foldable emergency coupler intended primarily for maintenance, recovery, and emergency towing situations. The operational concept of the system does not assume the creation of longer freight trains or regular coupling between multiple cargo units during standard operation. The coupler is therefore included mainly to allow the unit to be connected to another rail vehicle in the event of technical failure or operational intervention.

Fig. 6-42 Coupler placing on the front

The coupler is integrated between the front bumpers similarly to contemporary tram and metro vehicle solutions, where the coupling system remains hidden during normal operation. In the proposed design, the coupler is folded inside the vehicle body and only becomes accessible after opening the dedicated front panel section. This approach preserves the clean autonomous appearance of the vehicle while still maintaining full operational compatibility with railway service and rescue procedures.

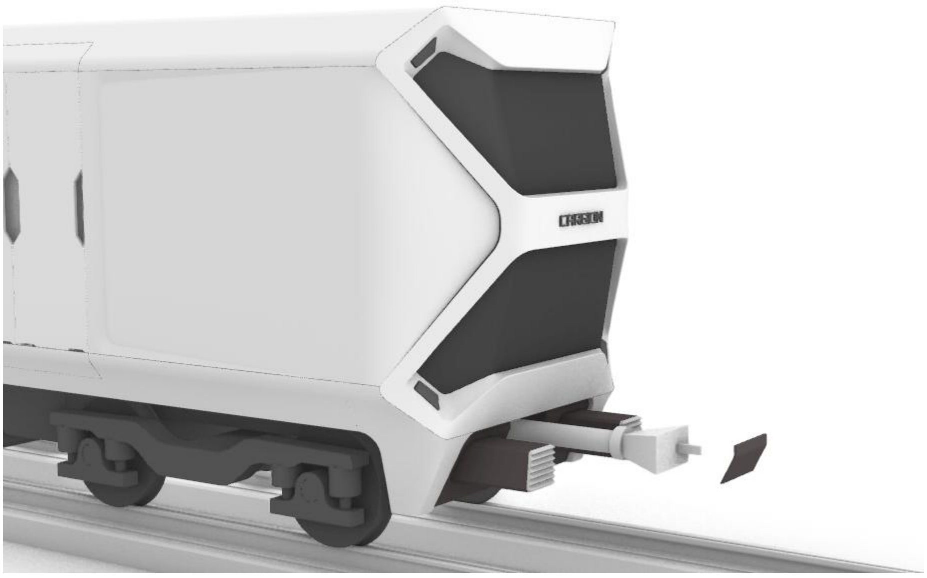

Fig. 6-43 Coupler and the detached cap

6.3.5 Bumpers

The metro unit is equipped with a pair of front bumpers positioned in the lower section of the vehicle body above the bogie area. From a side view, the bumpers represent the furthest protruding structural element of the vehicle and therefore form the primary contact surface in the event of collision or operational contact with another rail vehicle or infrastructure element.

Fig. 6-44 Front bumper position

The bumpers are assumed to be manufactured from high-strength steel similarly to contemporary railway and metro vehicle bumper systems. Since the bumpers are exposed to the highest mechanical loads on the vehicle, their construction prioritizes structural durability, deformation resistance, and operational safety over weight reduction. The front section of the bumpers uses a corrugated impact pattern inspired by contemporary railway vehicle construction.

Fig. 6-45 Corrugated bumper detail

6.3.6 Bogies

The bogie dimensions and overall wheelbase configuration of the proposed metro unit were developed based on technical consultations and dimensional references provided by Škoda Group. The bogies themselves are assumed to use high-strength steel construction similarly to contemporary metro and railway vehicle solutions due to the high mechanical loading and safety requirements associated with wheel and suspension systems.

The spacing between the two bogies defines the primary functional area in the lower section of the vehicle. This space accommodates several important operational and technical components required for autonomous metro operation. These include traction motors, electrical equipment cabinets, control units, battery systems, communication hardware, and tracking systems responsible for vehicle positioning and autonomous navigation within the metro infrastructure. These underbody components are positioned between the bogies similarly to conventional metro vehicle layouts.

Due to the compact proportions of the currently proposed metro unit, the available space between the bogies becomes relatively limited when combined with the cargo box layout and autonomous unloading systems. However, considering the conceptual and futuristic character of the project, some technical components that would traditionally be positioned underneath the vehicle are instead assumed to be integrated directly inside the body structure of the unit.

For this reason, the project also considers an alternative longer vehicle configuration previously mentioned in Chapter 6.1.3 Alternative Solutions. In this extended version, the increased wheelbase allows a more comfortable integration of the technical underbody components according to current metro vehicle engineering standards while simultaneously increasing the cargo capacity of the vehicle.

The currently proposed shorter version remains the primary design solution of the project, as it better reflects the compact and highly agile character of the proposed autonomous freight system. The longer alternative configuration is therefore presented mainly as a potential future development direction for systems requiring increased cargo capacity or additional technical equipment integration.

6.3.7 Autonomous Sensor Systems

The proposed metro unit integrates several autonomous sensor systems required for navigation, obstacle detection, positioning, and safe operation within the metro infrastructure. The placement and general distribution of these sensors are based on research of contemporary autonomous railway systems described in Chapter 2 Research - Automation and Control Systems.

