Deliverable D 4.3
Estimation of economical effort

Project acronym:	FA7 Pods4Rail
Starting date:	01/09/2023
Duration (in months):	30
Call (part) identifier:	HORIZON-ER-JU-2022-01
Grant agreement no:	101121853
Due date of deliverable:	29/02/2024
Actual submission date:	22/04/2024
Responsible/Author:	Roman Čermák, UWB
Dissemination level:	PU
Status:	I

Reviewed: Yes
Reviewers: SMO, DLR

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101121853.

Document history		
Revision	*Date*	*Description*
1	11-01-2024	First draft
2	12-04-2024	First issue for internal review – WP leaders
3	20-04-2024	Second issue after internal review
4	22-04-2024	Final version - submitted

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1 Executive Summary

This deliverable provides an initial overview of the socio-economic parameters that influence the development of a new inter-modal transport system (a Pods system) and the extent to which these parameters will be affected by this new system.

The Pods system will allow a part of road transport to be shifted to rail and maintain door-to-door transport. It will use the same road, rail and energy infrastructure as conventional transport systems. From the users' point of view, the Pods system will need to offer a similar or higher level of quality as existing road transport, especially in terms of comfort (for passengers), reliability, flexibility, door-to-door capability and accessibility.

It can be assumed that the size and capacity, speed and other transportation characteristics of pods and transportation units will limit their use to specific niches in the market. For example, mass transit flows of commuters who use the subway and other heavy-duty rail systems are unlikely to be served by pods. The same applies to large volumes of cargo and long-distance flows, e.g. of building materials, containers, waste etc.

Precise information is not yet available on the design of pods vehicles, the necessary infrastructure related to their operation, or the impact of some important factors on the development of mobility in the future (electrification, automation, distribution of energy sources, population development and mobility requirements, technological development, investment policy and strategy etc.). Therefore, the determination of the costs is carried out as a qualitative estimate of the impact and an approximate specification of boundary conditions for the implementation of the Pods system.

This report assesses the application of the Pods system in two different scenarios (one freight and one passenger transport scenario, UC1-4, UC17-20 as mentioned in D4.1) on its societal impact in a qualitative manner. From this analysis can be derived that the Pods system may positively influence the reliability, emissions of greenhouse gasses and pollutants, as well as the spatial impact of a regional transport system.

For the sake of comparison and an overall estimate of the absolute amount of funds required, the costs of current transport systems are quantified at current prices as much as possible. These costs are quantified both according to the CE Delft methodology [1,2] as total infrastructure costs (capital expenditure, renewal and maintenance, and operating expenses) and external costs. Furthermore, the user's view of the transport costs is mentioned and the preferences of potential users for several specific scenarios are derived. In the scenarios assessed, a first indication of costs of current transport systems is given, as a boundary conditions under which the Pods system should operate. For the freight transport scenario, based on the example of distribution of retail and parcels in a densely populated region in the Netherlands, the cost per kilometre that a Pods system should compete with is around 6,00 Euro. For the scenario of regional transport in the Plzen agglomeration in the Czech Republic, the costs per passenger kilometre are around 0,20 Euro. It should be noted that these prices cannot be generalised throughout Europe, since cost

elements differ greatly throughout Europe. For the passenger scenario, these differences are even bigger, as pricing and subsidies in public transport are also politically determined.

A more precise comparison of the existing modes of transport with the newly planned inter-modal system will only be possible at a later stage of the project, when parameters of the system have been specified in more detail. With this increased level of detail on the technical and operational characteristics of a Pods system, it is possible to provide a more detailed overview of the costs necessary for such a system. The key parameters will be the costs of the pods, transshipment, and the mobility management system.

2 Abbreviations and acronyms

Abbreviation / Acronym	Description
CBA	Cost Benefit Analysis
CO2	Carbon-dioxide
BEMU	Battery Electric Multiple Unit
DC	Distribution Centre
DMU	Diesel Multiple Unit
EC	European Commission
EEA	European Environment Agency
EMU	Electric Multiple Unit
EU28	EU Member States (2013-2019)
FC	Fuel Cell
GHG	Green House Gasses
HEMU	High-Speed Electric Multiple Unit
HGV	Heavy Goods Vehicle
H2	Hydrogen
IWT	Inland Water Transport
LCV	Light Commercial Vehicle
MAWP	Multi-annual Work Programme
NOx	Nitrogen Oxides
OR	Occupancy Rate
pkm	Passenger-kilometre
PM10	Particulate Matter (particle size 10 $x10^{-6}$m)
PM2.5	Particulate Matter (particle size 2.5 $x10^{-6}$m)
PPP	Purchasing Power Parity
SCBA	Social Cost Benefit Analysis
t	Metric tonne
TCO	Total Costs of Ownership
tkm	Tonne-kilometre
TU	Transportation Unit
UC	Use Case (e.g. UC1, UC2)
vkm	Vehicle-kilometre
WP	Work package
WTT	Well-to-tank
WTP	Willingness to pay

3 Background

The present document constitutes the Deliverable D4.3 “Estimation of economical effort” (WP4 Socio-Economical Evaluation and Requirements, Task 4.3 Allocation / estimation of economical effort) in the framework of the Flagship Area 7, project Pods4Rail as described in the EU-RAIL MAWP.

The current transport system in Europe is characterised by dominant road transport, despite a well-developed rail network. Road transport is characterised by a high carbon footprint and many other negative external influences such as lower safety, pollution, noise and space requirements. Despite all these negative influences, road transport is preferred by its users for both passenger and freight transport, as it offers relatively fast, flexible, reliable and (for passengers) comfortable door-to-door transport.

In today's era of increasing transportation demand, traditional transportation systems often fall short in meeting the requirements for faster, more cost-effective, user-centred and environmentally sustainable solutions. As a response to this pressing need, disruptive approaches have emerged as potential alternatives or complements to conventional systems. These innovative solutions emphasise the utilisation of railway systems as a sustainable mainstay for passenger and freight transportation in combination with cutting-edge technologies. In Pods4Rail, the aim is to give insight into the concept of a digitalised, decentralised mobility system with inter-modal interfaces to different transport modes in order to create a door-to-door-transport chain. While the design of operational management for such an innovative system is contingent upon the system's scope and the implementation phase (assuming basic to advanced phases) defined in the later phases of the project, there is the need for utilising/modifying as needed the existing technologies and understanding the need for the missing ones. Accordingly, the deliverable explores various multi-modal mobility systems by addressing economic, environmental as well as user-centred aspects with relation to passenger and freight transportation to gain insights for future Pod systems.

4 Objectives, system definition and trends

4.1 Objectives

This document has been prepared to provide an essential pre-requisite of the project. In this context, Deliverable 4.3 aims to evaluate/estimate economical effort for the proposed inter-modal Pod system with a focus on, but not limited to, ground-bound systems.
The current phase of the project is mainly focused on the design of transport units for rail transport and their transshipment, with a general definition of interfaces to other elements of the system such as transport units for road transport, cableways, parking and charging stations, signalling and communication.
The main objectives of this task are to:

- Give insight into the contexts where such a system would be operating (system definition).
- Create an overview of the parameters that a Pod system will affect in society.
- Explore different scenarios (one of passenger, one of freight) to obtain insight into the economic and societal advantages and disadvantages a Pod system would have in the future in comparison with conventional transport systems, given that these will develop too.
- Determine in what context a Pod system defined in Pods4Rail would be viable and beneficial for society as a whole.
- Determine the boundary conditions (scope) for an economically viable introduction of the Pods system.

Based on the results of WP2 and T4.1 the list of evaluated use cases is grouped into the main categories “Passenger transport services” and “Freight transport services”.
Two different practical examples (‘scenarios’) have been described for passenger and freight application of pods (UC1-4, UC17-20 as mentioned in D4.1) compared to conventional transport systems.

As there is no sufficiently accurate information about the construction of Pods system vehicles, the necessary infrastructure related to their operation, or about the future influence of some important factors on the development of mobility in the future (electrification, automation, distribution of energy sources etc.), the estimate of economic effort is made as a qualitative estimate of the impact and an approximate specification of boundary conditions for the deployment of Pod systems.
For comparison and a general estimate of the absolute amount of funds, the costs of current transport systems at current prices are quantified as an example. These costs are quantified both according to the CE Delft methodology [1] as total infrastructure costs (including capital expenditures, renewal and maintenance, and operating expenditures) and external costs [2]. In addition, the user's view of travel costs is mentioned and the preferences of potential users for several specific scenarios are inferred.
It is assumed that a detailed economic analysis will be carried out after the system design phase.

4.2 Socio-economic developments

Before (socio-)economic parameters can be discussed, some trends and developments which influence the potential of the new transport system should be mentioned. This provides some background information about transportation modes and changes that are expected to take place in the coming years. It should be noted that this list is not extensive, but tries to give the most important trends and developments of transport systems.

Commuting

Eurostat statistics [3] show that 34.8% of the EU population has to commute to work/study/etc. for more than 30 minutes.

Table 1: Commuting

	More than 60minutes	30-59minutes	1-29minutes	No commuting
EU avg.	8.2 %	26.6 %	61.1 %	4.1 %

Average trip distance

A 2015 EU study [4] shows that the average time of the most frequent journeys is approx. 35 minutes for a car and 75 minutes for a train. The average distances of the most frequent journeys in kilometres are given as approx. 20 km for a car and 38 km for a train [4]. These figures are broadly in line with EU commuting statistics.

Frequency of the trips

The same study [4] reports the average frequency of journeys in the EU28. It is stated that 67% of the population travels every working day of the week, 23% travel 2-3 days a week, 10% travel once a week or less.

Problems related to the most frequent trips

The same study [4] lists the problems that arise during the most frequent journeys. The most important of these are congestion (27%), difficulty of parking (24%), infrequency of public transport connections (10%), and lack of coverage of public transport (10%). The intensity of these problems depends on the location. In metropolitan areas and large cities, the problem of congestion increases to 35% compared to the rural areas, where it is less than 20%. A similar situation occurs with parking problems, which are close to 30% in cities and less than 20% in rural areas. On the other hand, in rural areas, there is a more significant problem with the lack of coverage of public transport and the infrequency of public transport connections, which reaches almost 15%.

Main transport mode

The same study [4] lists the most common transport modes. The EU28 average is 56% by car, 20% by public transport (bus, coach, tram and metro), 7% by train, 1% by motorcycle, 6% by bicycle, 10% by walking. The percentage of passenger car transport increases significantly in rural areas up to 65%, while in metropolitan areas it is around 30%.

Occupancy rate (OR)

The occupancy rate of passenger cars varies by EU country and appears to correlate with the number of vehicles per household. The average occupancy rate in the EU28 is reported to be approx. 1.7 [4]. OR is also different for commuting 1.1-1.2, family trips 1.4-1.7, and travel/tourism 1.6-2.0.

The OR for trains depends on the type of train and location. Various studies indicate occupancy according to the type of train, e.g. EC/IC trains typically 50%, city and suburban trains over 30% during peak hours. Typical average values for regional trains are reported to be 40%, with the OR decreasing with the distance from the metropolis towards the terminal stations. For example, Czech Railways reports 29.4% for 2022 [5].

The OR for buses is quite difficult to calculate because there are no official statistics. It is stated that the optimal OR for buses is between 85-95%. It is known that at peak times the local OR exceeds 100% (i.e. there are more passengers in the vehicle than there are seats and places for standing). Towards the terminal stations/stops, however, the OR decreases significantly, e.g. up to 5%.
Various studies conducted in different locations report the following figures. For example, a study conducted in the UK reports an average OR of approx. 40% in metropolitan areas and approx. 20% in rural areas [6], a study conducted on several routes in Sweden reports average bus occupancy between 40-60% (with min. values of approx. 5% and max. approx. 105%). The OR always decreases in the direction from the metropolis to the terminal stations/stops [7].

For Germany the following figures were identified in 2019 (see table below). [8]

Table 2: Capacity utilisation of passenger transport types

Mode of Transport	
ICE	59 %
EC, IC	49 %
RE, RB, IRE	25 %
S-Bahn	29 %
Public transport with bus, tram, city-train or metro	19 %
Long-distance bus (e.g., Flixbus)	55 %

Electromobility

Electromobility will have a significant impact on the amount of greenhouse gas emissions generated by transport.
The EU Survey on issues related to transport and mobility [4] states that about a third of the population surveyed is ready to consider purchasing an electric or hybrid in the near future. Given that the production of new cars with internal combustion engines should end in 2035, it can be assumed that in 2050 at least 50% of passenger cars will be powered by other powertrains, probably electric.
The speed of introduction of electric cars, vans and trucks depends to a large extent on the support and financial policies in a country. For instance, the sales have risen to more than 30% of all new cars sold in the Netherlands, where subsidies for electric cars were introduced app. 5 years ago.

Car sharing

Car sharing could be one of the alternatives for dealing with problems related to vehicle ownership (initial relatively high investment, repairs and maintenance, parking, congestion, etc.) but for still enjoying the benefits of individual personal car transport (relative freedom of movement, comfort and privacy, flexibility, speed of transport, etc.).
However, the EU survey [4] shows that only 10% of the population surveyed is considering car sharing as an alternative to owning a car. 30% of the population surveyed were not interested in car sharing.
It can be expected that these numbers will improve in favour of car sharing with an increase in parking problems in cities, etc.

Micro-mobility

Micro-mobility (bicycles, scooters, e-scooters) could be an important transport mode for short distances both in cities (commuting to work) and outside cities (transport to the nearest public transport hub), especially in locations with light terrain. Statistics [4] show that currently approx. 6% of the population uses a bicycle for commuting. With the growing popularity of e-scooters and bike-sharing services, an increase can be expected.

Automated/autonomous driving

Possible areas of application for automated and networked driving for local passenger transport include motorised private transport as well as local public transport, i.e., city buses, S-Bahn and metros, and trams. For mobility in the immediate vicinity of living and working locations, there are different usage scenarios for automated road transport vehicles in private and public ownership.

The use of automated and connected privately owned vehicles opens up previously untapped possibilities for owners in road transport: By eliminating the driver's activity, the time in the vehicle can be used for other purposes, similar to the current use of public transport. [9] The advantage of this type of use in comparison with public transport is the privacy. While many passengers commuting to work can only deal with work-related topics using their cell phones, automated vehicle users can work comfortably and undisturbed in private on larger electronic devices such as tablets or laptops.

