Cargo-Hyperloop Holland

A pre-project feasibility for connecting Noord- and Zuid Holland via hyperloop

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The Stichting Hyperloop Development Program ("Stichting HDP") is the lead partner for the Hyperloop Development Program. Stichting HDP's goal is to facilitate development of hyperloop up to commercialization, to be further developed by commercial parties into concrete market propositions. To this end, the Stichting HDP promotes public-private partnerships, initiates and governs R&D programs, and creates awareness by dissemination of results.

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Definitions

Term	**Description**
CAPEX	Capital Expenditures
CBA	Cost-benefit analysis
Corridor	The Cargo-hyperloop Holland project in its entirety is being defined as the corridor
EHC	European Hyperloop Center
ENPV	Economic Net Present Value
ERR	Economic Rate of Return
HDP	Hyperloop Development Program
Hyperloop	Hyperloop is a mode of land transportation capable of high speed and driverless operations, in which a vehicle is guided through a low pressure tube or system of tubes, for passengers and/or cargo
MIRT	MIRT is the abbreviation for the Dutch "Meerjarenprogramma Infrastructuur, Ruimte en Transport', which is the multi-annual program for infrastructure, space and transport by the Dutch national government.
OPEX	Operational Expenditures
PCU	Passenger car unit
RoRo	Roll-on/roll-off of wheeled freight like trucks
Section	A part of the Cargo-hyperloop Holland corridor evaluated separately as a potential pilot route
Segment	A part of hyperloop infrastructure
SPV	Special Purpose Vehicle
TEU	Twenty-foot equivalent unit - a measure of volume in units of twenty-foot long containers.
TFEC	Total final energy consumption
VAT	Value-added tax

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1. Introduction

1.1 Study Background

Cargo-hyperloop Holland corridor is being investigated as the first step in creating a pan-European emission-free hyperloop network. Such a network would make it possible to transport passengers and send goods across Europe in hours, while drastically reducing emissions and road congestion.

The location of the first hyperloop corridor in the Netherlands is a result of a number of preparatory studies conducted since the hyperloop promoters and partners created a critical mass and became an innovative industry with a strong potential to drive the future growth of the Dutch economy.

- In 2016, Rebel Group was commissioned by the Ministry of Infrastructure and the Environment to carry out a pre-feasibility study into a hyperloop knowledge center, a test track and a commercial line[1]. 17 test locations were assessed, and the Dutch business interests were mapped out.
- In the spring of 2017, a consortium led by TNO carried out the first comprehensive feasibility study into the potential of a hyperloop test facility in Flevoland[2].
- In beginning 2018 Hardt conducted a preliminary study to explore hyperloop on the Amsterdam-Frankfurt route together with a large group of partners such as NS, Royal Schiphol Group, KLM, Movares, BAM, Arcadis.
- In September 2018, Royal Schiphol Group announced to execute a pre-feasibility study of hyperloop together with Hardt.
- In April 2019, the Province of Noord-Holland announced to study the economic impacts of hyperloop transportation for the region with National and International connections.
- In 2020, the Hyperloop Development Program has been initiated to support technological advancement of the hyperloop, develop of The European Hyperloop Center (EHC) in Groningen (an open testing facility where the technology will be tested and validated for commercial operations), and prepare the necessary studies for the first commercial routes.
- In 2021, the official EN standard development for hyperloop was launched: Joint Technical Committee for Hyperloop Systems (JTC20). All hyperloop developers worldwide are represented in this standardization effort to ensure hyperloop is interoperable globally.

The Cargo-hyperloop Holland project is a part of the Hyperloop Development Program, with more than 30 private and public entities signing a covenant to support the development of an Amsterdam – Rotterdam route as the first commercial hyperloop corridor focused on cargo transport. The stakeholders/covenant partners include: Agora Flores Holland, Air Cargo Netherlands, Amsterdam Airport Area, Amsterdam Logistics, APMT (Maersk), Bakker Barendrecht, Berg Roses, ABC Logistics (Best Fresh), Dümmen Orange, Dutch Flower Group, Euro Pool System, evofenedex, Kwekerij Baas, De Wintertuin, Greenport Aalsmeer, Greenport Duin- en Bollenstreek, GroentenFruithuis,