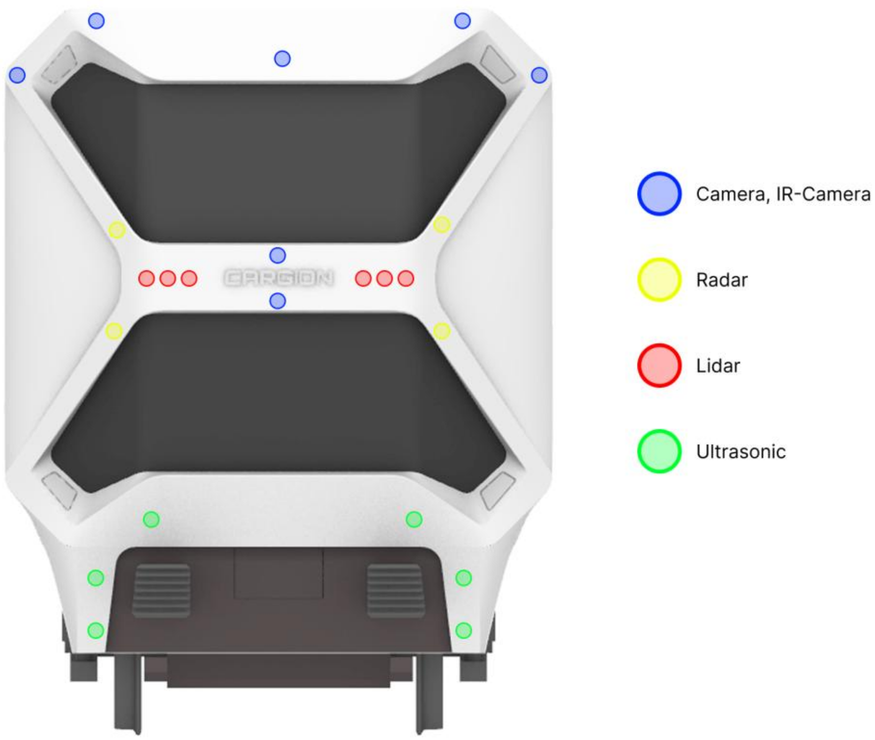

Fig. 6-46 Sensor placement on the metro unit

The primary sensors are positioned mainly in the front section of the vehicle where the highest visibility of the surrounding environment is required. The sensor suite is assumed to combine multiple technologies including LiDAR sensors, radar systems, cameras, and ultrasonic sensors similarly to existing autonomous railway and metro systems. The combination of these technologies allows the vehicle to detect obstacles, monitor tunnel infrastructure, analyse surrounding conditions, and support autonomous movement through the metro network.

Additional localization, communication, and autonomous control systems are integrated in the lower section of the vehicle between the bogies, where they support accurate positioning and operational management of the metro unit within the underground infrastructure.

6.4 Ergonomics

The ergonomic aspect of the proposed metro freight system is focused primarily on the cargo boxes and their handling process, since the rest of the metro unit is expected to come into contact with people only minimally during normal operation. The ergonomic development of the project therefore concentrates mainly on loading, unloading, manipulation, accessibility, and operational comfort of the cargo boxes while maintaining compatibility with both manual and autonomous logistical scenarios described in previous chapters.

6.4.1 Cargo box handling

The ergonomic development of the cargo box system focuses primarily on manual manipulation, accessibility, and adaptability of the cargo boxes during loading and unloading operations. The external dimensions, handle proportions, manipulation zones, and opening logic were developed according to standard ergonomic principles and anthropometric data based on an average adult operator corresponding approximately to the 50th percentile human figure (P50). The dimensions of the manipulation areas and handles were determined using standard ergonomic tables and recommendations for reachability and comfortable hand interaction.

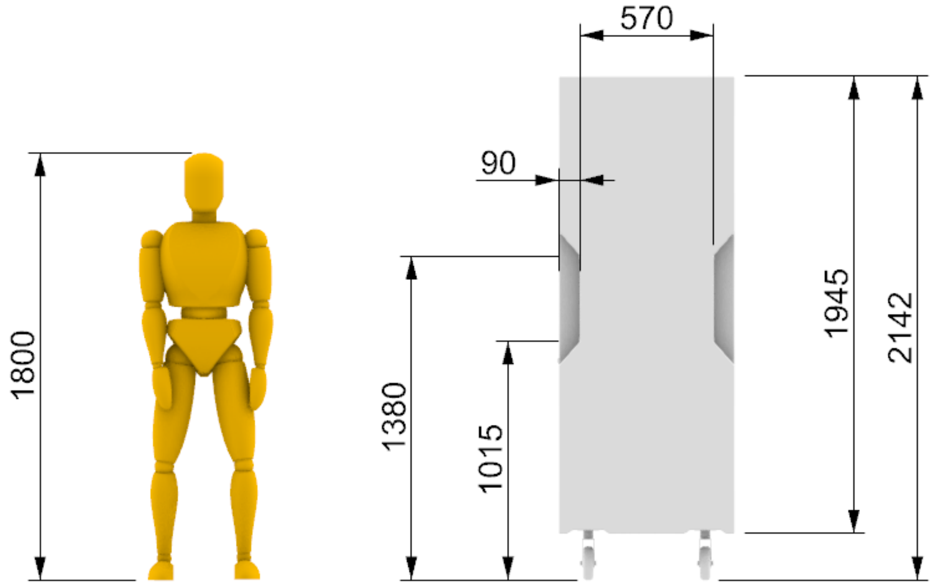

Fig. 6-47 Cargo box front dimensions (in millimetres)

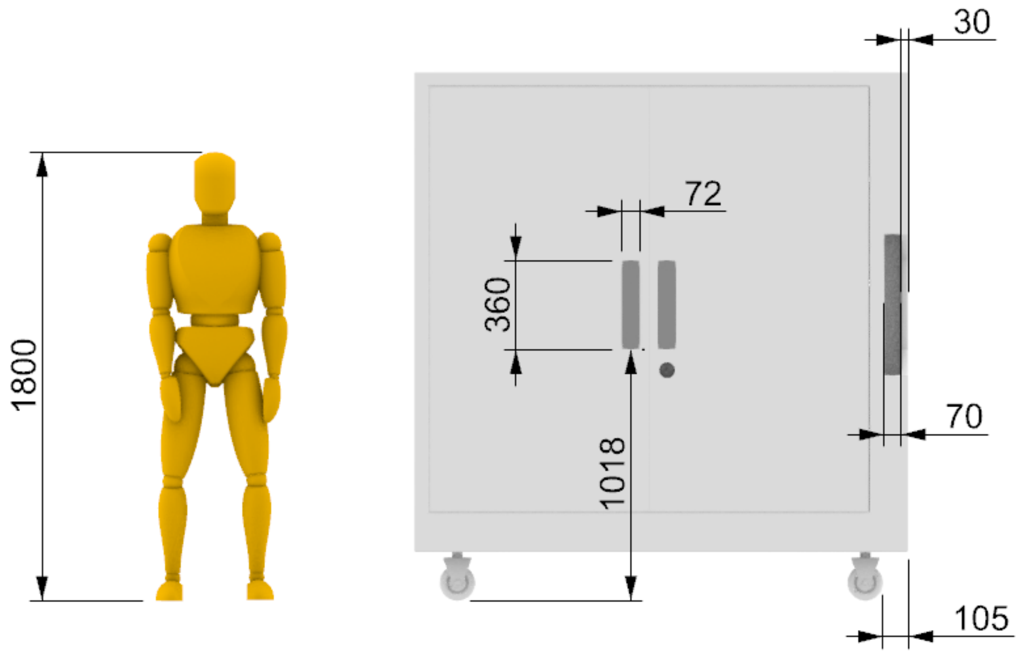

Fig. 6-48 Cargo box side dimensions (in millimetres)

The following diagrams demonstrate the primary handling scenarios of the cargo box system. These include pulling the cargo box from the metro unit, accessing the handle areas, opening the cargo doors, and removing transported parcels from the interior storage space. The handling process was intentionally designed to minimize complex movement and reduce physical strain by focusing mainly on simple linear pulling and pushing motions.