Especially in traffic jams during rush hour, many people see this as a great added value of automated driving: the opportunity not to have to worry about what is happening on the road, but to use this time in other ways. [10] In addition, the more efficient traffic flow not only significantly reduces the risk of traffic jams caused by excessive traffic or accidents, but also lowers the stress levels of the driver. It is important to note that the effects on traffic flow can only occur once the market has been heavily penetrated by autonomous vehicles, since only then is there a sufficient data basis for assessing the changed traffic flow. [11]

Automated publicly owned vehicles also promise to reduce travel time. Their ability to network with each other and with the users means, more individual route guidance can also be achieved. Since a driver is no longer needed to operate the vehicle, there is significant cost reduction potential here. [12]

Deployment of autonomous vehicles will have a positive impact on externalities, especially accidents and fatalities. Statistics show that the majority of road accidents are caused by human error. Quantitative prediction of the effect is not possible, but several papers declare a positive effect on accidents depending on the so-called penetration rate (i.e. autonomous vehicles/all vehicles). The higher the penetration rates, the lower the number of accidents.

5 Impact parameters

5.1 Introduction

Innovations in the transport sector always raise the question of what socio-economic impact the innovation has and how the innovation can be financed when implemented. Transport solutions that work with autonomous driving systems in particular are expected to enable more dynamic and intelligent forms of public transport, as in the case of the Pods4Rail project with an inter-modal solution for door-to-door transport. In addition to comfort, travel time and reliability, price remains the key characteristic of a transport service. This is significantly influenced by the investments and operating costs that the new system has.

In addition, the external costs of the transport system must also be taken into account for a socio-economic assessment. These external costs include environmental pollution, climate-damaging greenhouse gas emissions, accidents and noise emissions, and excessive resource consumption. Here it is important to estimate the extent to which a new system will have a positive effect on the development of external costs.

Therefore, the prediction of the socio-economic impact for a new transport system depends on a number of factors, some of which can only be estimated or have to be extrapolated from a comparison with existing transport systems. At the current point in time when the Pods4Rail project is being considered, neither the procurement costs for a new vehicle nor the operating costs for a new mobility management system can be precisely stated. Thus, the validity of the scenarios and conclusions considered here depends heavily on the accuracy of the assumptions compared to current offers.

Different classifications into categories of impact and types of impact parameters can be made. A first division that can be distinguished concerns the impacts that can be attributed to the transport system itself on the one hand and the external impacts of the system on the other.

The overview below shows the most important parameters for these two categories:

Transport impacts	**External impacts**
Transport costs	Space requirement
Travel time (passengers)	Traffic safety
Transport time (freight)	External safety
Operating balance	Greenhouse gas emissions
Network impacts	Pollutants emissions
Reliability	Noise
Comfort	Social inclusion (accessibility)
Generative impacts	Congestion

External impacts are, by their nature, not directly paid for by the transport users, nor do the users directly benefit from them. For that reason, they can also be described as “external or societal costs”. This is in contrast to the economic impacts of the transport system, which are paid for or earned directly by the users of the system.

Both categories of impacts can be monetarised, although some parameters can only be valued indirectly or qualitatively. In a societal cost benefit analysis (SCBA), all the effects of a policy measure, including the non-monetary ones, are expressed financially in order to determine whether the societal benefits outweigh the total costs.

An integral SCBA is not carried out in the framework of this economic impact assessment of T4.3. The costs for the Pod system are not identified yet, whereas the design and system choices determine to a large extent the height of the impacts.

The next section of this chapter describes the economic parameters (i.e. costs) and an indication of the different cost categories per transport mode is provided wherever possible. The parameters that are related to the users of the transport system (passengers and freight companies) are described in section 5.3. The societal parameters (external impacts) are dealt with in section 5.4.

A first assessment of the economic performance of the Pods application is carried out for the two scenarios of passenger and freight transport in Chapter 6.

5.2 Economic parameters

A transport system can be described in various ways from an economic perspective.
Economic parameters include the costs and benefits of the system as a whole. On the cost side, a distinction can be made between the costs of construction and maintenance of infrastructure, the means of transport, personnel costs and the costs for management and organisation of the system. The external effects and user aspects also have an economic component. This will be further discussed in the following sub-sections.

5.2.1 Infrastructure costs

Infrastructure costs consist of the following elements: construction costs, maintenance and renewal costs, removal costs and the costs for operating the transport infrastructure (traffic management costs, safety costs etc.). Besides the infrastructure costs, the other system component costs are related to the transport vehicles, energy costs, staff costs, transshipment costs etc.

The infrastructure costs per transport mode vary widely per country and per transport system. The overall division of the total infrastructure costs, including capital costs, renewal and maintenance costs, and operational costs according to the methodology presented in CE Delft publication [1] for the three inland modes for the entire EU28 in 2016 was as follows:

Table 3: Infrastructure costs per transport mode [1]

Road	Rail	IWT
69%	30%	1%

Table 4: Allocation between freight and passenger infrastructure costs in the EU [1]

Passenger	Freight
71%	29%

When we look at the average infrastructure costs (€/1000km) for road and rail passenger and freight transport in the EU28, the picture is as follows [1]:

Table 5: Average infrastructure costs for road and rail passenger transport in the EU28 (€/1000km) [1]

Passenger car	Bus	Conventional rail electric	Rail diesel
20.8	38.9	145.8	219.4

Table 6: Average infrastructure costs for road and rail freight transport in the EU28 (€/1000km) [1]

HGV	Rail electric	Rail diesel	IWT
23	30	32	18.5

In more detail, CE Delft [13] has calculated the infrastructure costs per transport mode per travel-kilometre (for passenger modes), trip-kilometre (for vans) and ton-kilometre (for trucks and freight trains and ships) in the Netherlands. This is presented in the Table 7 below.

Although the figures in this table present data specific to the Dutch situation, the comparison between the modes and the types of fuel/drive is applicable to other EU-countries as well. It is remarkable that public bus transport and trains have a relatively high share of infrastructure costs compared to road. Rail infrastructure in general is relatively expensive compared to road infrastructure. When the vehicles using the infrastructure have a low occupancy, which is generally the case in bus transport, the level of infrastructure costs increases substantially. Electric road vehicles do not imply higher infrastructure costs, whereas the costs for electric rail infrastructure are substantially higher than those for non-electrified railways.

Table 7: Average infrastructure costs per mode [13]

Vehicle category	Costs
Passenger transport on Dutch territory (€/1.000 passenger-km)	
Passenger car average	47
-passenger car gasoline	49
-passenger car diesel	41
-passenger car LPG	43
-passenger car electric	49
-passenger car PHEV	49
Motorbike	20
Moped	43
Bus average	78
-Public transport diesel	183
-Public transport electric	183
Touring car	28
Bicycle average	22
-normal bicycle	22
-electric bicycle	22
Passenger train average	169
-highspeed passenger train	419
-passenger train diesel	318
-passenger train electric	143
Van on Dutch territory (€/1.000 vehicle-km)	
Van average	62
-van diesel	62
-van electric	62
Freight transport on Dutch territory (€/1.000 ton-km)	
Truck average	42
-trailer truck	45
-small truck (<10 ton)	77
-medium-sized truck (10-20 ton)	58
-large truck (>20 ton)	29
Freight train average	87
-freight train diesel	69
-freight train electric	93
Inland shipping barge	23

5.2.2 Vehicle investment costs

In addition to the cost items listed above, the procurement costs for means of transport are a key factor that affects the design of transport options. Depending on the type of transport, these vary greatly, but should not be viewed as singular. On the one hand, the useful lifetime of the different means of transport must be considered, which is on average 10 to 15 years for buses and 30 years for rail vehicles. On the other hand, the procurement of vehicles for local public transport in the EU is supported to varying degrees. Furthermore, the procurement costs must consider the fact that different models are used to procure new vehicles. Today, many companies offer the rental of rail vehicles, where the operators only lease their vehicles.

Since each time a vehicle is purchased, the operating company makes a central decision for several decades of its business activity, the procurement costs are an essential factor that must be considered when developing a new system. The following overview provides a summary of the procurement costs for public transport vehicles, as well as vehicles that form a comparison with the use cases listed in D4.1 as part of the Pods4Rail project. The price of a vehicle basically depends on the manufacturer, the number ordered, the required equipment and the country. Therefore, the procurement costs as mentioned in following table are only to be understood as a guide.

To achieve a comparable cost base to today's means of transport and to achieve a competitive advantage, the planned transport units and the associated carriers should be within a cost framework that corresponds to today's systems and can be increased by a factor yet to be named due to the envisaged autonomous operating concept. The comparison in the procurement costs of a conventional minibus (VW Multivan) with an autonomous minibus suggests a factor of 5, which is caused by the complete equipment for autonomous driving. However, it should be considered that the known procurement costs of autonomous minibuses relate to prototypes or small series and are therefore not representative of a vehicle from series production.

Based on the procurement costs presented and those in D4.1, Section 7, Basic dimensions for Transport Units, the "TU Type C" in the form for use in public transport can best be compared with standard buses. For the "TU Type B" in the form for use in public transport, a cost comparison with minibuses would be relevant. If a “TU Type B” is used for purely private purposes, it makes sense to compare the costs with a caravan.

For the planned carrier, a pure cost comparison is difficult because there are no comparable vehicles in the railway sector. The proposed carrier could best be compared with Automated Guided Vehicles (AGV) used for internal transport in industry and logistics. Otherwise, only a cost calculation based on the necessary equipment for the rail carrier would be possible. In general, it must be said that a direct comparison of the procurement costs of the vehicles for the system envisaged in the Pods4Rail project does not make sense, as the entire system must always be considered and the total procurement costs for the system are compared to the overall benefits that the system offers compared to conventional transport modes, similar to how a cost-benefit calculation for AGV is done, for example in the logistics sector. [14]

The Table 8 shows the great range in investment costs for the various types of modes and vehicles. In general, rail vehicles are far more expensive to purchase than road vehicles. At this moment, electric traction for road vehicles is still relatively expensive (up to 3x more investments required), but the prices for electric cars, buses, vans and trucks are dropping quickly. It should also be noted that the purchasing costs are only a part of the total costs of operation. Maintenance, depreciation, staff and management costs determine to a large extent the overall operational costs of a certain vehicle.

Table 8: Procurement costs of rail and road vehicles

Type of transport vehicle	Procurement costs [per piece]	rel. Year	Source
Train			
EMU, Type "Flirt" (similar SBB RABe 521.0, Bo' 2' 2' 2' Bo')	5,000,000 €	2022	[15]
Tram			
Tram (30 / 50 m length, 117 pcs. Flexity Berlin)*	3,000,000 €	2020	[16]
Tram (43,3 m length, 30 pcs. NGT DX DD for Dresden)*	4,200,000 €	2022	[17]
Tram (42,5 m length, 10 pcs. Tramlinks for Erfurt)*	4,050,000 €	2023	[18]
Tram (38,2 m length, 35 pcs. NGT 10 D – Flexity Magdeburg)*	5,400,000 €	2023	[19]
* … incl. service and spare parts			
Bus			
Articulated Bus (18 m length)	350,000 €	2023	[20]
Standard Bus (12 m length)	250,000 €	2023	[20]
Standard Bus (12 m length, gas-powered)	290,000 €	2023	[20]
Standard Bus (12 m length, low-floor technology, combustion engine)	254,000 – 311,000 €	2021	[21]
Standard Bus (12 m length, electric drive, battery)	180,000 – 220,000 €	2023	[20]
Standard Bus (12 m length, low-floor technology, electric drive)	418,000 – 628,000 €	2021	[21]
Standard Bus (12 m length, electric drive, occasional battery charging)	550,000 – 690,000 €	2023	[20]
Conventional Trolleybus (12 m length)	540,000 – 610,000 €	2023	[20]
Hybrid Trolleybus (12 m length)	580,000 – 670,000 €	2023	[20]
Fuel cell buses (12 m length)	580,000 – 650,000 €	2023	[20]
Minibus			
Minibuses with combustion engines	174,000 €	2021	[21]
Minibuses with electric drive (estimation)	300,000 €	2021	[21]
VW Multivan (150 kW, 7 seats, combustion engine)	53,056 €	2024	[22]
VW ID. Buzz Pro (150 kW, 5 seats, electric drive)	64,581 €	2023	[25]
Taxi			
Taxi	30,000 to 50,000 €	2021	[21]
Autonomous Minibuses			
Navya's small autonomous shuttles	300,000 $	2018	[22]
EasyMile's shuttles	250,000 $	2018	[23]
MILLA Pod (v_{max} 30 km/h)	< 35,000 €	2020	[24]
Caravan and Camper			
Caravan trailer, 6 m length (Knaus, Sport)	20,190 €	2024	[26]
Caravan trailer, 6 m length (Bürstner, Premio Plus)	22,830 €	2024	[27]
Camper, 6 m length (Bürstner, Lineo T)	61,430 €	2024	[28]
Camper, 12 m length (Vario Perfect 1200)	1,155,160 €	2024	[29]
Container, Swap Body			
20' Standard Container	2,650 – 5,400 €	2024	[31]
20' Office Container (13 m^3)	7,730 €	2024	[32]
Swap Bod, Class C (acc. EN 284, smooth exterior wall)	14,650 – 15,990 €	2024	[33]
Automated Guided Vehicles (AGV)			
AGV	60,000 – 150,000 €	2021	[30]
Krane			
Reach stacker	130,000 – 250,000 €	2024	[34]
Van			
Delivery van diesel (Volkswagen Crafter)	30,000 – 45,000 €	2024	[35]
Delivery van electric (Volkswagen iD Buzz Cargo)	60,000 €	2024	[35]
Truck (medium sized)			
Medium sized truck diesel	55,000 €	2024	[36]
Medium sized truck electric	90,000 €	2024	[36]
Truck (large)			
Large truck diesel (MAN TGS 22.480 BB SA)	95,000 €	2024	[36]
Large truck electric	150,000- 175,000 €	2024	[36]
City Trailer	25,000 €	2024	[36]

5.2.3 Personnel costs

Another factor when considering a new, autonomously operated transport system is personnel costs. Following table shows known personnel costs for Germany.