1 This report is not publicly available.
2 Report "Hyperloop in The Netherlands, TNO, 09-10-2017": Link

InnovationQuarter, Metropolitan Region Rotterdam The Hague, Municipality of Aalsmeer, Municipality of Amsterdam, Municipality of Haarlemmermeer, Municipality of Rotterdam, Municipality of Westland, Port of Amsterdam, Port of Rotterdam, PostNL, Province of Noord-Holland, Province of Zuid-Holland, Royal Schiphol Group, SADC, SVB Transportgroep, The Greenery, TLN, Vervoerregio Amsterdam.

This pre-feasibility study has been conducted to investigate the economic viability of the Cargo-hyperloop Holland corridor as a hyperloop network transporting cargo in the provinces of North Holland and South Holland. The aim for this study is threefold. Firstly, to advance a concept for hyperloop and ensure that the functionalities of the hyperloop system meet the needs and wishes of shippers in the region. Secondly, to design the corridor, including alignment, integration and hubs and perform a demand and socio-economic assessment. Finally, to identify and assess the feasibility of implementing a pilot route for hyperloop somewhere along this corridor and how to approach the project realization and governance.

1.2 Study Scope

The Cargo-hyperloop Holland pre-feasibility study includes the results of research and cooperative effort of all project stakeholders, signatories of the Cargo-hyperloop Holland covenant. In the course of the project, a number of workshops have been held with the stakeholders to facilitate the research conducted by the project team, provide input and discuss the outcomes. The study has been organized following a multidisciplinary pre-feasibility framework, and covers the results of research conducted in the following areas:

- Strategic context of the Cargo-hyperloop Holland, including main policy objectives to which the hyperloop corridor will contribute upon completion
- Technical development of the hyperloop system for cargo, including identification and implementation of industry needs and requirements,
- The Cargo-hyperloop Holland infrastructure alignment, including the location of hubs and integration of the linear infrastructure into a diverse environment of the North and South Holland.
- Cost estimations for the corridor infrastructure development and operations
- Demand for future hyperloop services for cargo, including identification of cargo flows along the corridor, assessment of expected modal shift to hyperloop for different cargo types, and projections of growth resulting from a generic growth of cargo demand and the network effects expected when the Dutch and European hyperloop networks will become operational.
- Economic performance of the corridor, including a range of positive and negative socio-economic impacts generated by its implementation, and a risk assessment identifying the key variables impacting the economic results of the project.
- Delivery model for the corridor, examining options for public and private involvement in the project implementation and operations.
- Project schedule, mapping the timeline for the implementation of the corridor.

1.3 Document Structure

The remainder of this document is as follows.

- Chapter 1 describes the scope and objectives of this study along with background information.
- Chapter 2 discusses sustainable transport polices (CH2.1), introduces the envisioned European Hyperloop network (CH2.2), provides information on the connectivity between North and South Holland (CH2.3) and the transport infrastructure development in the Amsterdam – Rotterdam corridor (CH2.4)
- Chapter 3 sets the project objectives (CH3.1) and the scope (CH3.2)
- Chapter 4 gives an overview of the hyperloop system (CH4.1), the network (CH4.2) and its components: links (CH4.3), hubs (CH4.4), vehicles (CH4.5). The system's operations and costs are discussed in CH4.6 and CH4.7.
- Chapter 5 provides a description of the Cargo-hyperloop Holland corridor, the location of its hubs (CH5.1) and the alignment of the infrastructure (CH5.2).
- Chapter 6 assesses hyperloop's demand for different scenarios and cargo segments (CH6.1, CH6.2) and reports the results of different cargo-demand scenarios (CH6.3, CH6.4, CH6.5).
- Chapter 7 discusses the economic impact assessment of the Cargo-hyperloop Holland corridors (CH7.1., CH7.2) and the evaluation of the economic performance (CH7.3)
- Chapter 8 analyzes (CH8.1, CH8.2, CH8.3) and assesses the risk (CH8.4.)
- Chapter 9 gives an overview of the project delivery models (CH9.1) along with information regarding the governance (CH9.2), funding (CH9.3) and legal considerations (CH9.4)
- Chapter 10 examines the planning of the project schedule.
- Chapter 11 presents the conclusions and the next steps.