Fig. 6-49 Cargo box handling

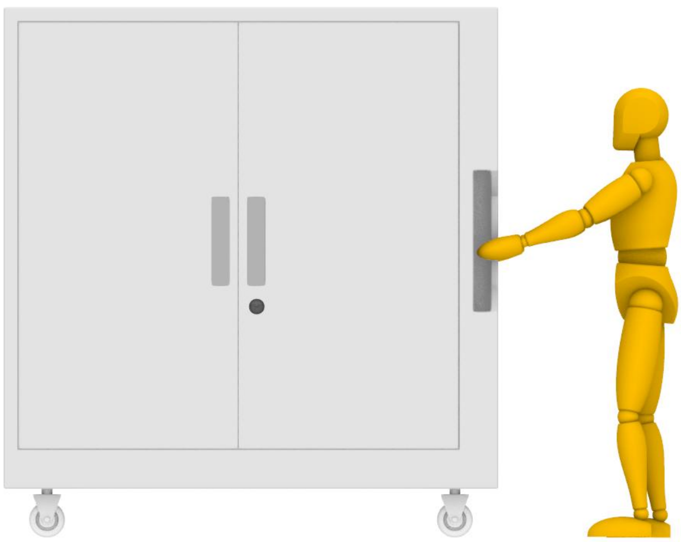

Fig. 6-50 Cargo box handling side view

Fig. 6-51 Visualization of the cargo box handling

The main handle area of the cargo box is integrated directly into the front surface of the box body. Instead of using protruding handles, the proposal utilizes recessed grip cavities allowing the operator to comfortably grasp and manipulate the box while maintaining a clean exterior surface suitable for autonomous unloading systems and compact storage.

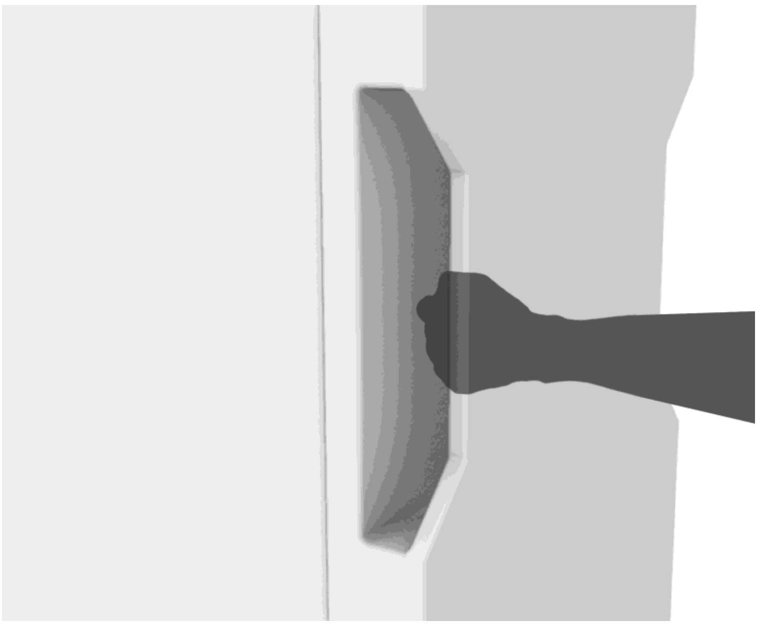

Fig. 6-52 Cargo box grip area

The cargo box doors use a conventional hinged opening system allowing full access to the interior storage space. The opening angle and handle positioning were developed to provide comfortable parcel manipulation while maintaining compatibility with compact metro station environments.

Fig. 6-53 Cargo box door handling 1

Fig. 6-54 Cargo box door handling 2

Fig. 6-55 Cargo box freight handling

The internal organization of the cargo box was developed primarily according to expected parcel dimensions and operational requirements of B2C and B2B logistics. One cargo box has approximate dimensions of 695 × 1785 × 1730 mm with an internal transport volume of approximately 2.14 m^3. Three cargo boxes together therefore provide an approximate combined volume of 6.43 m^3. These dimensions allow one cargo box to supply a smaller restaurant, fashion store, or heavily used pickup box, while three cargo boxes together can support larger restaurants, multiple smaller stores, or combined retail and parcel logistics operations.

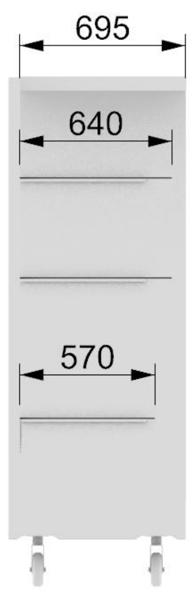

Fig. 6-56 Cargo shelf dimensions front view (in millimetres)

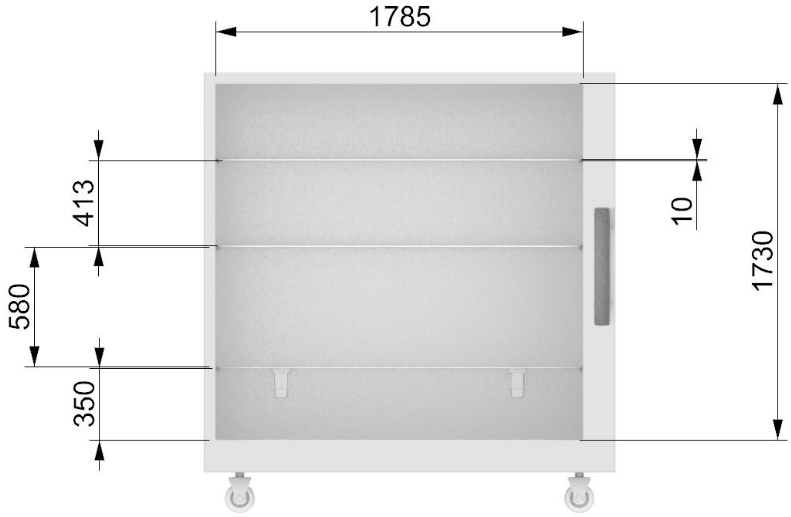

Fig. 6-57 Cargo shelf dimensions side view

The interior storage system consists of three removable shelves. The upper two shelves can be fully removed and repositioned using magnetic fixation points integrated into the side walls of the cargo box. The lowest shelf additionally includes a folding mechanism allowing it to rotate vertically backwards and attach directly to the rear wall of the cargo box using integrated magnets. This solution allows the lower storage area to become one large continuous space suitable for transporting oversized cargo such as beverage barrels, large packages, or other B2B freight requiring increased vertical space.