Table 9: Personnel Cost in Germany between 2015 and 2023 [37, 38, 39, 40]

Type	Personal Costs	Year
Personal Cost, Bus driver, Electro Bus	1,65 €/km	2015
Average Gross Income, Train driver	49.556 €/a	2022
Average Gross Income, Driver for bus, tram, city-train or metro	40.369 €/a	2022
Average Gross Income, Tram driver	36.000 €/a	2023
Personal Cost, Tram driver	300.000 €/a	2023

The premise for an autonomously operated transport system assumes that there would be no need for people to drive the vehicles, but staff would be required for emergency operations from an operations centre and staff to support the mobility management system. The current assumptions as to how great the cost savings can actually be achieved vary greatly. A Swiss study from 2017 indicates that, assuming there is no longer a need for train drivers, a 4.7% reduction in costs per kilometre can be expected. [41] Other studies show a cost saving of 10% when considering the operation of autonomous buses compared to conventional scheduled operations in local public transport. [42]

5.3 User parameters

The competitive position of a transport system is determined by a combination of economic impacts (prices for the users and costs for the society) and the more qualitative impacts for the users. In the case of a passenger application of Pods, the most important user parameters are:

- Comfort
- Reliability
- Punctuality
- Flexibility

Quantification of these impacts in terms of costs and benefits is not always possible, whereas the different parameters are interrelated. Comfort for instance is a less objective parameter for a passenger, who will compare a certain transport system or vehicle type with other known means of transportation. The reliability of a system depends on the number of delays or disruptions of a planned service or, in the case of private car, the amount of congestion or technical condition of a vehicle. Flexibility is generally influenced by the number of services and/or alternatives a traveller has.

For freight transport, the objective economic indicators (prices and costs) are more dominant in the choice of a certain transport mode. However, the following user parameters are of important indirect influence on the proposition of a transport mode:

- Flexibility
- Reliability

The main reason for the enormous growth of road transport in the past decades, mostly at the cost of rail, is the combination of decreasing costs and high flexibility and reliability. A transport system that wants to compete with road has to achieve a certain degree of flexibility and reliability. The Pods system will be able to compete with autonomous road transport with respect to flexibility and reliability when it is using the road infrastructure. For the rail stretch, the flexibility and reliability can be lower than on the road, depending on the level of congestion on the latter.

5.4 Societal parameters

The introduction of a Pods system as described earlier has an impact on a variety of societal parameters as well. The most relevant are: space requirements, safety, greenhouse gas emissions, pollutants, noise, accessibility and agglomeration effects.

As can be seen in following table (Table 10), these parameters have been quantified in costs per ton-kilometre or passenger-kilometre. From this table, it can be seen that the most influential societal parameter in that research is congestion/delay costs, followed by accidents and emissions from either greenhouse gasses or air pollutants.

Table 10: External costs per passenger and tonne kilometre [2]

	Passenger transport			Freight transport		
	Car	Bus	Rail	LCV	HGV	Rail
Cost category	€-cent/pkm	€-cent/pkm	€-cent/pkm	€-cent/tkm	€-cent/tkm	€-cent/tkm
Accidents	4.5	1.0	0.5	4.1	1.3	0.1
Air-pollutions	0.7	0.7	0.12	2.4 *)	0.8	0.2
Climate	1.2	0.5	0.05	2.7 *)	0.5	0.06
Noise	0.6	0.3	0.9	1.1	0.5	0.6
Congestion (delay cost)	4.2	0.8	0	11.6	0.8	0
Well-to-tank	0.4	0.2	0.7	0.8	0.2	0.2
Habitat damage	0.5	0.1	0.6	0.9	0.2	0.2
Total	12.0	3.6	2.8	23.6	4.2	1.3

*) average petrol and diesel

The current transport/mobility systems emit substances such as CO2 and NOx, PM10 and PM2.5, which negatively impact the environment and air quality. Changes within the existing systems (electrifying vehicles, limiting the number of vehicle kilometres, etc.) are already improving these parameters, but the introduction of a new system could improve this even further, depending on the scenario. Noise is another parameter that impacts society as a whole; a transport system that creates a lot of noise creates less liveable places. Changes in the transport system could reduce the noise created by transport systems and therefore reduce nuisance and improve liveability around corridors of these systems.

It is currently difficult to estimate what influence the autonomous operation of vehicles will have on the frequency of accidents, as only small to no relevant values are available. It is assumed that autonomous and therefore safer driving on the road would reduce insurance premiums by 50%. This is considered conservative because with today's Tesla Autopilot, accident rates have already reportedly decreased by 40%. [41] When looking at the number of accidents, it must also be taken into account that the risk of death and injury with buses and trains is significantly lower than with ordinary cars. [43] Automated driving systems do not suffer from human weaknesses such as fatigue, inattention, arrogance or impatience. An autonomous vehicle will always adhere to the rules programmed into it and is also able to process a large amount of information simultaneously and immediately, as well as adapt its behaviour immediately and without a moment of shock. [G] This is shown by the diverse experiences with automated rail transport systems, such as the Metron in Nuremberg.

Other societal parameters are not quantified by CE Delft [2] or other sources, and therefore are not included in the table. Nonetheless, these parameters are relevant for this research. The parameters included in this report regarding this matter have spatial implications, and are categorised into spatial requirements, accessibility and agglomeration effects. The first category is the actual space that is needed for a new mobility/transport system. This includes not only roads or rails, but also points of transfers (e.g. stations, transshipment points, parking places, etc.).

Another important societal implication of transport systems is the accessibility that such a system creates. The more a certain place is accessible, the more that place could (economically) interact with other places. An example is tourism; the more a place is accessible, the more tourists it is able to attract, and therefore value is created.
By connecting places to each other (and thereby enhancing the accessibility of those places), inherently other places will to some degree be excluded and potentially be economically harmed by that. An example of this is a direct train line that is set up between Amsterdam and Rotterdam. This direct train line crosses multiple villages and small towns, and excludes them from profiting from the line. Potentially, this could harm the excluded villages, because economic activity and people tend to be attracted by accessibility. Changes in transport systems could help mitigate such a trend of agglomeration shadows.

Economic activity is attracted to nodes in transport systems, since people are at those places and these nodes are the most accessible. By putting nodes in certain places, economic activity could be fostered. This phenomenon is called the agglomeration effect.

6 Assessment of the Pods system in two selected scenarios

6.1 Introduction

This chapter assesses the performance of the Pods system in two different scenarios. Firstly, scenarios are formulated for both passenger and freight transport by picking a region and a system and describing the performance of current systems in the selected scenarios. From there, the Pods system in the scenario will be discussed following the parameters mentioned in the previous chapter. Since there are no real-world values of, for example, infrastructure costs of a Pods system, this discussion will give minimum benchmark values that a Pods system needs to comply with to be a competitive mode of transport.

The passenger scenario is described and analysed in paragraph 6.2 and the freight transport scenario in 6.3. The conclusions for the application of pods in the two scenarios are summarized in paragraph 6.4. The synergy between the passenger and freight transport scenarios is also described in the last paragraph of this chapter.

6.2 Passenger transport scenario

The scenario “local passenger transport network around the city of Plzen” was chosen for benchmarking Pods deployment in passenger transport in a regional transport subsystem.

Short description of the system
A local railway network (a mixture of main lines and branch lines) combined with a relatively dense bus network, city mass transport and a high density of passenger cars.
The main part of the railway network has a star structure, where Plzen - Main Railway Station is in the centre. The terminal nodes included in this study are towns located close to the city. The majority of passengers from these regions commute daily for work, studies, and similar reasons. The rail network uses both double- and single-track lines, electrical and independent (mainly diesel) drives are used (see Fig. 1 and detailed description in Annex 10.1).

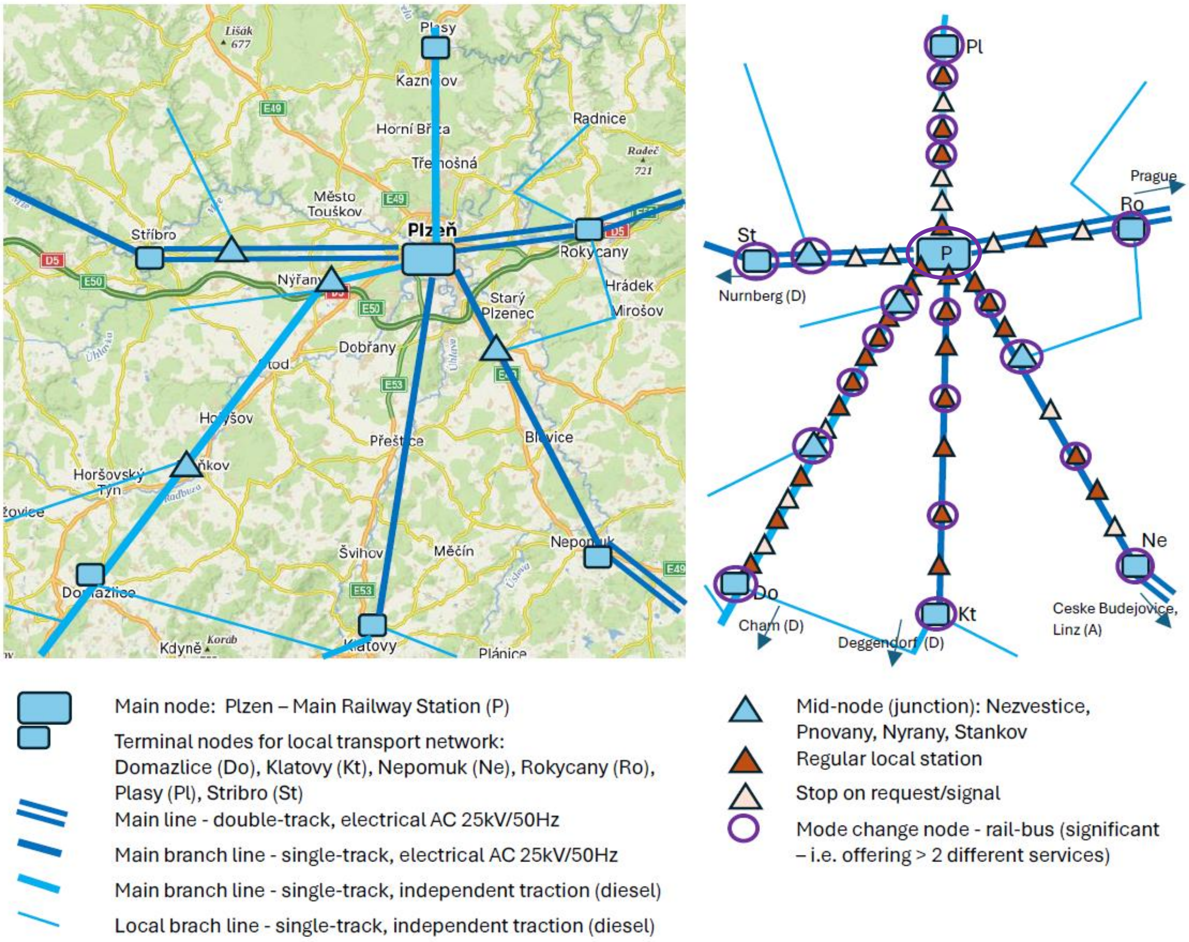


Figure 1: Local passenger transport network around the city of Plzen

Fast services (long-distance trains) typically stop only at terminal nodes or 'important' mid-nodes (junctions or connections to another transportation mode), and continue to more distant destinations. Slow services stop almost everywhere and are intended to serve the local area.

There is also a bus-service network complementary to the rail network, with a net structure servicing the areas beyond the rail lines. Buses are powered by diesel engines.

The whole subsystem is interconnected with the city mass transport, consisting of trams, buses, and trolleybuses.

There is also heavy passenger car traffic, which causes congestion every day during rush hours.

Route parameters

Table 11: Route parameters

Route	Distance [km]	# of mid-stations/stops			Fast (long-distance)-train services per workdays			Slow (local)-train services per workdays			Bus services	
		Total	Regular	On signal	# of services (mid-stops)	Travel time [hour-min]	Est. transport performance *) [person / day]	# of services (mid-stops)	Travel time [hour-min]	Est. transport performance *) [person / day]	# of services (avg. travel time) [hour-min]	Est. transport performance ***) [person / day]
P-Ne	34	8	6	2	9 (2)	25m	1080 **)	18 (6-8)	40m	1750	N/A	
P-Kt	45	7	7	0	9 (3)	49m	1080 **)	7 (7)	57m	840	14 (1h)	280
P-Do	59	15	12	3	8 (2)	50m	780 **)	15 (12-15)	1h15m	1800	13 (1h30m)	320
P-St	32	3	1	2	9 (1)	25m	1080 **)	7 (1-3)	29m	840	12 (50m)	200
P-Pl	33	7	4	3	7 (1)	32m	670 **)	16 (4-7)	40m	570	>10 (ap.50m)	240
P-Ro	17	3	1	2	17 (0)	10m	2000 **)	36 (1-3)	15m	4200	>15 (ap.10m)	500 **)

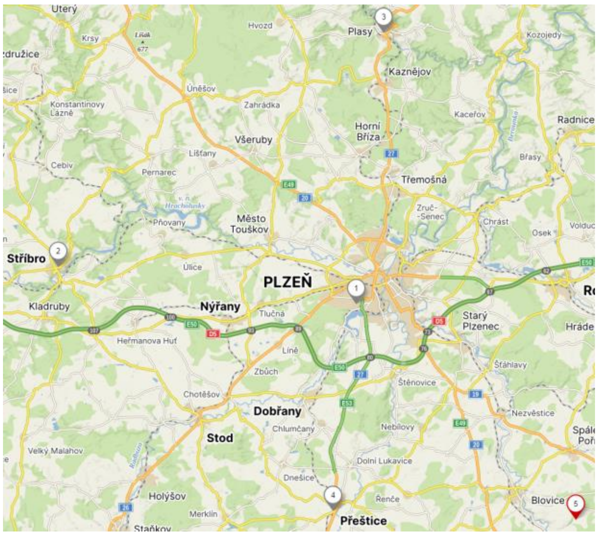
*) Average occupancy for trains is 29.4% (CD year report 2022 [5])
**) Part of the passengers continue to distant destinations
***) Estimated avg. occupancy 40%

Node description

Table 12: Node description

Route	Region/ Municipality	Population [persons]	Total population in towns on route	Land Registry Area [km²]	Average density of population [persons/km²]
	Region Plzen	605,388		7,561	80
	City of Plzen	181,240		137.64	1300
P-Ne	Nepomuk	3,560	14,624	12.8	280
	Stary Plzenec	5,414		18.4	290
	Nezvestice	1,466		6.4	230
	Blovice	4,184		28.96	140
P-Kt	Klatovy	22,496	37,283	80.9	280
	Dobrany	6,360		35.32	180
	Prestice	6,750		25.41	270
	Svihov	1,677		34.5	50
P-Do	Domazlice	11,010	35,564	24.6	450
	Nyrany	6,935		22.79	300
	Stod	3,610		20.04	180
	Holysov	5,489		29.32	190
	Stankov	3,388		20.50	170
	Horsovsky Tyn	5,132		71.31	72
P-St	Stribro	7,975	7,975	47.8	170
P-Pl	Plasy	2,993	15,544	57.1	50
	Tremosna	5,020		18.12	280
	Horni Briza	4,411		14.5	300
	Kaznejov	3,120		12.3	250
P-Ro	Rokycany	14,309	14,309	30.67	470

Evaluation of several potential trips



Example trip #1
Daily commuting from a village (Lounova) (5) to Plzen (1).