2. Challenge of Sustainability and Growth

2.1 Sustainable transport policy

2.1.1 The importance of efficient and sustainable transport in Europe

A substantial share of the high standard of living of the modern human is attributable to the availability of excellent transport infrastructure. It increases mobility, quality of life and grants access to goods and services, and it's a key factor in a region's competitive advantage.

While the transport sector fulfils a pivotal socio-economic role, the sector is simultaneously one of the largest energy consumers, responsible for about 25% of the global CO_2 emissions. Unless immediate measures are taken, the global transport emission will grow by another 60% by 2050. This will cause the international community to fall dramatically short of the Paris Agreement goal of limiting global warming to well below 2˚C. Therefore, the transport sector has a large responsibility in implementing clean transport alternatives to combat climate change.

The European Green Deal seeks a 90% reduction in greenhouse emissions by 2050. Moving to more sustainable transport means putting users first and providing them with more affordable, accessible, healthier and cleaner alternatives[3]. According to a proposal from the European Commission an estimated €1,500 billion needs to be invested in the comprehensive European transport infrastructure during this decennium. In selecting the projects for these investments, short-term congestion relief needs to be carefully weighed against the long-term sustainable opportunities that new solutions could bring, as the consequences of these investments last a lifetime.

The European Commission wants to set an enabling environment for game changing mobility technologies, like hyperloop, as they are included in the Sustainable and Smart Mobility Strategy[4].

Competitiveness and integration of the single EU market largely depends on the quality of infrastructure. A hyperloop system, that allows European businesses to deliver products same or next day across the continent cost-effectively and sustainably could greatly improve the reach of individual businesses, create continental-scale industrial clusters and greatly improve the economic performance of European industries.

2.1.2 Sustainable transport policy in Netherlands

In Netherlands, in order to achieve the sustainability and decarbonization goals, the government, companies and civil society organizations in the Netherlands have concluded the *"Klimaatakkoord"*, to set out how much CO_2 emissions are to be reduced. The agreement recognizes that logistics is a key cornerstone of the Dutch economy and Dutch society (Holland International Distribution Council, NDL), and at the same time, logistics operations are a key source of carbon dioxide and other types of emissions. The representatives of the logistics sector agreed to develop knowledge, new innovative concepts and pilot projects in order to create demonstrably sustainable logistics solutions, and the public sector agreed to set up measures facilitating and supporting the implementation of these new concepts. Hyperloop has the potential to be one of the key innovations to support these objectives and developing the pilot hyperloop sections and the first hyperloop corridor in Netherlands will be a huge step towards achieving sustainability and decarbonization goals in the logistics sector.

Also, Toekomstbeeld OV 2040[5] and "Klimaatakkoord" denote the importance of an international and cross-border network in order to connect the Netherlands fast and sustainably to the main economic centers of Germany, Belgium, France and England for distances under 700 km[6]. This is in line with the European agenda, where *TEN-T* projects aim to establish and develop the key links and interconnections needed to eliminate existing bottlenecks to mobility. The importance for the Netherlands of development of direct land-based connections with international power houses to the International Entrance to NL these connections is recognized and highlighted by *Enter[NL]*. The hyperloop corridors and network in Netherlands, together with expanding the hyperloop network into Europe, has the potential to fulfill these objectives and provide direct, ultrafast and sustainable transport connections within the country and internationally.

2.1.3 Hyperloop as a response to strategic policy objectives

The European and Dutch policy lines, development strategies and regional agendas put a strong emphasis several themes for which hyperloop is capable of providing radical improvements and unmatched efficiency gains:

- ***Sustainability & Climate Change:*** The "Klimaatakkoord" has set the mission to reduce CO_2-emissions by 49% in 2030 and 95% in 2050 compared to 1990. The European Green Deal promotes more sustainable means of transportation and "seeks a 90% reduction in these emissions by 2050."[7]. Hyperloop can reduce transport emissions by about 50% for a single corridor by attracting cargo and passengers currently using road transportation or aviation.