Fig. 6-58 Bottom shelf holes for manipulation

Fig. 6-59 Bottom shelf joint mechanism

Fig. 6-60 Lifting of the bottom shelf

Fig. 6-61 Position of the magnets on the bottom shelf

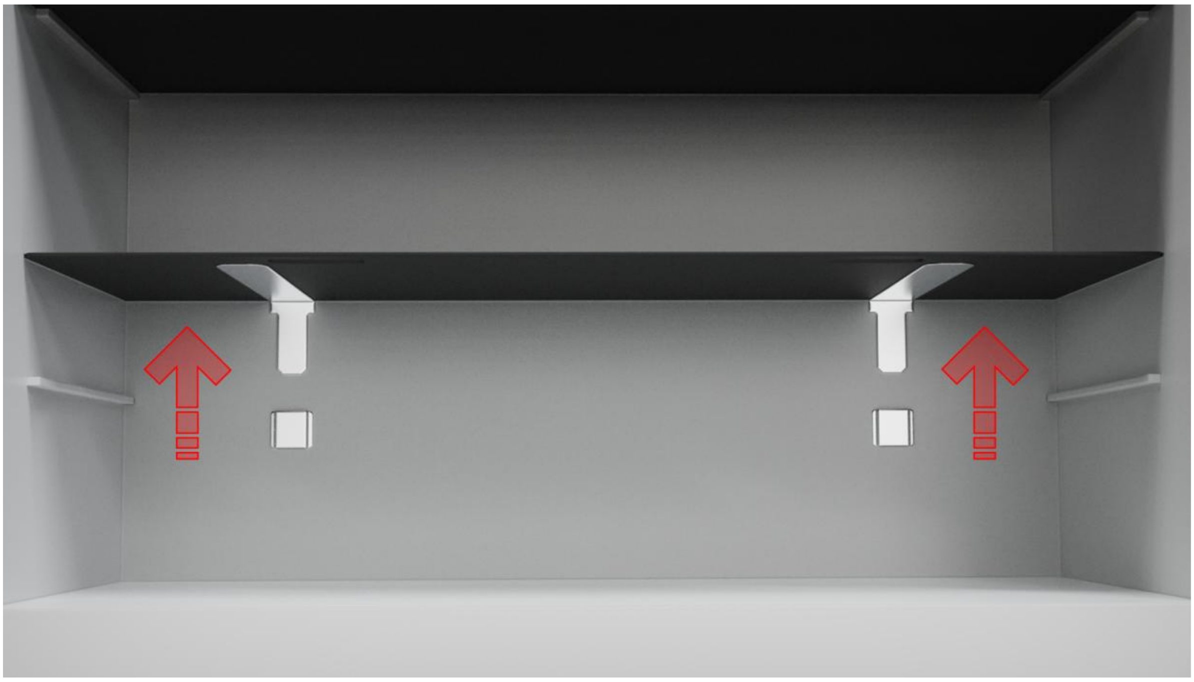

Fig. 6-62 Detaching of the bottom shelf

The cargo box system additionally integrates visual LED communication elements positioned behind the manipulation handles. These lighting elements support operational orientation and communicate the status of the cargo box during loading and unloading procedures. During standard operation the lighting remains white, while a green light indicates that the cargo box is ready for manipulation or unloading. Red lighting is used for warning states, operational errors, or emergency situations requiring attention from the operator.

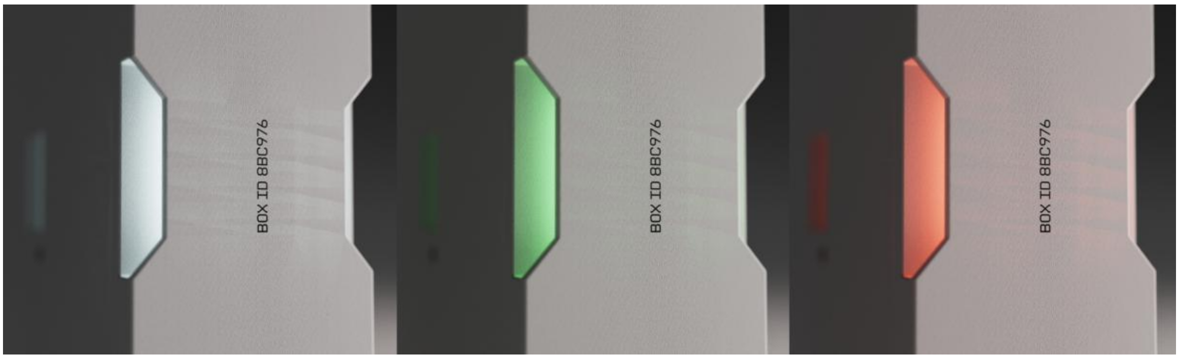

Fig. 6-63 Cargo box light options

6.4.2 Maintenance

The proposed metro unit integrates several maintenance access panels positioned on the side surfaces of the vehicle body. These access doors are visually integrated into the exterior body panels to maintain the clean and continuous appearance of the unit while still allowing direct access to important technical components.

Fig. 6-64 Access to important technical components

Fig. 6-65 Access to important technical components

The maintenance panels are positioned primarily within the side sections located between the cargo box groups. Their placement reflects the compact proportions of the proposed metro unit, where some technical systems are integrated directly inside the vehicle body instead of the traditional underbody layout commonly used in conventional metro vehicles. The access panels therefore provide service access to electronic systems, autonomous control hardware, lighting components, cargo box locking mechanisms, communication systems, and other operational equipment integrated inside the unit structure.