Example trip #2
Commuting from a village (Lounova) (5) to Stribro (2)

Example trip #3
Commuting from a village (Lounova) (5) to Plasy (3)

Example trip #4
Daily commuting from a village (Lounova) (5) to Prestice (4)

Figure 2: Potential trips

A detailed description of the trips is available in Annex 10.1

For the following comparison the shortest waiting times are chosen. Thus, the everyday reality will be less optimistic.

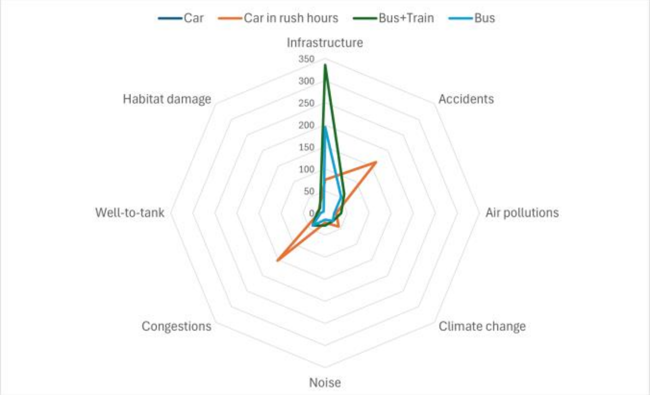
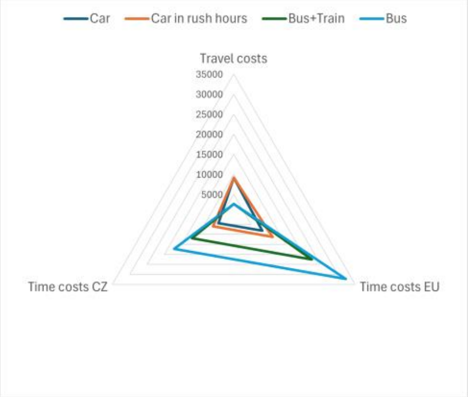
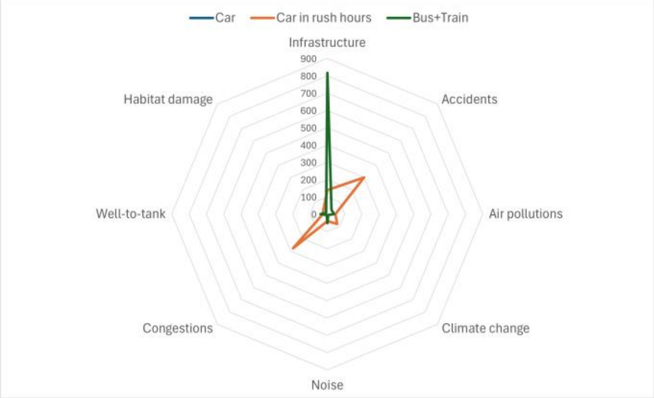
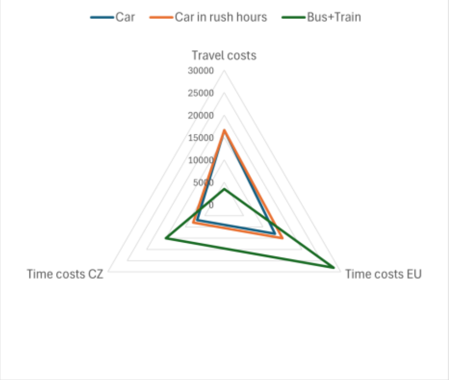
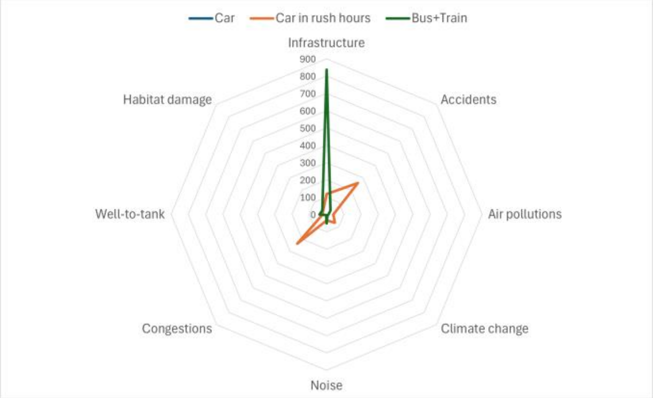
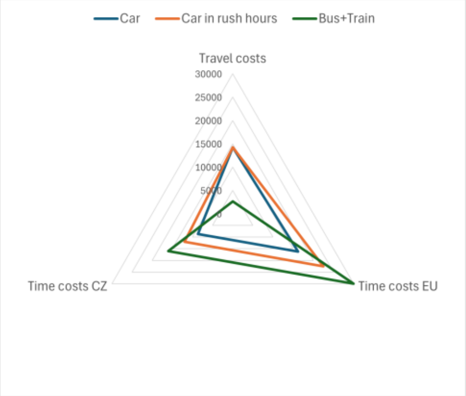
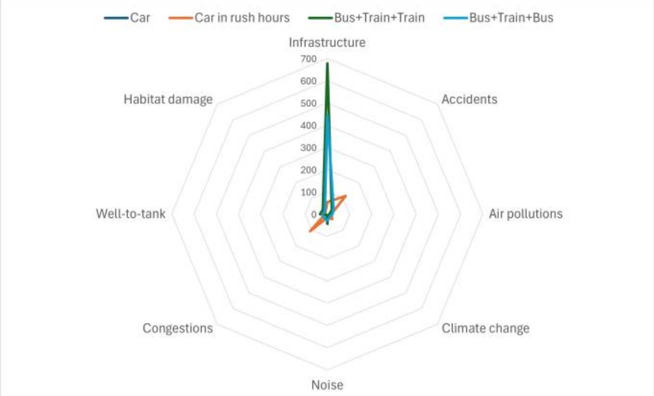
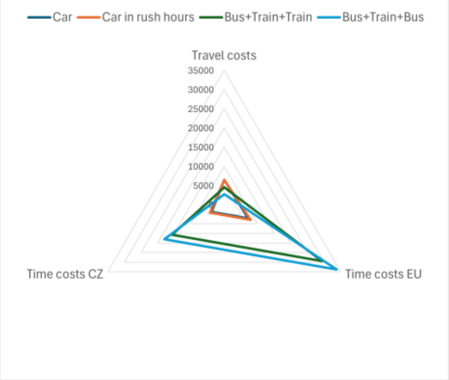
For all trips by car, it is typical, that the vehicle is used for only a short time in the day and the rest of the day it remains parked. Fees for parking are not considered.

Comments on the results

Evaluation of the costs per pkm shows that all the combinations are comparable a from “society-point-of-view” and the differences in total costs are not very significant. The higher infrastructure costs of rail transport are compensated by the negative impact of cars to the externalities. However, the situation is very different from the “user-perspective”. Time costs connected with the trip are very high in comparison with the travel costs. The difference is more important for the population with higher incomes (i.e. close to the average salary and higher). People with lower incomes (lower salaries, lower car availability, less chances for making more money in overtime) usually prefer using public transport and tolerate long waiting times.

Note: The difference between “user perspective” for different mode combinations is more visible when the trip is relatively short, and the target destination lies in the suburbs on the same side of the city (i.e. it is not necessary to cross the city by car).

Table 13: Costs comparison for potential trips

Trip	Costs (society-point-of-view) in €-cents	Costs of the trip from user perspective in €-cents
#1		
#2		
#3		
#4		

Potential for Pods system deployment

To estimate of the impact of the Pods system the average length of a typical trip for daily commuting when using pods is assumed to be about 30 km (from 20 to 50, shorter more frequent), of which about 20 km on average will be made by rail.

Table 14: Potential benefits of Pods for 30 km trip (see Table 10)

Trip 30km	Rail	Road conventional	Pods
Congestion [€-cents]	0	126	42
Accidents [€-cents]	15	135	55
Noise [€-cents]	27	18	24
Total per trip [€-cents]	42	279	121
Total per vkm [€-cents]	1.40	9.30	4.03

For longer journeys, where a significant part will be shifted to rail, the benefits of the Pods system will be even more visible. The following table shows a comparison of important parameters for journeys of 100 km, of which 80 km are carried out by rail.

Table 15: Potential benefits of Pods for 100 km trip (see Table 10)

Trip 100km	Rail	Road conventional	Pods
Congestion [€-cents]	0	420	42
Accidents [€-cents]	50	450	90
Noise [€-cents]	90	60	87
Total per trip [€-cents]	140	930	219
Total per vkm [€-cents]	1.40	9.30	2.19

The Pods system can offer higher comfort of travel (door-to-door, without changing/leaving the vehicle at the mid-stops). For the trips above the Pods can compensate:
- the time and discomfort of walking to the bus stop,
- the necessity of changing vehicles several times and the discomfort connected to that,
- using public transport and walking to the site,
- the pods concept can also increase the utilisation rate of the vehicles (circulating carriers operating 24/7).

Positive impacts of the Pods can be seen in the externalities, especially reducing the congestion by transfer of part of the road traffic to rail.
An important requirement for the Pods from a user perspective is that the handling time (handling costs) must be comparable to current times for mode change. Fares should not be significantly higher than for other public transport.

The infrastructure costs for both rail and road Pods are supposed to be comparable, an increase for Pods handling and storing costs, logistics and planning costs must be taken into account. These extra costs for the additional subsystems should not be very high in order to make the whole system viable.

Capacity requirements

The capacity requirements of the Pods system are estimated based on estimated current average transport performance on individual lines.
In accordance with D4.1, Type A transport modules (UC1-UC4 - public transport) are considered.

Table 16: Transport unit Type A parameters

Module	Length [mm]	Width [mm]	Height [mm]
Type A	6,058	2,550	2,900

Use-case	UC1	UC2	UC3	UC4
# of seats	12	6	2	18 *)

*) leaning seats – space for 1 passenger 650x650mm, 6rows, 3seats each

Table 17: Capacity requirements

Route	Avg. # of passengers in one direction per hour (current situation)	Avg. # of TU (UC4) in one direction per hour	Avg. # of TU (UC1) in one direction per hour	Avg. # of TU (UC4) per hour (corrected for # of tracks)	Avg. # of TU (UC1) per hour (corrected for # of tracks)	Avg. time interval between services in both direction [minutes]	Comment
P-Ne	109	6-7	9	13	18	3.3-4.6min	Single-track line (only first ap.10km doubled)
P-Kt	120	7	10	14	20	3.3-4.3min	Single-track line
P-Do	112	6-7	9-10	13	18	3.3-4.5min	Single-track line
P-St	120	7	10	7	10	6-8.6min	Double-track line
P-Pl	54	3	4-5	6	9	6.7-10min	Single-track line
P-Ro	113	6-7	9-10	6-7	9-10	6-8.6min	Double-track line

It is clear from the table above that the intervals between individual transport units (TUs) are extremely short. For single-track lines, these times are (currently) unfeasible due to the distance of stations where oncoming connections may meet. For double-track lines, the intervals are longer and there is no need to take into account the meeting of oncoming connections, but these lines are designed for higher travel speeds (i.e. the potential risk of collisions is increased).

It is therefore obvious that the concept of operation of isolated TUs (Type B, or 2xType A) will be feasible only to a very limited extent, i.e. only at certain times and only on certain lines.
Average times between individual connections are calculated assuming that the average occupancy is approx. 30%. Depending on the time of day, occupancy will vary between approx. 5% to 100%. This can be compensated by a decrease in passenger comfort (e.g. by including more UC4 units during peak hours), by increasing the frequency of connections (# of TUs), by

chaining/connecting TUs, etc. Furthermore, it can be assumed that the current single-track lines will be upgraded to double-track lines in the future.

In any case, for the operation of the Pods system the development of an operational system (planning and logistics) will be crucial, and a significant strengthening of safety features on both moving and fixed infrastructure is required.

Transshipment (handling of transportation units)
Compared to conventional transport modes there are additional requirements for transshipment infrastructure – storage and recharging of carriers, additional equipment of vehicles for reloading capsules, coupling devices etc.
Costs of transshipment is thus an important factor to take into account.
Transshipment points must be located where it is possible to build parking and charging infrastructure for carriers, with optimal coverage of the surrounding area using Pods on the roads. This will require detailed analyses and planning of transport capacities depending on the location. In the case of a network like the analysed scenario, we assume 2-3 transshipment points on the rail branch line and the main terminal in the centre.
The exact price of transshipment per vkm or per pkm is difficult to estimate since detailed requirements and costs are unknown.

The Pods system is assumed to have a technology that enables the Pods to transship from modality autonomously. This would reduce the costs of transshipment (and possibly increase the costs per Pod). An external infrastructure (e.g. cranes, depots, etc.) will probably be used only in high-capacity terminals.
It is crucial for the viability of the Pods system that the transshipment time is not higher than the average time for changing the transport mode in the conventional system.

User impacts
The introduction of the Pods system will impact the user experience of each system (logistic service providers in this scenario). As discussed in the previous chapter, this mostly relates to flexibility, reliability and punctuality of the system. These parameters are relevant for the assessment of the Pods system, since these factors heavily influence the modal shift potential, as can be seen in the previous chapter:

- Flexibility: between conventional and autonomous road and rail;
- Reliability: higher than road, comparable to rail;
- Punctuality: higher than rail, comparable to autonomous road.

Societal impacts
The main impact on the environment of a new transport system is caused by the shift from road to rail. The latter mode has a higher energy efficiency, lower emissions and spatial requirements and a better safety record than road.
The external impact in this example can be calculated in terms of kilometres per vehicle type that are shifted to the rail stretch of the Pods system. As there is not enough information available yet

on the characteristics and performance of the Pods system, it is assumed for the road part of the transport chain that the Pods system is comparable to an autonomous driving microbus.