- ***Improving competitiveness and business climate of the region:*** To strengthen connectivity of top locations from an economic perspective and creating an internationally competitive portfolio of top locations. Hyperloop can drastically reduce transit times between top economic and population centers and thus strengthen economic and social links between regions and cities.

- ***Improving the mobility and transportation networks:*** Innovation in mobility is necessary to meet future challenges in the field of accessibility and sustainability in Europe and in the Netherlands[8]. Hyperloop provides an efficient alternative to costly and land-consuming expansion of existing transport infrastructure and bring more than 20% savings in the infrastructure expenditures for the public sector.

- ***Infrastructure development of the trans-European transport network:*** establishment and development of key links and interconnections to eliminate existing bottlenecks to mobility, fill in missing sections and complete the main routes - especially their cross-border sections, and improve interoperability on major routes.[9] Hyperloop can provide an interoperable network integrated with other modes of transportation to complement and supplements existing transport solutions on the continent.

3 https://ec.europa.eu/transport/themes/sustainable_en

4 https://ec.europa.eu/transport/sites/default/files/legislation/com20200789.pdf

5 "Contouren Toekomstbeeld OV 2040, Programma Toekomstbeeld OV, 2019": Link

6 "Klimaatakkoord, 2019": Box Huidige top 10 van maatregelen Anders Reizen, pg 71, "Geen vliegtuig maar trein voor afstanden onder de 700 km; waarbij reistijd deur tot deur met trein <150% reistijd vliegreis is.": Link

7 "EU Green Deal Sustainable mobility, 2019": Link

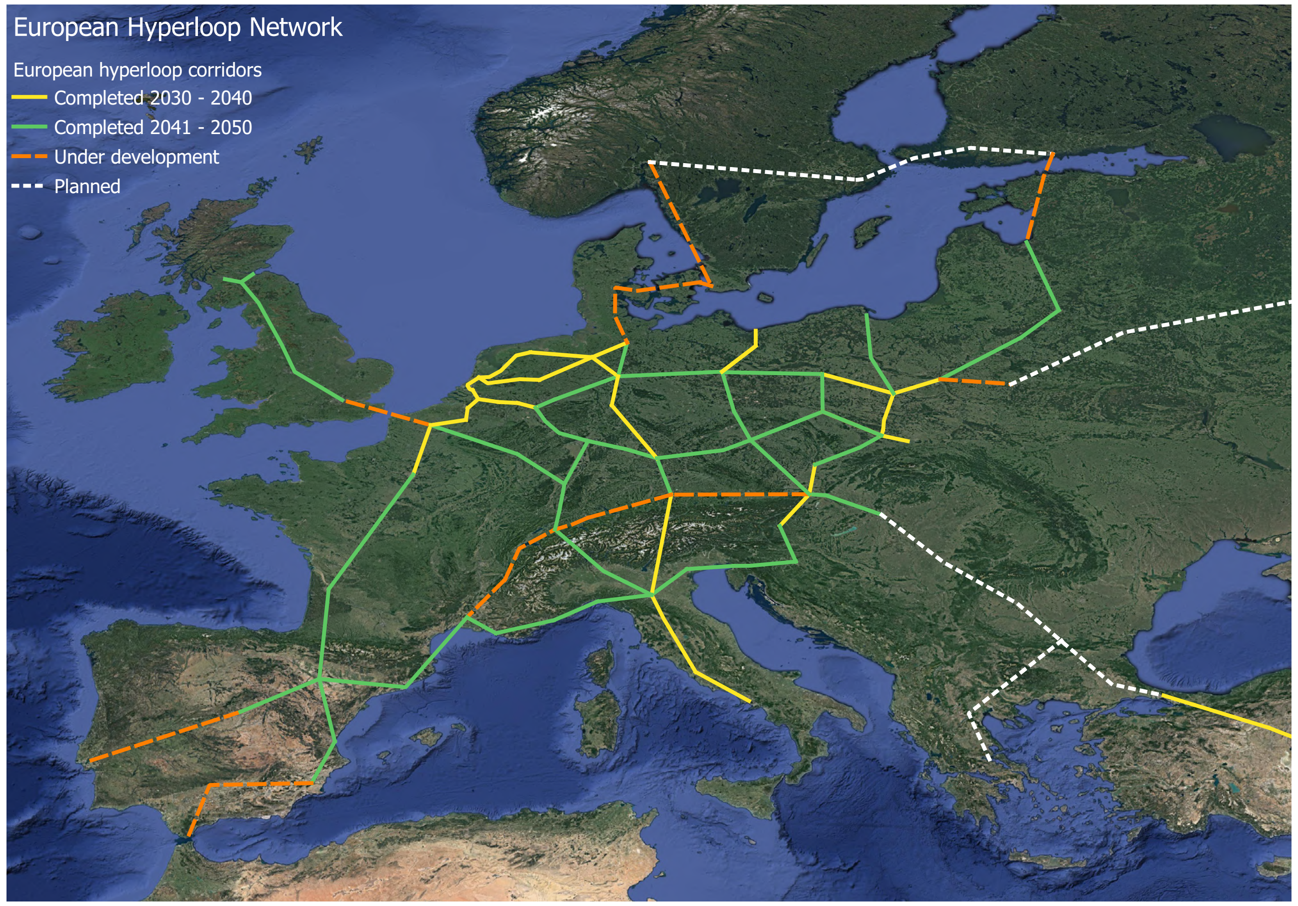
8 Kamerstukken II 2017-2018, 31305, nr. 325, p. 4: Link