6.4.3 Safety

Since the proposed metro unit does not transport passengers, the safety considerations of the system are focused primarily on protecting people surrounding the unloading process within metro stations. These safety principles were already discussed in chapter 6.1.2 The manual option. The most critical situation occurs during the manual unloading operation, when cargo boxes are temporarily moved between the metro unit and the platform environment.

For this reason, the unloading area around the integrated platform rails is visually separated using graphic warning elements directly integrated into the station floor. These markings clearly define the operational unloading zone and visually communicate to passengers that the space is reserved exclusively for cargo manipulation and authorized personnel.

The proposed system also assumes the future implementation of sliding platform safety doors similarly to those already used in contemporary automated metro systems. These barriers would prevent unauthorized access to the rail area and would only open during controlled unloading operations or passenger metro arrivals. In the case of the freight metro unit, the safety doors positioned at the platform edge would open only in the specific unloading section where cargo manipulation takes place.

This approach significantly reduces the possibility of accidental access to the tracks, unauthorized interaction with the cargo unit, or unsafe movement near the unloading process. The combination of physical barriers controlled unloading zones, and graphic safety communication therefore creates a safety system adapted specifically for autonomous underground freight transportation.

6.5 Graphical design

The graphical design of the proposed metro unit extends the technical and autonomous character established by the shape design and construction of the vehicle. The visual communication system combines industrial graphic elements, technical typography, and directional motifs in order to create a coherent visual identity for the entire freight transport system.

Fig. 6-66 Graphical elements on the unit

6.5.1 Logo and Brand Identity

The proposed system operates under the name CARGION, a name derived from the word "cargo" and intended to directly communicate the logistical purpose of the vehicle. The branding of the system is designed to feel technological, autonomous, and industrial while remaining visually simple and easily recognizable within the metro environment.

The main graphical symbol of the project is based on the front face geometry of the metro unit, particularly the two large shield-like front surfaces forming the characteristic cross motif described in Chapter 6.2.1 Face Design. The resulting logo symbol abstractly references the same "X" geometry and visually connects the branding system with the physical design of the vehicle.

Fig. 6-67 Logo vertical variant

Fig. 6-68 Logo horizontal variant

The primary logotype uses the typeface Orbitron SemiBold, selected for its technical and futuristic appearance. The typography supports the autonomous and technologically advanced character of the proposed transport system while remaining highly legible within the metro environment.

6.5.2 Vehicle Graphics

The graphical layout of the metro unit is based on a combination of technical graphic elements inspired by industrial transport systems, logistics infrastructure, and autonomous technologies. The side graphics heavily utilize visual motifs such as directional arrows, technical markings, QR-code inspired elements, line hatching, and operational graphics commonly associated with automated systems and industrial environments.

The typography used throughout the vehicle graphics primarily utilizes the typeface Montec 01 in multiple font weights and sizes. This typeface complements the more futuristic character of the Orbitron logo typography while providing a more technical and informational appearance for operational markings and graphic communication elements.

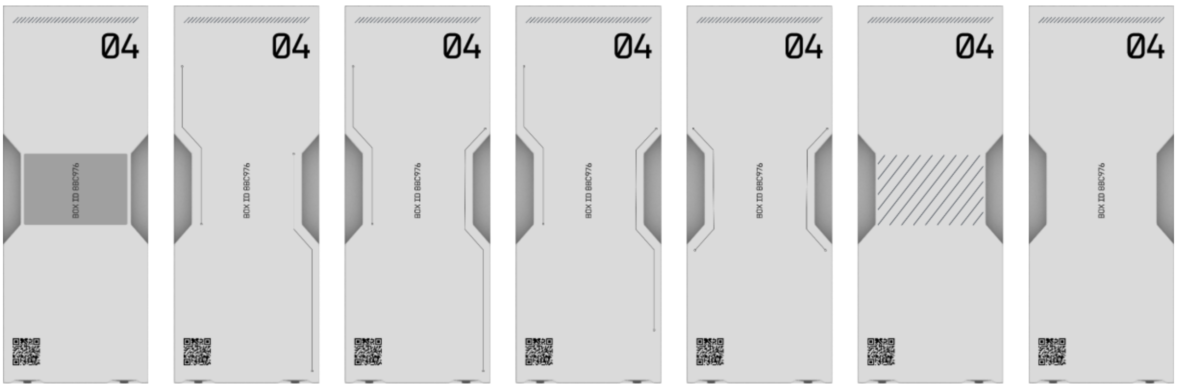

Fig. 6-69 The exploration of cargo box graphics

The graphical colour palette is intentionally minimal. Most graphic elements use black or very dark grey tones applied onto the light body surfaces of the vehicle. Red is used as the primary accent colour and appears mainly in directional graphics, warning markings, and selected visual communication elements.

A recurring graphic motif used throughout the vehicle is the arrow form. These arrows visually continue the directional geometry already established in the front face design of the metro unit and further reinforce themes of movement, efficiency, speed, and cargo flow. Similarly to the cross motif on the front face, the arrows visually suggest the securing, directing, and controlled movement of transported cargo within the system.