The external impacts of a shift from conventional road transport to the Pods system using rail can be reduced to the following parameters:

- Congestion - The shift of part of the traffic to rail will positively influence the density of the road traffic and decrease congestion,
- Noise – The level of the total noise is expected to be somewhere between rail and road traffic,
- Traffic safety (Accidents) – The number of accidents and the additional costs induced by the accidents will be significantly reduced by transferring part of the road traffic to rail,
- Habitat damage – This is expected to be similar to roads and rails,
- Use of space - The Pods system will require additional space for temporary storage of the carriers, recharging, and handling process, but it will be compensated by saving space for parking personal cars and higher utilisation rate of Pods (number of operational hours of the vehicle per day) due to circulation of the carriers. It can be also expected that circulation and sharing of the carriers will decrease the need for owning a personal car (i.e. number of registered vehicles), which can also have a positive influence on road traffic density.

The impact on greenhouse gas emissions will be negligible, assuming that in both situations the electric energy for transport and transshipment is generated on a sustainable basis. It can be assumed that Pods systems will have a positive impact on the accessibility of mobility services and decrease the agglomeration effects.

6.3 Freight transport scenario

The scenario chosen for the benchmark of the Pods deployment in freight includes the transport of retail goods and the distribution of mail and parcels on a regional scale and using regional rail and urban rail and road networks.

The region selected for this scenario is the area called Metropoolregio Rotterdam-Den Haag, in the south of the province South Holland in the Netherlands. It has a total population of app. 2.5 million people, with the metropolitan cities of Rotterdam and The Hague as the biggest agglomerations. With an area of only app. 1,300 m^2, the population density is very high. The centre of the region however has a more rural character, acting as a ‘green lung’ between the large cities.

Short description of the freight flows and current transport system:
A substantial part of the regional freight flow consists of distribution to retail outlets and delivery of parcels to households. The retail freight sector has its distribution centres (DCs) often near large urban areas, whereas the DCs of parcel and post companies are in the populated areas of the region.

The flow of products between production locations and DCs (and between DCs in the case of parcels and post) is carried out by road transport, using semi-trailers. The transport from DCs to supermarkets and other retail outlets is also carried out by road, using medium-sized to heavy trucks. The distribution of parcels is carried out by delivery vans. These vehicles are increasingly electrified in order to reduce the emission of pollutants, noise and greenhouse gasses.

The following figure gives an example of the potential usage of rail infrastructure and the DCs in the Rotterdam-The Hague area in the Netherlands. In this region there are a few major DCs from PostNL and DHL, as well as three large retail DCs (Albert Heijn, Hoogvliet and Jumbo). The rail infrastructure includes regional light rail connections between Rotterdam and the Hague and in and around Zoetermeer. With a minor extension of these networks the Pods could be transported on this rail network around the entire region.

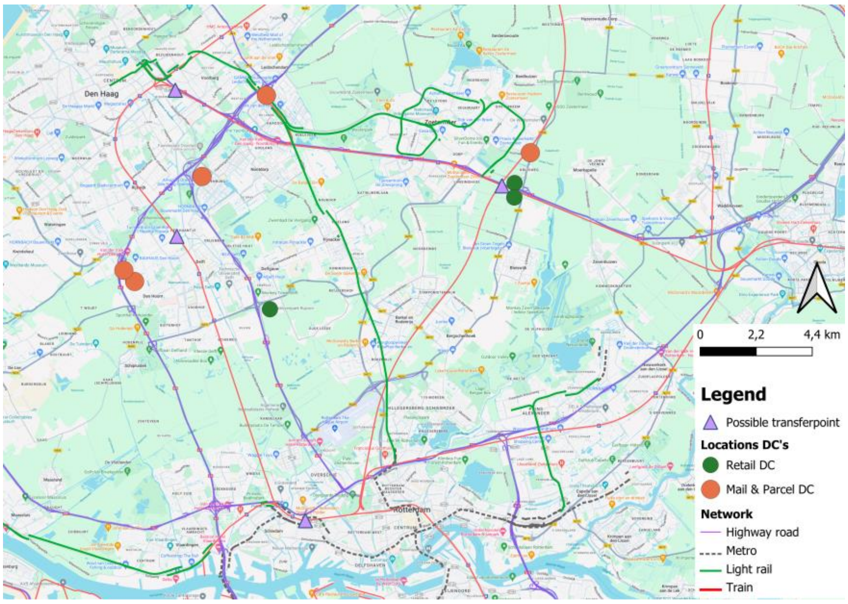


Figure 3: Map of the freight transport scenario, including retail and parcel DCs

Freight flow characteristics:

The flows from the DCs of retail freight are extensive. The number of trucks leaving the DC for supermarket delivery can reach up to 150 per day, servicing 200 to 300 stores in the region. The number of trolleys per transport is between 36 and 50, so daily something between 4,000 and 7,000 trolleys are transported. The average trip length of a retail delivery will be app. 60 to 100 km per day per truck, being 20 to 30 km per store with an average of 2 to 4 stops per trip.

For parcel and post distribution, between 100 and 200 vans daily start their delivery trip from the DC. The number of stops per van is large, between 50 to 75 stops per trip.

Potential for the deployment of Pods

For the transport between the retail DCs and stores, the Pods can use the existing regional and light rail infrastructure between and into the cities. For the last mile, transshipment from a rail terminal to the road infrastructure road v.v. is required. Connection terminals at or in the vicinity of the DCs is also required. The Pods used for retail will be larger than the Pods for the parcel and post distribution.

Pod capacity and trip length

A standard size 20 feet Pod has a capacity of app. 20 trolleys, a 40 feet Pods could carry 40 trolleys, which are both sufficient for store delivery. A 10 feet Pod will transport the equivalent of a medium-sized van.

The average trip length when using Pods will be around 25 to 50 km in the example of this region for retail delivery, of which 15 to 30 km is using the rail infrastructure.

The trip length for post and parcel delivery will be up to 60 km, of which 10 to 20 km is transported by rail.

Required transshipment infrastructure:

The number of transshipment points and terminals will depend on the structure of the network and the number of intermediate stops at DCs. In the example of the Rotterdam- The Hague area a total number of 3 to 5 transshipment points per line is envisaged.

Summary of the system characteristics/performance:

Table 18: Summary of the system characteristics/performance

	Retail flows	Parcel flows	Total
# DCs	3	5	8
Average trip length (total km)	75	60	
Average trip length on rail (km)	25	20	
Trip type	Point-point, roundtrip	Roundtrip	
# trips per day per DC	100	150	
# of trips on the network	300	750	
# of kilometres on the rail network/day	7,500	15,000	22,500
# of kilometres on the road network/day	7,500	30,000	37,500
Total # kilometres/day	15,000	45,000	60,000
Average # stops per trip	2-4	50-150	
Average weight per trip (kg)	12,000	300-1,000	
Average weight per stop (kg)	4,000	4	
Total # tonne kilometres/day	180,000	22,500	202,500
Of which on the rail network	90,000	7,500	97,500
# trips per day per DC	100	150	

Economic parameters

The present system of retail and parcel distribution is characterised by highly efficient and relatively low-cost transport.

The cost price of a semi-truck with a city-trailer, which is typically used in supermarket delivery, is on average around € 240,000 per year or € 800 per day (based on 6 working days per week and 12 hours driving time). Per stop, the costs of retail distribution will be around 300 Euro. When, in the near future, electric trucks are used, the distribution will be slightly more expensive, particularly in the transition period. It can be expected that the total distribution costs will increase by 10 to 15 %. The costs per stop will rise to a maximum of € 350, the costs per day could go up to € 900 with an electric truck. The average costs per km are app. € 5.30, based on a total average mileage of 45,000 km/year.

The costs for a van and driver for parcel delivery are app. € 75,000 per year (€ 300 per day or € 2.00 per stop), of which app. € 65,000 are salary costs. For an electric van, the total costs per year will be app. € 80,000, or € 2.20 per stop. The expectation is that the TCO (Total Costs of Ownership) of an electric van will be equal to that of a diesel variant within 2 to 4 years. The costs per km for parcel delivery are around € 5.50 to € 6.00, given an average annual mileage of 15,000/year for a delivery van in this example.

Table 19: Economic performance of the freight scenario

	Retail flows	Parcel flows
Km per year per vehicle	45,000	15,000
Costs per year per vehicle	€ 70,000 - € 90,000	€ 10,000
Cost per year per driver(s)	€ 150,000	€ 65,000
Total costs per year per vehicle	€ 220,000 – € 240,000	€ 75,000
Total costs per vehicle-km	€ 5,30	€ 6,00
Total costs per stop	€ 300 - € 350	€ 2.00 - € 2.30

These figures give a first indication of the financial limits within which a new transport system should compete with conventional transport. As far as the driver costs are concerned, an assumption can be made that there is no principal difference between the Pods system and the use of autonomous trucks and vans on the conventional road system. The last-mile distribution of parcels to homes will require human input, unless automated drop-off at pick-up points is applied, or the pods are equipped with an automatic issuance system.

Transshipment

Compared to the conventional flows there are additional transshipment points needed, as the DCs are not directly connected to the railway infrastructure and the last mile will be done via the road network to the end receiver. Costs of transshipment is thus an important factor to take into account. The exact price of transshipment per container is around €70. Transshipment of goods from road to rail in a European context are a big cost element for the cost of transport (in 2021 from 15 to 30% of the total costs of transport [44]).

The Pods system is assumed to have technology that enables the Pods to tranship from modality autonomously. This would reduce the costs of transshipment (and possibly increase the costs per pod), since no external infrastructure (e.g.: cranes, depots, etc.) is needed. It would only need extra time to tranship from road to rail near to the DCs, and vice versa near city centres.

Therefore, we assume that for every trip, the costs will be 30% of a ‘traditional’ transshipment (€21), which would mean that for every 100 kilometres (retail) or 80 kilometres (parcels) €21 will be added to the total costs to give an indication of the price for transshipment of a Pods system. The conventional system has no transshipment.

User impacts

The introduction of the Pods system will impact the user experience of each system (logistics service providers in this scenario). As discussed in the previous chapter, this mostly relates to flexibility, reliability, and punctuality of the system. These parameters are relevant for the assessment of the Pods system, since these factors heavily influence the modal shift potential, as can be seen in the previous chapter.

When looking at flexibility, road transport is the most flexible mode of transport, whereas rail transport is the least flexible. The Pods system would operate in between the road and rail system, since it is possible for Pods to switch the mode of transport at certain point if there are disruptions to the network.

With respect to flexibility, only a qualitative assessment can be made for the performance of the Pods system compared to (autonomous) road and rail. In general, rail freight is the least flexible inland transport mode due to the nature and specific character of the infrastructure, the need for a strict timetable for operation and the specific characteristics of the transport vehicles and safety requirements.

Societal impacts

A Pods system will mainly impact society because it is a partial shift from road to rail. This shift results in higher energy efficiency, lower emissions, better safety, lower spatial requirements, and a positive spatial impact.

The societal impact in this example can be calculated in terms of kilometres per vehicle type that are shifted to the rail stretch of the Pods system. As there is not enough information available yet on the characteristics and performance of the Pods system, it is assumed for the road part of the transport chain that the Pods system is comparable to an autonomous driving delivery van and truck.

The total potential for a modal shift, expressed in tonne-km is app. 100,000 per day or 30 million tonne-km annually. A detour factor should be included for the extra kilometres that the rail leg requires decreasing the shift potential. With 15% detour, the amount of shifted tonne-km is app. 25 million per year.

The societal impacts of a shift from conventional road transport to the Pods system using rail can be quantitatively reduced to the following parameters:

- Congestion
- Noise
- Traffic safety
- Habitat damage
- Use of space

The impact on greenhouse gas emissions will be negligible, assuming that in both situations the electric energy for transport and transshipment is generated on a sustainable basis.

Quantification of these parameters is partially possible based on the figures of external costs presented in paragraph 5.4. For the comparison between (electric) vans and trucks the following savings compared to road are taken into account, using the category of LCV (Light Commercial Vehicle or small truck) as an average.

Table 20: External costs for the freight scenario

Parameter	Extra costs (€-cent/tkm) light commercial vehicle compared to rail
Congestion	11.6
Noise	0.5
Safety	4.0
Habitat damage/space	0.7
Total	16.8

The modal shift is calculated to be app. 25 million tonne-km annually, leading to external costs savings of 4.2 million €. Not included in this figure is the potential saving of energy when the transport is carried out on rail which has lower friction than rubber-tyred road vehicles.

The introduction of a Pods system will also impact the modal shift due to accessibility and agglomeration effects. Quantification is difficult at this stage, as there is not enough information to assess the degree of improved (or decreased) accessibility and agglomeration effects. The assumption is that accessibility is somewhat improved because the Pods system increase the transport capacity of the transport system as a whole. There will be additional transfer points in the system. These points are expected to attract commercial activity (as these points have the advantage of being easily reachable by rail and road via the Pods system).

6.4 Concluding assessment for freight and passenger Pods system and synergies

In the previous paragraphs, two analyses are carried out on two different scenarios: one on passenger transport and one on freight transport. In order to conclude these assessments and create an overview of the impact of a Pods system in each scenario, two radar diagrams with qualitative estimations of the different impact parameters are presented. In order to make a comparable overview, the costs of the systems and other quantified parameters are placed on a scale from 1 to 5, as are the non-quantifiable parameters. The interpretation of the scores are: the higher the score, the better a certain system performs. This would mean that a high score in for example transport cost means that that system is relatively cheap.

The assessments of these scores are based on the arguments set out earlier and judged using multiple expert opinions. What should be noted is that the modes compared differ for the two scenarios. For the logistics scenario, only conventional road (the current transport system in the scenario) and autonomous road (the most probable mode of transport in a future scenario) are included. Rail is not included, since there is no logistics system for retail and parcels in this region via rail. For passengers, transport by both road and rail is available and both modes are included in the diagram. Some of the parameters are summarised and explained here:

- **Network impacts.** Adding nodes and other infrastructure to a transportation network impacts the whole system. For example, when an extra line is added somewhere, the amount of transport can increase somewhere else too, since a bottleneck is solved. The higher the score on this parameter, the more positive the impact which a transport mode makes on a transportation network.