9 "Webpage – TEN-T": Link

2.2 European hyperloop network development

Hyperloop has an unmatched potential to be an indispensable piece of the puzzle in tackling European (and global) transport sustainability challenge. This can be achieved on a continental scale by creating the European hyperloop network. In its envisaged shape (Figure 1), the continental hyperloop network in Europe supports all strategic corridors within the Trans-European Transport Network policy (TEN-T policy)[1], and provides fast and sustainable connections to all major economic and population centers.

Figure 1: European hyperloop network 2050 (draft), Global Market Analysis, Hyperloop Development Program



Implementation of the European hyperloop network is already perceived as a major objective for transport infrastructure development in Europe, gradually becoming a part of European and national strategies and plans. It is especially pronounced in Netherlands, being a home to the European Hyperloop Center and hosting the international Hyperloop Development Program. It is an ambition of the Dutch government, regional and local authorities and industrial partners to initiate the development of the European hyperloop network in the Netherlands, by implementing a pilot route and the first hyperloop corridor in Europe.

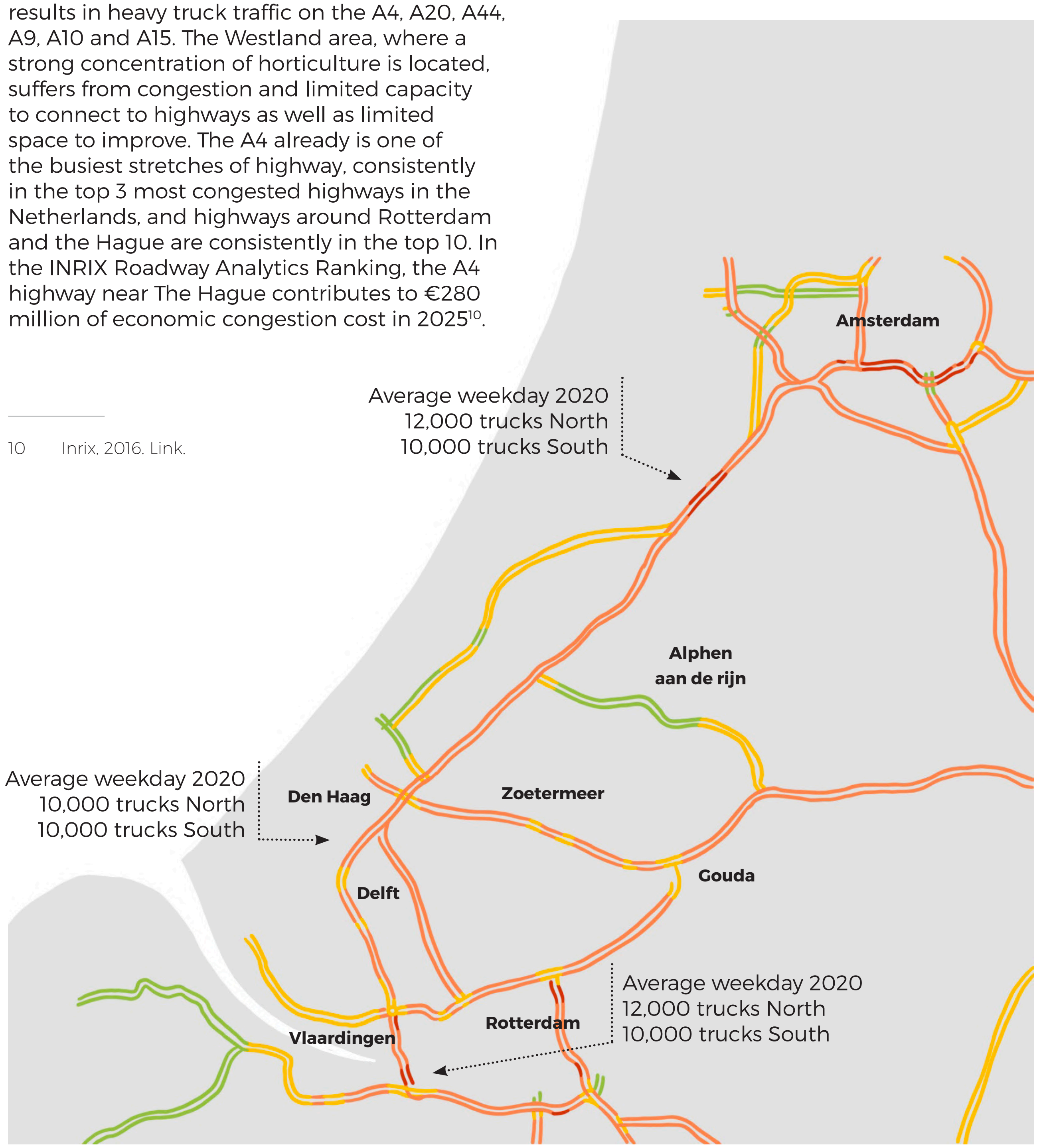
2.3 Connectivity between North and South Holland

2.3.1 Capacity constraints

Transport of products between industrial and port areas, production locations and consumption areas in North and South Holland is currently almost exclusively by road. This results in heavy truck traffic on the A4, A20, A44, A9, A10 and A15. The Westland area, where a strong concentration of horticulture is located, suffers from congestion and limited capacity to connect to highways as well as limited space to improve. The A4 already is one of the