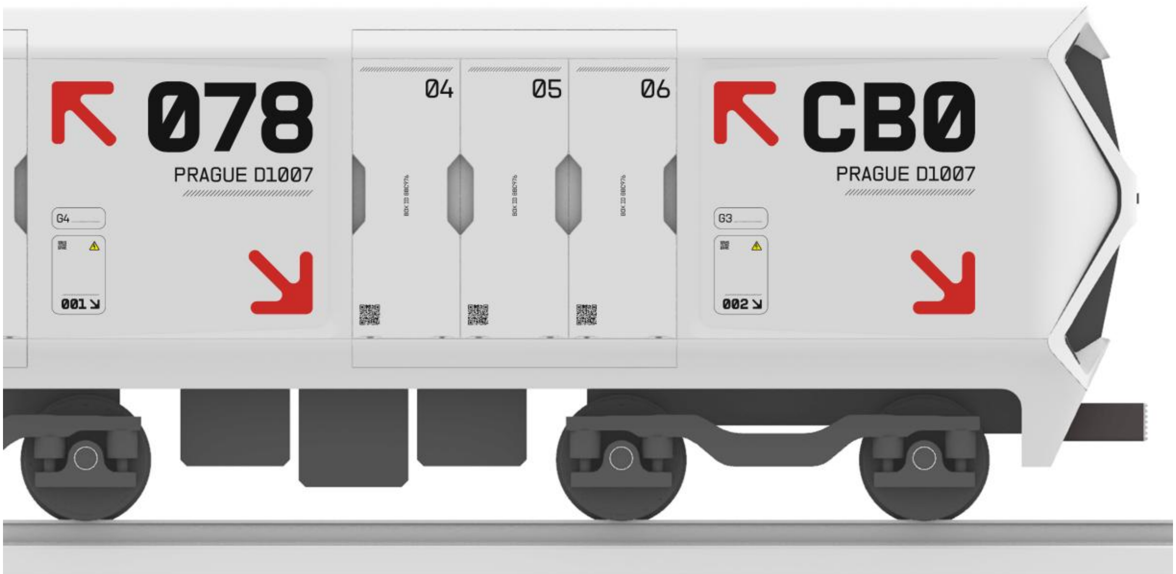

Fig. 6-70 Unit side graphics

The overall graphical design therefore functions not only as visual branding, but also as an extension of the functional and autonomous identity of the proposed freight transport system.

6.6 Colour variants

The final colour design of the proposed metro unit is based primarily on a matte off-white surface combined with dark grey graphical elements and red accent details. This variant was selected as the primary colour solution due to its ability to communicate the clean, technical, and futuristic character of the proposed autonomous freight system while simultaneously maintaining high visual clarity within the metro environment.

Fig. 6-71 Primary white colour variant

The final colour solution was selected through a process of multiple visual explorations and colour studies focused on finding a balance between industrial functionality, autonomous technological aesthetics, and integration into contemporary public transport environments. During this process, several monochromatic and neutral colour combinations were tested to evaluate their visual impact, readability of graphic elements, and compatibility with the overall shape design of the vehicle.

Fig. 6-72 RAL colours used

Fig. 6-73 Overview of explored colour variants

In addition to the selected white variant, two additional colour directions were identified as potentially viable alternatives for the proposed system. The first alternative uses a darker grey body colour creating a more industrial and technologically aggressive appearance. The second alternative utilizes a warm light-grey or beige tone producing a softer and slightly more infrastructural character while still preserving the technical identity of the vehicle.

Fig. 6-74 Unit dark grey variant

Fig. 6-75 Unit beige variant

Despite the viability of these alternative solutions, the white variant was ultimately selected as the final proposal due to its strongest balance between futuristic appearance, visibility, graphic readability, and visual cleanliness within underground public transport infrastructure.

6.7 Environmental impact

The proposed autonomous freight metro system has the potential to significantly reduce the environmental impact of contemporary urban logistics. Current parcel transportation relies heavily on road-based delivery vehicles, which contribute to traffic congestion, noise, and increasing carbon emissions within city centres.

By transferring part of the growing delivery demand into existing metro infrastructure, the system reduces dependence on surface-level freight transport and decreases the number of delivery vans operating in dense urban areas. This becomes increasingly important with the continuous growth of e-commerce and last-mile delivery services, which are placing growing pressure on already saturated urban streets.

An important advantage of the proposed system is its ability to utilise existing underground transport infrastructure rather than requiring entirely new transport networks. In addition to reducing emissions, the system can contribute to lower traffic congestion, reduced noise levels, and improved overall efficiency of urban logistics operations.

The project therefore represents a potential long-term alternative to conventional road-based delivery systems, particularly in cities where the current logistics infrastructure is approaching its operational and spatial limits.

6.8 Financial estimate

The following financial estimate is focused only on the B2C market within Prague and serves primarily as a simplified demonstration model showing the possible economic potential of the proposed freight transport system. The calculation assumes that the proposed system would take over approximately 50 % of the current parcel delivery volume operated by conventional delivery vans within the city. The presented values are therefore intended as indicative estimates based on publicly available information, operational observations, and simplified logistical modelling rather than exact commercial data.

Based on the created model, the currently used delivery system would require approximately 900 delivery vans and around 900 couriers operating simultaneously within Prague. Assuming an average monthly salary of approximately 30 000 CZK per courier, the estimated monthly personnel costs reach approximately 27 million CZK. In comparison, the proposed metro-based system would require approximately 61 operators with an estimated monthly salary of approximately 40 000 CZK, resulting in monthly personnel costs of approximately 2.4 million CZK.

The fuel consumption estimate of the current delivery system was calculated at approximately 144 000 litres of fuel per month, representing monthly fuel costs of approximately 6.2 million CZK. In contrast, the proposed autonomous metro system is estimated to consume approximately 600 000 kWh of electrical energy per month. Even when accounting for the electrical consumption of the metro units and supporting infrastructure, the operational energy costs remain significantly lower than those associated with conventional van-based delivery systems.

An important difference between the two systems lies in the required initial investment. The currently used delivery model operates using existing road infrastructure and commercially available delivery vehicles, meaning the initial infrastructure investment is effectively negligible in this simplified comparison. The proposed metro system, however, requires the production of autonomous metro units.

The presented estimate assumes the operation of nine metro units running approximately 18 hours per day across the Prague metro network. Within this operational model, the transport capacity of the system is estimated to be equivalent to approximately 50 % of the current B2C parcel delivery volume handled by conventional delivery vans in Prague. The number of proposed units is therefore directly connected to the assumed transported parcel volume and operational frequency of the system. At the same time, the model demonstrates that increasing the fleet size would theoretically allow the system to absorb an even larger percentage of the existing delivery load in the future.

Based on the estimated manufacturing price of approximately 42 million CZK per unit, a fleet of nine metro units would represent an investment of approximately 378 million CZK, rounded to approximately 400 million CZK.

Despite the significantly higher initial investment, the simplified financial model suggests substantial long-term operational savings. The estimated monthly operational costs of the current delivery model reach approximately 33.2 million CZK, while the proposed metro-based system is estimated at approximately 4.4 million CZK per month. Based on these values, the estimated return period of the initial investment would be approximately 2.7 years if the system successfully absorbed approximately 50 % of the current B2C delivery volume within Prague.

It is important to acknowledge that the presented financial estimate is based on simplified modelling and publicly accessible information. During the development of this thesis, attempts were made to contact multiple logistics companies, transport operators, and public institutions including Zásilkovna, Alza, Amazon, Dopravní podnik hl. m. Prahy, Wiener Linien, and the City of Vienna to obtain more precise operational data. However, only limited information was made available. The presented calculations should therefore be understood primarily as indicative estimates intended to demonstrate the potential economic direction of the proposed system. Nevertheless, even if the estimates deviated by several tens of percent, the resulting operational and financial potential of the system would remain highly significant.