- **Flexibility.** The degree of flexibility of that mode of transport when a disruption occurs. The higher the score, the greater the possibility to change a route or work around the disruption.
- **Comfort.** The amount of comfort a passenger experiences during a trip. For freight, this is the number of transshipments needed to reach the end consumer.
- **Generative impact.** The amount of demand for transport is generated by implementing/enlarging the capacity for that mode. The higher the score the less so-called 'latent demand' is generated.
- **Space requirements.** The actual space needed for the infrastructure of that mode. The higher the score, the less infrastructure is needed.
- **Social inclusion.** The degree to which the mode of transport is accessible for anyone, or excludes people. The higher the score, the better that mode's inclusion of people.
- **Spatial impact.** The economic geographical impact of that mode of transport. The higher the score, the more a certain node of that mode of transport attracts economic activity.

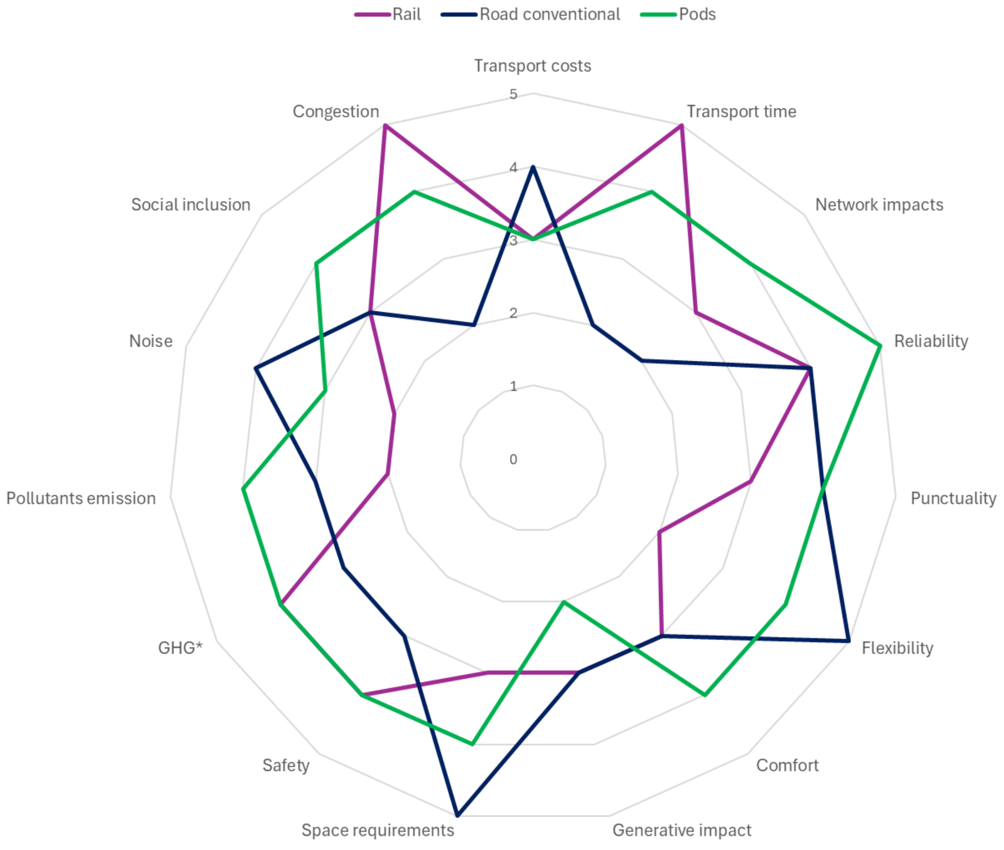


Figure 4: Overview analysis of passenger scenario

As can be seen in Figure 4, a Pods system could be beneficial for the transport system when it comes to reliability, comfort of travel, and social inclusion. Comfort increases compared to other systems, as transferring from modes is no longer needed and negative associations such as time loss for parking a car are also not applicable to a Pods system. Reliability is expected to increase with a Pods system, as it is able to use both rail and road infrastructure and is therefore less prone to disruption. Since the use of a Pods system is assumed to be cheaper or at least competitive with traditional modes, a Pods system is more likely to connect less accessible places. Also, a Pods system is able to create more nodes in a system than rail, attracting more economic activity.

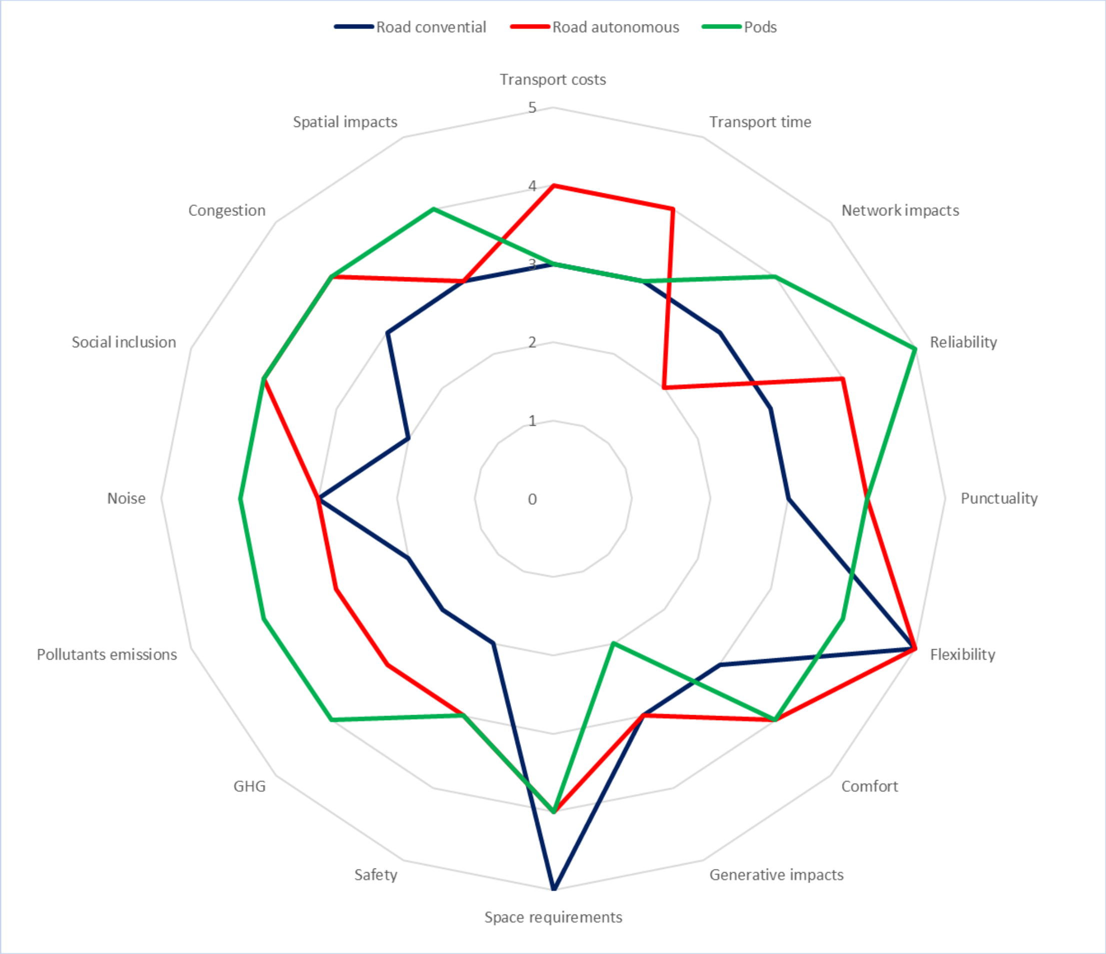


Figure 5: Overview analysis of freight scenario

What can be derived from Figure 5 is that the Pods system operates better than road systems across multiple parameters, such as reliability, emissions of greenhouse gasses, pollutants and noise, and spatial impacts.

The costs per kilometre are benchmarked for current systems and should be equal or less than 6.00 Euro per kilometre to be competitive with the current systems in the researched freight scenario. The probable future scenario for this comparison is not included since it is unclear what the exact impact will be on price when this mode is implemented. Note that these indications of prices are not fit to use generally, as prices differ throughout Europe.

Another factor that is not yet included in the diagram is the cost of transshipment. In this report a first insight is given into this parameter, but too little is known about the costs of transshipment for pods. Following the assumption that pods will have transshipment technology themselves, these costs should be included in the price of the pod.

Synergy impacts

So far, this report has focused on the socio-economic effects of a Pods system on either passenger or freight transport. When the infrastructure and pods are used for both systems, this can lead to multiple other (positive and negative) effects. The utilisation rate of vehicles could be higher, because vehicles can be used in both systems. This higher utilisation rate leads to lower transport costs per passenger/ton-kilometre, less congestion, less use of space (because fewer vehicles are needed), and lower CO2 emissions. One possible disadvantage of finding synergy in both systems is that extra kilometres must be travelled by the pods. The origin and/or destination of the individual systems differ, so the different distances between those systems should be travelled in order to use pods for both systems.

These effects could occur, but the following conditions (among others) should be met to be able to use pods for both systems. The rail infrastructure in Europe should have enough space to use all the gaps for both passenger and freight transport; a Pods system would need to operate in between those gaps. Another important factor to take into account is the internal design of the pods. These should be fit for both passenger and freight transport.

7 Conclusions and recommendations

7.1 Conclusions

This deliverable provides an initial overview of the socio-economic parameters that influence the development of a new inter-modal transport system and to what extent these parameters will be impacted by that new system.

The current transport system in Europe is characterised by dominant road transport, despite a well-developed rail network. Road transport is characterised by a high carbon footprint and many other negative external impacts, such as safety, pollution, noise and spatial requirements. The use of this infrastructure is continuously increasing, which has a negative impact on the degree of congestion on this type of infrastructure (with increased fuel consumption, travel time, accidents, etc. as a consequence).
Despite all these negative impacts, road transport is preferred by its users for passenger and freight because it offers relatively fast, flexible, reliable and (for passengers) comfortable door-to-door transport.

The EU's objective is to shift a significant part of transport from road to rail. There are various ways to make rail transport more attractive. From the user's point of view, it is important to offer door-to-door transport (ideally without transfers), with a price and transport time comparable to that of a car. This option is also offered by the Pods system.

Based on the results of the research carried out in WP2 and T4.1, the list of evaluated use cases is grouped into two main scenarios of the transport types “Passenger transport services” and “Freight transport services”.

There is no accurate information available yet on the construction of Pods system vehicles, the necessary infrastructure related to their operation, or about the influence of some important factors on the development of mobility and related technologies in the future. Therefore, the determination of the economic effort is made as a qualitative estimation of the impact and an approximate specification of boundary conditions for the deployment of the Pods system.

For comparison and a general estimate of the absolute amount of funds required, the costs of current transport systems at current prices are quantified as much as possible. These costs are quantified both according to the CE Delft methodology [1,2] as total infrastructure costs (including capital expenditures, renewal and maintenance, and operating expenditures) and external costs. In addition, the user's view of transport costs is mentioned and the preferences of potential users for several specific scenarios are inferred.

To estimate the socio-economic impacts of the Pods system, a qualitative comparison of significant socio-economic indicators was chosen, supplemented by a quantitative analysis of current transport modes to determine the approximate financial value of the impact of the Pods systems.

The analyses were carried out for two scenarios on passenger and cargo transport in two different locations (the surroundings of the city of Plzen for the transport of passengers and the area of Rotterdam-The Hague for the freight transport scenario).

The development of a new transport system cannot be seen separately from technological and social developments in existing transport systems. The following trends are particularly relevant for the potential introduction of pods:

- electrification of transport
- autonomous driving
- micromobility
- digitisation and automation

A fair assessment of the socio-economic effort and impact of the introduction of the Pods system should take these developments into account. This means that the Pods system will have to compete with autonomously driven electric vehicles (cars, buses, vans, and trucks). The characteristics of the pods are not fully elaborated yet, but it can be assumed that the size and capacity of the pods and transportation units, the speed and other transport characteristics will limit their application to specific market niches. For instance, mass transit flows of commuters using metro and other heavy rail systems are not likely to be served by the Pods system. The same applies for heavy bulk flows of cargo and long-distance flows of construction materials, containers, waste etc.

The lack of information about the design and technical and operational features of the new system implies that only boundary conditions can be given about the current systems that should be met to become competitive. With respect to the costs, the calculations in the two scenarios provide some insight into the maximum cost level that a new system should take into account to be viable. Of course, other qualitative, societal and/or user parameters will influence the socio-economic potential of the system.

On the infrastructure costs, it is not possible to make an assessment at this stage, as the implementation and design of the transshipment of the pods has not yet been determined. Other details on infrastructure design are also still not clear, such as the required systems for management and operation, energy supply etc.

It is assumed that the Pods system will use the same road, rail and energy infrastructure as conventional transport systems. The external impacts of the system will be mainly related to a potential shift from the road stretch to rail. The latter is more energy efficient, safer and requires less space than road transport. These societal benefits can make a crucial difference when it comes to the overall societal costs and benefits. In the analyses of this report mainly emissions of greenhouse gasses and other pollutants, and the reliability of the system are factors on which the new inter-modal system has a more positive impact than current systems.
The transport costs for the users will have to be lower than or equal to the costs of the competing systems in road and rail transport. For passengers, this means that the costs per passenger kilometre as described in the scenario should not exceed approximately € 0.20/pkm. For freight

transport, the costs per vehicle kilometre in retail distribution and parcel deliveries should stay within the range of € 5.50 to € 6.

From the users' perspective, the Pods system will have to offer a similar level of quality as road transport, particularly with respect to the following aspects:

- – comfort (for passengers)
- – reliability
- – flexibility, door-to-door capability and availability

One of the main features of the new inter-modal Pods system is the capability to combine freight and passenger Pods on the same infrastructure, thus combining the two scenarios examined in this work. The following synergy effects can be identified:

- better use of available infrastructure, higher transport density, leading to lower infrastructure costs per vehicle, passenger and ton-kilometre
- higher occupation of transportation units, leading to lower costs per kilometre

7.2 Recommendations

A more precise comparison of existing transport modes with the newly envisaged inter-modal system will only be possible in a later project phase when essential parameters of the system have been specified in more detail. With this increased level of detail of the technical and operational characteristics of a Pods system, it will be possible to give a more detailed insight into the costs necessary for such a system. The key parameter will be the cost of the pods (vehicles). Another important factor that possibly influences the total costs of the new inter-modal system is the cost of transshipment.