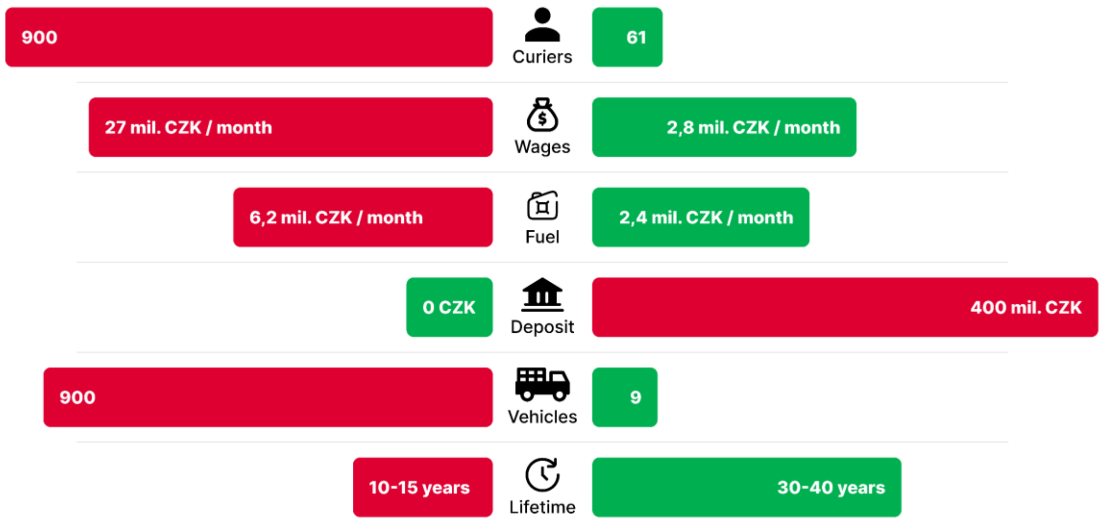

Fig. 6-76 Financial comparison of current and proposed B2C delivery systems in Prague.

7 CONCLUSION

The aim of this thesis was to explore the possibility of utilizing existing metro infrastructure as part of a future autonomous urban freight transport system focused primarily on last-mile delivery. Through research, conceptual development, technical proposals, ergonomic studies, and final design outputs, the project attempted to demonstrate how underground public transport infrastructure could partially respond to the continuously increasing pressure placed on contemporary city logistics systems.

Throughout the development of the project, the thesis combined multiple areas including industrial design, transportation design, logistics, autonomous systems, and urban infrastructure. The final proposal presents a speculative but technically grounded vision of an autonomous metro freight unit operating within existing metro systems while utilizing contemporary technologies already partially present within logistics and autonomous transport industries.

An important outcome of the project is the demonstrated financial and operational potential of the proposed system. Even within the simplified B2C model created for Prague, the estimated operational costs, delivery efficiency, and long-term return potential suggest that underground freight transportation could become a highly relevant alternative to conventional van-based delivery systems in dense urban environments.

At the same time, the project highlights several additional long-term benefits beyond the purely financial aspect. One of the most visible advantages could be the reduction of visual smog within city centres. A significant portion of pickup infrastructure, delivery operations, and logistical processes could potentially be transferred underground, reducing the amount of visible delivery infrastructure occupying contemporary public space.

The proposed system also directly responds to the increasing speed and frequency demands of contemporary e-commerce. Current trends within companies such as Amazon and other large-scale logistics providers clearly demonstrate that delivery times continue to shorten while delivery frequency continues to increase. Future logistics systems will therefore require transport infrastructure capable of operating at extremely high frequency and with high spatial efficiency. Existing metro infrastructure represents one of the few already built urban systems capable of potentially supporting this type of operation.

Another important aspect is the potential environmental and urban impact of reducing conventional delivery traffic within city centres. Fewer delivery vans operating in dense urban environments could contribute not only to lower emissions and reduced traffic congestion, but also to safer pedestrian environments. Delivery vehicles are heavily involved in urban pedestrian collisions and represent a substantial operational burden within already congested city streets.

Another important aspect of the proposed system is its overall flexibility and adaptability. Throughout the development process, the project was intentionally designed with the assumption that the surrounding logistical context may continue evolving in the future. For this reason, the proposal does not depend on only one strictly defined operational scenario but instead allows multiple levels of integration and future modification while still utilizing the same core metro unit and cargo box system.

The project therefore proposes a transport platform capable of operating within several logistical models simultaneously. Cargo unloading can function manually, autonomously, or as a combination of both approaches depending on the technological level, financial possibilities, or infrastructural conditions of a particular city. Similarly, the proposed cargo units are not limited exclusively to B2C and B2B parcel transportation. The same system could theoretically be adapted for food distribution, waste transport from city centres, rapid transportation of fresh goods, or other forms of urban logistical operation requiring high-frequency underground transport.

The modular logic of the cargo box system additionally allows future modifications of transported cargo formats. While the project primarily operates with standardized groups of three cargo boxes, the system architecture also creates the possibility for alternative cargo modules or specialized transport inserts depending on future operational requirements.

From a design perspective, the thesis also focused on creating a visual and formal language appropriate for an autonomous freight vehicle operating within public urban environments. The resulting design attempts to visually communicate efficiency, technological precision, and autonomous functionality while remaining connected to contemporary railway vehicle design language. Both the shape design and graphical identity were developed to support the operational purpose and character of the proposed transport system.

The thesis does not claim to provide a final or universally applicable solution to the future of last-mile delivery. The topic of autonomous freight transportation within urban infrastructure is already being explored by multiple companies, institutions, and research projects worldwide, and will continue evolving alongside technological and societal changes. This project therefore represents one possible perspective on how existing metro systems could be utilized more efficiently in the future.

Overall, the thesis fulfilled its originally defined objectives and successfully developed a comprehensive conceptual proposal of an autonomous metro freight transport system. The resulting project combines speculative future thinking with realistic technological references and demonstrates the potential for industrial design to participate in discussions surrounding future urban mobility and logistics systems.