In the following Work Packages of this project focused on vehicle design, it will be necessary to pay increased attention especially to:

- the transshipment system from the point of view of infrastructure costs (if that system is not included in the design of the transportation unit itself),
- transportation unit reloading system from the point of view of the time of change of transport mode (transport speed),
- increasing the interval between individual vehicles, e.g. by virtual coupling of carriers
- system of charging and temporary storage of free pods and its capacity (flexibility of the whole system and space requirements).

This will lead to more insight into the costs and performance indicators of the Pods system. Based on these insights the economic assessment of the system in different use cases and scenarios can be detailed. Also, it might be possible to carry out a societal cost-benefit analysis on a Pods system, which would potentially give a better insight into its specific societal impact.

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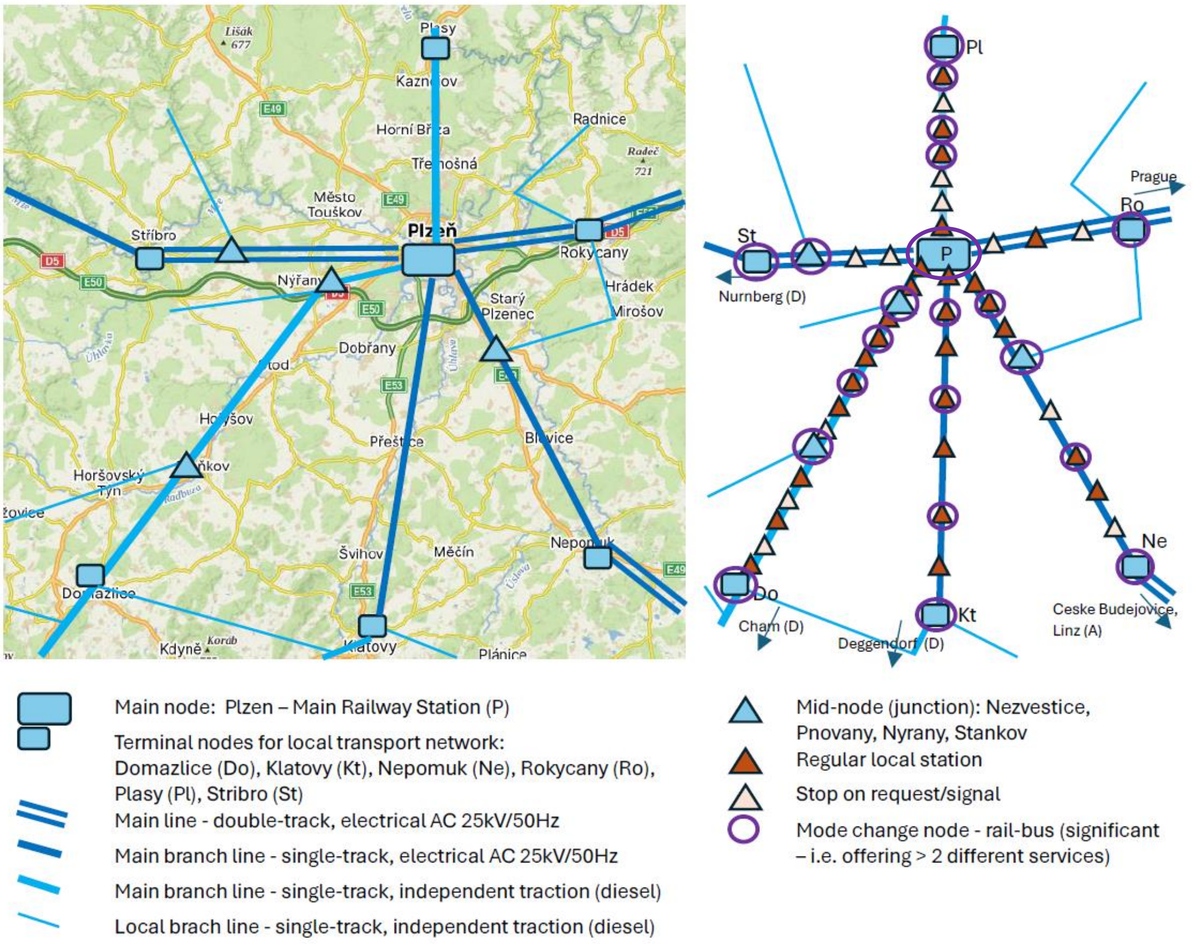
10 Appendices

10.1 Local passenger transport network around the city of Plzen

The scenario chosen for benchmarking Pods deployment in passenger transport is a regional transport subsystem using partly main rail lines, regional and urban railways and road networks.

Short description of the system

Local railway network (a mixture of main lines and branch lines) combined with a relatively dense bus network, city mass transport and high density of passenger cars.
The main part of the railway network has a star structure, where Plzen - Main Railway Station is in the centre. The terminal nodes included in this study are towns located close to the city. The majority of passengers from these regions commute daily for work, studies, and similar reasons. The rail network uses both double and single-track lines, electrical and independent (mainly diesel) drives are used.



Fast services (long-distance trains) typically stop only at terminal nodes or 'important' mid-nodes (junctions or connections to another transportation mode), and continue to more distant destinations. Slow services stop almost everywhere and are intended to serve the local area.
There is also a bus service network complementary to the rail network, with a net structure servicing the areas beyond the rail lines. Buses are driven by diesel engines.
The whole subsystem is interconnected with city mass transport consisting of trams, buses and trolleybuses.
Among the above, there is heavy passenger car traffic, which causes congestion every day during rush hours.

Main/local routes description

P-Ne (Plzen - Nepomuk)

Part of the main line from Plzen to Ceske Budejovice (South Bohemia Region) and to Linz (Austria). Between Plzen and Nepomuk single-track, electrical drive (AC 25KV, 50Hz). From Nepomuk double-track. Connection to local branch line in Nezvestice (to Rokycany). Connection to the bus network in Plzen, Stary Plzenec, Nezvestice, Blovice, Nepomuk.

P-Kt (Plzen – Klatovy)

Part of the main branch line from Plzen to Zelezna Ruda and to Deggendorf (Germany). Between Plzen and Klatovy single-track, electrical drive (AC 25KV, 50Hz). From Klatovy to Zelezna Ruda single-track, independent drive (diesel).
Connection to the bus network in Plzen, Dobrany, Prestice, Svihov, Klatovy.

P-Do (Plzen – Domazlice)

Part of the main branch line from Plzen to Ceska Kubice and to Cham / Munich (Germany). Single-track with independent drive (diesel). Connection to local branch line in Stankov (to Domazlice via Horsovsky Tyn, Pobezovice).
Connection to the bus network in Plzen, Nyrany, Stod, Holysov, Stankov, Domazlice.

P-St (Plzen – Stribro)

Part of the main line from Prague to Cheb (Karlovy Vary Region) and to Nuremberg (Germany). Between Plzen and Stribro double-track, electrical drive (AC 25KV, 50Hz). From Stribro to Cheb single-track, electrical drive (AC 25KV, 50Hz). Connection to local branch line in Pnovany (to Konstantinovy lazne).
Connection to the bus network in Plzen, Pnovany, Stribro.

P-Pl (Plzen – Plasy)

Part of the main branch line from Plzen to Zatec (North Bohemia Region) and to Germany.
Single-track with independent drive (diesel).
Connection to the bus network in Plzen, Tremosna, Ceska Briza, Kaznejov, Plasy.

P-Ro (Plzen – Rokycany)

Part of the main line from Prague to Cheb (Karlovy Vary Region). Double-track, electrical drive (AC 25KV, 50Hz). Connection to local branch line in Rokycany (Nezvestice-Rokycany-Radnice). Connection to the bus network in Plzen and Rokycany.

Routes parameters

Route	Distance [km]	# of mid-stations/stops			Fast (long-distance)-train services per workdays			Slow (local)-train services per workdays			Bus services	
		Total	Regular	On signal	# of services (mid-stops)	Travel time [hour-min]	Est. transport performance *) [person / day]	# of services (mid-stops)	Travel time [hour-min]	Est. transport performance *) [person / day]	# of services (avg. travel time) [hour-min]	Est. transport performance ***) [person / day]
P-Ne	34	8	6	2	9 (2)	25m	1080 **)	18 (6-8)	40m	1750	N/A	
P-Kt	45	7	7	0	9 (3)	49m	1080 **)	7 (7)	57m	840	14 (1h)	280
P-Do	59	15	12	3	8 (2)	50m	780 **)	15 (12-15)	1h15m	1800	13 (1h30m)	320
P-St	32	3	1	2	9 (1)	25m	1080 **)	7 (1-3)	29m	840	12 (50m)	200
P-Pl	33	7	4	3	7 (1)	32m	670 **)	16 (4-7)	40m	570	>10 (ap.50m)	240
P-Ro	17	3	1	2	17 (0)	10m	2000 **)	36 (1-3)	15m	4200	>15 (ap.10m)	500 **)

*) Average occupancy for trains is 29.4% (CD year report 2022 [5])

**) Part of the passengers continue to distant destinations

***) Estimated avg. occupancy 40%

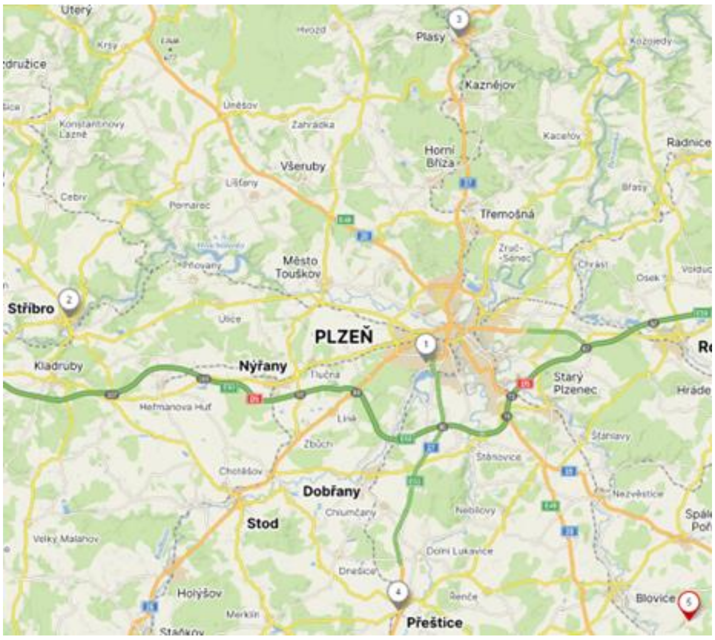
Node description

Route	Region/ Municipality	Population [persons]	Total population in towns on route	Land Registry Area [km^2]	Average density of population [persons/km^2]
	Region Plzen	605,388		7,561	80
	City of Plzen	181,240		137.64	1300
P-Ne	Nepomuk	3,560	14,624	12.8	280
	Stary Plzenec	5,414		18.4	290
	Nezvestice	1,466		6.4	230
	Blovice	4,184		28.96	140
P-Kt	Klatovy	22,496	37,283	80.9	280
	Dobrany	6,360		35.32	180
	Prestice	6,750		25.41	270
	Svihov	1,677		34.5	50
P-Do	Domazlice	11,010	35,564	24.6	450
	Nyrany	6,935		22.79	300
	Stod	3,610		20.04	180
	Holysov	5,489		29.32	190
	Stankov	3,388		20.50	170
	Horsovsky Tyn	5,132		71.31	72
P-St	Stribro	7,975	7,975	47.8	170
P-Pl	Plasy	2,993	15,544	57.1	50
	Tremosna	5,020		18.12	280
	Horni Briza	4,411		14.5	300
	Kaznejov	3,120		12.3	250
P-Ro	Rokycany	14,309	14,309	30.67	470

	More than 60minutes	30-59minutes	1-29minutes	No commuting
EU avg.	8.2 %	26.6 %	61.1 %	4.1 %

Source: Key figures on European transport 2022, Eurostat [3]

Evaluation of several potential trips



Example trip #1
Daily commuting from a village (Lounova) (5) to Plzen (1).

Example trip #2
Commuting from a village (Lounova) (5) to Stribro (2)

Example trip #3
Commuting from a village (Lounova) (5) to Plasy (3)

Example trip #4
Daily commuting from a village (Lounova) (5) to Prestice (4)

Lounova is a small village (about 110 inhabitants). Distance to the nearest train station (Zdirec) is about 3.7km, to Blovice about 8.1km. There is a bus stop in the village, but only a few services per day are available (typically school buses). The majority of the buses use a bus stop on the main road, which is app.1.5km from the village centre.

The majority of the inhabitants commute to work every day. Because of the relative isolation of the village, the main transport modes are passenger cars (private transport or sharing a car with co-workers), and bus in combination with train.

Blovice is a relatively important node for mode change, where the rail network meets the bus network. There is a train station collocated with the bus terminal and car parking. Waiting times for transfer from bus to train varies from 15 minutes to 1.5 hours depending on the day of the week, time of day, and the particular bus service.

Plzen is the main node in the rail and bus network. The bus terminal is a 5-minute walk from the main railway station. Connection to mass public transport is adjacent to the station. Waiting times for changing from train to train varies from 10 minutes to 1 hour, and from train to bus from app. 15 minutes to 1 hour, depending on the day of the week, time of day, and the particular train/bus service.

Notes: For the following comparison the shortest waiting times are chosen. Thus, the everyday reality will be less optimistic.

For all trips by car, it is typical that the car is used only for a short time and the rest of the day it is parked. Fees for parking are not considered.

Example trip #1 Lounova - Plzen

Transport modes	**Distance [km]**	**Time [hour-minute]**	**Cost of the trip from user perspective (in current prices in CZ and avg. salaries in CZ and EU)**					**Comments**	
	Infrastructure costs [€-cents]	Accident costs [€-cents]	Air pollutions [€-cents]	Climate change [€-cents]	Noise [€-cents]	Congestion [€-cents]	Well-to-tank [€-cents]	Habitat damage [€-cents]	Total [€-cents]
Car (door-to-door) 1.6 engine (petrol), 8liter/km (reimbursement 0.25EUR/km)	36.3	33m	Travel costs = 0.25 €/km *36.3 = 9.1 € Time costs EU = 0.55*15 €/hour = 8.25 € Time costs CZ = 0.55*8 €/hour = 4.4 €						
	75.6	163.3	25.4	43.6	21.8	152.5	14.5	18.2	514.9
Car (door-to-door) in rush hours 1.6 engine (petrol), 8liter/km (reimbursement 0.25EUR/km)	36.3	45m	Travel costs = 0.25 €/km *36.3 = 9.1 € Time costs EU = 0.75*15 €/hour = 11.25 € Time costs CZ = 0.75*8 €/hour = 6 €						
	75.6	163.3	25.4	43.6	21.8	152.5	14.5	18.2	514.9
Walking to nearest bus-stop Bus to Blovice Waiting for train Train Blovice-Plzen Main Station Mass public transport to the site - 5min walk,1 change	1.5 5.2 -- 23 4.8	15m 15m 15m 25m 20m	Fare (bus+train) = 1.83 € Fare (mass public transport) = 0.75 € Time costs EU = 1.5*15 €/hour = 22.5 € Time costs CZ = 1.5*8 €/hour = 12 €						
	335.4	61.5	36.4	25.6	28.1	40.0	18.1	16.5	561.6
Walking to nearest bus-stop Bus to Blovice Waiting for bus Bus Blovice-Plzen Bus Terminal Mass public transport to the site - 5min walk,1 change	1.5 5.2 -- 41.8 4.2	15m 15m 30m 50m 20m	Fare (bus+bus) = 1.83 € Fare (mass public transport) = 0.75 € Time costs EU = 2.15*15 €/hour = 32.25 € Time costs CZ= 2.15*8 €/hour = 17.2 €						
	194.6	51.2	21.0	25.0	15.0	40.0	10.0	5.0	361.8
Pod-system (avg. 40km/h) Road to Blovice Rail Blovice – Plzen Jizni Predm. Road to the site	 6.7 25 3.4	 53m + handl.	Travel costs = unknown Handling costs = unknown Time costs EU = 0.88*15 €/hour = 13.2 € Time costs CZ = 0.88*8 €/hour = 7.04 €						
	385.5	57.95			28.56	42.42			

Comments: Evaluation of the costs per pkm shows that all the combinations are comparable from a “society-point-of-view” and the differences are not very significant. The higher infrastructure costs of rail are compensated by the negative impact of cars to the externalities. However, the situation is very different from the “user-perspective”. Time costs connected with the trip are very high in comparison with the travel costs. The difference is more important for the population with higher incomes (i.e. close to the average salary and higher). People with lower incomes (lower salaries, lower car availability, less chances for making more money by overtime) usually prefer using public transport and tolerate long waiting times.

Note: The difference between “user perspective” for different mode combinations is more visible because the trip is relatively short, and the target destination lies in the suburbs on the same side of the city (i.e. it is not necessary to cross the city by car).

Example trip #2 Lounova – Stribro

Transport modes	Distance [km]	Time [hour-minute]	Cost of the trip from user perspective (in current prices in CZ and avg. salaries in CZ and EU)					Comments	
	Infrastructure costs [€-cents]	Accident costs [€-cents]	Air pollutions [€-cents]	Climate change [€-cents]	Noise [€-cents]	Congestion [€-cents]	Well-to-tank [€-cents]	Habitat damage [€-cents]	Total [€-cents]
Car (door-to-door) 1.6 engine (petrol), 8liter/km (reimbursement 0.25EUR/km)	66.6	52m	Travel costs = 0.25 €/km *66.6 = 16.65 € Time costs EU = 0.87*15 €/hour = 13.05 € Time costs CZ = 0.87*8 €/hour = 6.96 €						
	138.7	299.7	46.6	79.9	39.9	279.7	26.6	33.3	944.4
Car (door-to-door) in rush hours 1.6 engine (petrol), 8liter/km (reimbursement 0.25EUR/km)	66.6	60m	Travel costs = 0.25 €/km *66.6 = 16.65 € Time costs EU = 1*15 €/hour = 15 € Time costs CZ = 1*8 €/hour = 8 €						
	138.7	299.7	46.6	79.9	39.9	279.7	26.6	33.3	944.4
Walking to nearest bus-stop Bus to Blovice Waiting for train in Blovice Train Blovice-Plzen Main Station Waiting for train in Plzen Train Plzen Main Station-Stribro Local public transport to the site	1.5 5.2 -- 23 -- 32 2	15m 15m 15m 25m 10m 25m 8m	Fare (bus+train) = 3.1 € Fare (mass public transport) = 0.4 € Time costs EU = 1.88*15 €/hour = 28.2 € Time costs CZ = 1.88*8 €/hour = 15.04 €						
	817.1	34.7	39.4	6.4	51.6	5.8	39.9	10.5	1005.4
Pod-system (avg. 40km/h) Road to Blovice Rail Blovice – Plzen Main St. - Stribro Road to the site	6.7 54 3.4	1h36m + handl.	Travel costs = unknown Handling costs = unknown Time costs EU = 1.6*15 €/hour = 24 € Time costs CZ = 1.6*8 €/hour = 12.8 €						
	808.3	72.45			54.66	42.42			

Comments: Evaluation of the costs per pkm shows that all the combinations are comparable from a “society-point-of-view” and the differences are not very significant. The higher infrastructure costs of rail are compensated by negative the impact of cars to the externalities. From a “user-perspective” the trip takes twice as long. Time costs connected with the trip are high in comparison with the travel costs, but they are compensated by relatively low fare. The difference is more important only for the population with higher incomes (i.e. close to the average salary and higher), which is not willing to tolerate time losses, or prefers a higher comfort of travel.

Note: The trip to the target destination by car is taken only outside of the city of Plzen, and a major part is on the motorway. Therefore, the time of the trip by car in the rush hour is almost equal to any other time of day.

Example trip #3 Lounova - Plasy

	Distance [km]	Time [hour-minute]	Cost of the trip from user perspective (in current prices in CZ and avg. salaries in CZ and EU)					Comments	
Transport modes	Infrastructure costs [€-cents]	Accident costs [€-cents]	Air pollutions [€-cents]	Climate change [€-cents]	Noise [€-cents]	Congestion [€-cents]	Well-to-tank [€-cents]	Habitat damage [€-cents]	Total [€-cents]
Car (door-to-door) 1.6 engine (petrol), 8liter/km (reimbursement 0.25EUR/km)	56.9	1h05m	Travel costs = 0.25 €/km *56.9 = 14.23 € Time costs EU = 1.08*15 €/hour = 16.2 € Time costs CZ = 1.08*8 €/hour = 8.64 €						
	118.5	256.1	39.8	68.2	34.1	239.0	22.8	28.5	807.0
Car (door-to-door) in rush hours 1.6 engine (petrol), 8liter/km (reimbursement 0.25EUR/km)	56.9	1h30m	Travel costs = 0.25 €/km *56.9 = 14.23 € Time costs EU = 1.5*15 €/hour = 22.5 € Time costs CZ = 1.5*8 €/hour = 12 €						
	118.5	256.1	39.8	68.2	34.1	239.0	22.8	28.5	807.0
Walking to nearest bus-stop	1.5	15m	Fare (bus+train) = 2.67 EUR						
Bus to Blovice	5.2	15m	Time costs EU = 2*15 €/hour = 30 €						
Waiting for train in Blovice	--	15m	Time costs CZ = 2*8 €/hour = 16 €						
Train Blovice-Plzen Main Station	23	25m							
Waiting for train in Plzen	--	10m							
Train Plzen Main Station-Plasy	33	32m							
Walking to the site	1	8m							
	836.4	33.2	10.4	8.0	51.9	4.2	40.2	34.1	1018.4
Pod-system (avg. 40km/h)			Travel costs = unknown						
Road to Blovice	6.7	1h36m	Handling costs = unknown						
Rail Blovice – Plzen - Plasy	56	+	Time costs EU = 1.6*15 €/hour = 24 €						
Road to the site	1.3	handl.	Time costs CZ = 1.6*8 €/hour = 12.8 €						
	833.12	64			55.2	33.6			

Comments: Evaluation of the costs per pkm shows that all the combinations are comparable from a “society-point-of-view” and the differences are not very significant. The higher infrastructure costs of rail are compensated by the negative impact of cars to the externalities. From a “user-perspective” the trip takes twice as long out of the rush hour, and about 1.3 times longer in the rush hour. Time costs connected with the trip are high in comparison with the travel costs, but they are compensated by the relatively low fare. The difference is more important only for the population with higher incomes (i.e. close to the average salary and higher), which is not willing to tolerate time losses, or prefers a higher comfort of travel.

Note: The trip to the target destination requires either crossing the city of Plzen or making the trip longer (a slightly longer distance and slower roads). The result is quite a big difference between the rush hour and off-peak times.

Example trip #4 Lounova - Prestice

Transport modes	Distance [km]	Time [hour-minute]	Cost of the trip from user perspective (in current prices in CZ and avg. salaries in CZ and EU)					Comments	
	Infrastructure costs [€-cents]	Accident costs [€-cents]	Air pollution [€-cents]	Climate change [€-cents]	Noise [€-cents]	Congestion [€-cents]	Well-to-tank [€-cents]	Habitat damage [€-cents]	Total [€-cents]
Car (door-to-door) 1.6 engine (petrol), 8liter/km (reimbursement 0.25EUR/km)	25.8	29m	Travel costs = 0.25 €/km *25.8 = 6.45 € Time costs EU = 0.48*15 €/hour = 7.2 € Time costs CZ = 0.48*8 €/hour = 3.84 €						
	53.7	116.1	18.1	30.9	15.5	108.4	10.3	12.9	312.2
Car (door-to-door) in rush hours 1.6 engine (petrol), 8liter/km (reimbursement 0.25EUR/km)	25.8	32m	Travel costs = 0.25 €/km *25.8 = 6.45 € Time costs EU = 0.53*15 €/hour = 7.95 € Time costs CZ = 0.53*8 €/hour = 4.24 €						
	53.7	116.1	18.1	30.9	15.5	108.4	10.3	12.9	312.2
Walking to nearest bus-stop Bus to Blovice Waiting for train in Blovice Train Blovice-Plzen Main Station Waiting for train in Plzen Train Plzen Main Station-Prestice Walking to the site	1.5 5.2 -- 23 -- 23.5 1.8	15m 15m 15m 25m 10m 26m 12m	Fare (bus+train) = 3.5 € Fare (mass public transport) = 1 € Time costs EU = 1.96*15 €/hour = 29.4 € Time costs CZ = 1.96*8 €/hour = 15.68 €						
	678.1	28.4	9.2	4.9	43.4	4.2	33.6	28.4	830.2
Walking to nearest bus-stop Bus to Blovice Waiting for train in Blovice Train Blovice-Plzen Main Station Walking Railway St.–Bus Terminal Waiting for bus in Plzen Bus Plzen Bus Terminal-Prestice Walking to the site	1.5 5.2 -- 23 -- -- 23.5 1.8	15m 15m 15m 25m 3m 15m 27m 20m	Fare (bus+train+bus) = 2.67 € Time costs EU = 2.25*15 €/hour = 33.75 € Time costs CZ = 2.25*8 €/hour = 18 €						
	444.4	40.2	22.8	15.5	29.3	22.9	21.8	16.7	613.6
Pod-system (avg. 40km/h) Road to Blovice Rail Blovice – Plzen Main St. – Prestice Road to the site	6.7 46.5 2	1h23m + handl.	Travel costs = unknown Handling costs = unknown Time costs EU = 1.38*15 €/hour = 20.7 € Time costs CZ = 1.38*8 €/hour = 11 €						
	696.07	62.4			47.07	36.54			
Pod-system (avg. 40km/h) Road to Prestice (costs similar to microbus/van)	25.4	48m	Travel costs = unknown Handling costs = unknown Time costs EU = 0.8*15 €/hour = 12 € Time costs CZ = 0.8*8 €/hour = 6.4 €						
	52.83	114.3			15.24	106.68			

Comments: Evaluation of the costs per pkm shows that from a "society-point-of-view" the bus and train combination is higher than by car, because the distance travelled is approximately doubled. From a "user-perspective" the trip takes twice as long. Time costs connected with the bus/train trip are very high, and the time loss and the discomfort for most of the population is hardly acceptable.

Note: There is no direct connection via public transport. The road is so-called 2nd class (i.e. slow), but there is no city to be crossed.

Capacity requirements

The capacity requirements of the Pods system are estimated based on estimated current average transport performance on individual lines.
In accordance with D4.1, Type A transport modules (UC1-UC4 - public transport) are considered.

Module	Length [mm]	Width [mm]	Height [mm]
Type A	6,058	2,550	2,900

Use-case	UC1	UC2	UC3	UC4
# of seats	12	6	2	18 *)

*) leaning seats – space for 1 passenger 650x650mm, 6rows, 3seats each

Route	Avg. # of passengers in one direction per hour (current situation)	Avg. # of TU (UC4) in one direction per hour	Avg. # of TU (UC1) in one direction per hour	Avg. # of TU (UC4) per hour (corrected for # of tracks)	Avg. # of TU (UC1) per hour (corrected for # of tracks)	Avg. time interval between services in both direction [minutes]	Comment
P-Ne	109	6-7	9	13	18	3.3-4.6min	Single-track line (only first ap.10km doubled)
P-Kt	120	7	10	14	20	3.3-4.3min	Single-track line
P-Do	112	6-7	9-10	13	18	3.3-4.5min	Single-track line
P-St	120	7	10	7	10	6-8.6min	Double-track line
P-Pl	54	3	4-5	6	9	6.7-10min	Single-track line
P-Ro	113	6-7	9-10	6-7	9-10	6-8.6min	Double-track line

It is clear from the table that the intervals between individual TUs are extremely short. For single-track lines, these times are (currently) unfeasible due to the distance of stations where oncoming connections may meet. For double-track lines, the intervals are longer and there is no need to take into account the meeting of oncoming connections, but these lines are designed for higher travel speeds (i.e. the potential risk of collisions is increased).

It is therefore obvious that the concept of operation of isolated TUs (Type B, or 2xType A) will be feasible only to a very limited extent, i.e. only at certain times and only on certain lines.
Average times between individual connections are calculated assuming that the average occupancy is approx. 30%. Depending on the time of day, occupancy will vary between approx. 5% to 100%. This can be compensated by a decrease in passenger comfort (e.g. by including more UC4 units during peak hours), by increasing the frequency of connections (# of TUs), by chaining/connecting TUs, etc. Furthermore, it can be assumed that the current single-track lines will be upgraded to double-track lines in the future.
In any case, the development of an operational system (planning and logistics) and a significant strengthening of safety features on both moving and fixed infrastructure will be crucial for the operation of the Pods system.