8 RESEARCH RESULT ACCORDING TO RIV

Result category	Functional sample
Result name	Autonomous Metro Unit
Author	Bc. Benedikt Müller
Location of the Result Storage	VUT Brno

Tab. 8-1 Research Results according to RIV

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10 LIST OF ABBREVIATIONS, SYMBOLS AND VARIABLES

m	meter
mm	millimetre
m^3	cubic meter
kg	kilogram
s	second
AGV	automated guided vehicle
kWh	kilowatt-hour

11 LIST OF FIGURES AND GRAPHS

12 LIST OF TABLES

13 LIST OF APPENDICES

- Reduced visual poster
- Reduced summary poster
- Reduced ergonomic poster
- Reduced technical poster
- Reduced design poster

Separate appendices:

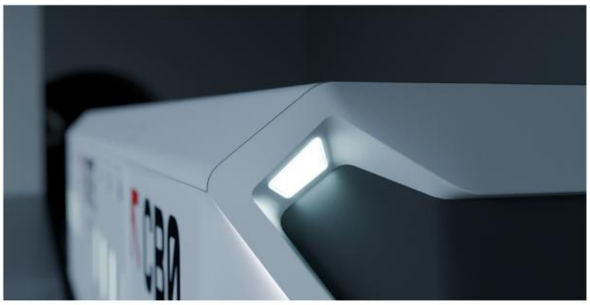
- Visual poster A1
- Summary poster A1
- Ergonomic poster A1
- Technical poster A1
- Design poster 100 × 70 cm
- Physical model 1:20

14 APPENDICES

CARGION

Design of an Autonomous Metro Unit

Cargion is a design concept of an autonomous metro freight unit and a related urban logistics system intended for future last mile delivery. The project proposes the use of existing metro infrastructure for high-frequency cargo transportation while minimizing road traffic, emissions, and interaction between freight operations and public passenger spaces. The system combines an autonomous metro unit, modular freight handling principles, and future-oriented logistics technologies into one flexible urban transport solution capable of responding to the rapidly growing demands of e-commerce and contemporary city logistics.



VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ | FAKULTA STROJNÍHO INŽENÝRSTVÍ

ÚSTAV KONSTRUOVÁNÍ

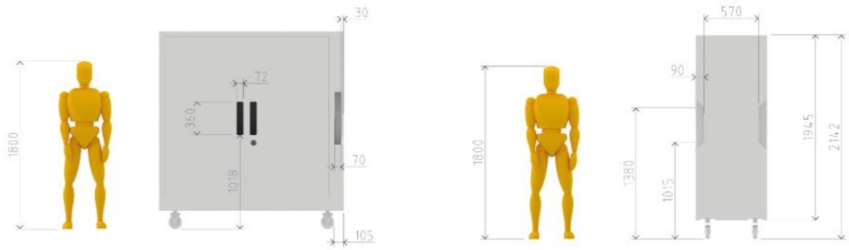
odbor průmyslového designu

DESIGN OF AN AUTONOMOUS METRO UNIT / DIPLOMOVÁ PRÁCE / Autor: Bc. Benedikt Müller / Vedoucí práce: M. A. Tanguy Hervé André Pierre Prévot / VUT v Brně / FSI / ÚK / OPD / 2025/26

CARGION

Design of an Autonomous Metro Unit

The ergonomics of Cargion are based on the direct and efficient manual handling of modular cargo boxes within the spatial limitations of metro infrastructure. The dimensions of the cargo modules were designed to enable safe manipulation by a single operator while maintaining sufficient transport capacity for urban logistics applications. Integrated wheels and side-based unloading reduce physical strain during handling and eliminate the need for additional lifting equipment. The unloading zone on the platform is clearly defined to improve safety, orientation, and operational clarity during interaction between the operator and the autonomous metro unit. The overall ergonomic solution focuses on intuitive handling, minimising unnecessary movement, and ensuring efficient operation within constrained underground environments.



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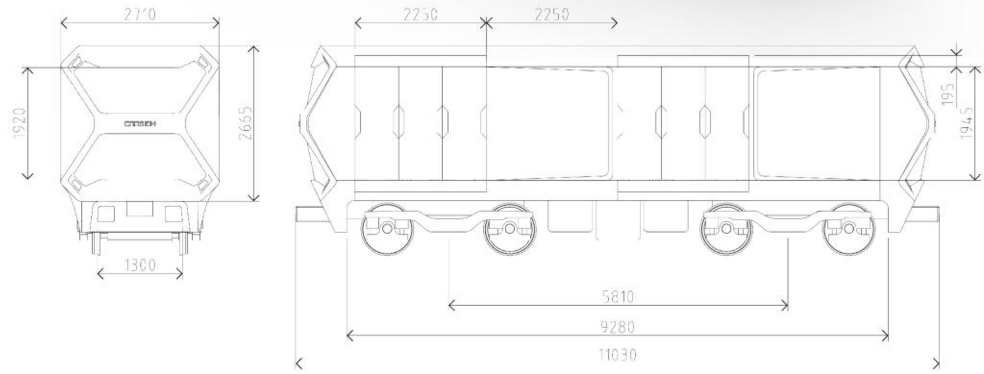
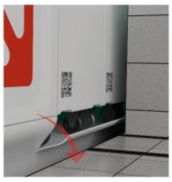
CARGION

Design of an Autonomous Metro Unit

The technical design of Cargion is based on the integration of standardized modular cargo boxes within the dimensional and infrastructural constraints of existing metro systems. The vehicle architecture is derived from conventional metro platform principles, including bogie placement, underfloor technical equipment, and clearance envelope limitations, while adapting the internal layout specifically for freight transport. Side-based unloading enables both manual and future autonomous handling scenarios, supported by integrated guidance systems and standardized interfaces for efficient cargo transfer. The compact vehicle proportions, lightweight structural approach, and modular cargo arrangement allow the system to achieve high transport frequency, operational flexibility, and compatibility with autonomous metro operation within dense urban environments.





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Autonomous Metro Unit

2026

Benedikt Müller

supervisor: M. A. Tanguy Hervé André Pierre Prévot

Cargion is a design concept of an autonomous metro freight unit and a related urban logistics system intended for future last mile delivery. The project proposes the use of existing metro infrastructure for high-frequency cargo transportation while minimizing road traffic, emissions, and interaction between freight operations and public passenger spaces. The system combines an autonomous metro unit, modular freight handling principles, and future-oriented logistics technologies into one flexible urban transport solution capable of responding to the rapidly growing demands of e-commerce and contemporary city logistics.