busiest stretches of highway, consistently in the top 3 most congested highways in the Netherlands, and highways around Rotterdam and the Hague are consistently in the top 10. In the INRIX Roadway Analytics Ranking, the A4 highway near The Hague contributes to €280 million of economic congestion cost in 2025[10].

10 Inrix, 2016. Link.

Figure 2: Truck traffic intensity 2020 per week day. Source: INWEVA 2021



Cargo traffic heavily adds to the congestion problems in the area. Freight traffic intensities on A4 between Rotterdam and Amsterdam reach 12,000 trucks per average working day (Figure 2). In passenger car units[11] (PCU), this is an equivalent of 27,600 passenger cars per day which accounts for about 30% of total traffic along this corridor (in PCU values).

Providing an alternative transport solution to remove a portion of cargo traffic from this corridor would significantly relieve congestion on A4 and adjacent roads and improve connectivity between the north and the south of the country.

2.3.2 Improve the connectivity of three major European ports

The Port of Rotterdam forms an essential link for freight transport in Europe and beyond. As Europe's major port of entry, it handles over 14 million TEU per annum from about 1,000 ports worldwide. In addition, the Port of Rotterdam supports about 385,000 direct and indirect jobs and add approximately 45 billion of value to the Dutch economy[12]. The port of Rotterdam is the most important port in Europe for the import and export of refrigerated and frozen cargo in reefer containers. A large share of these products are handled or further processed in the Cargo-hyperloop Holland area, such as Westland, Aalsmeer, Barendrecht, Maasvlakte or Rotterdam Cool Port.

Amsterdam is the fourth largest port in Western Europe. The Amsterdam port region has an annual cargo throughput of over 100 million tonnes and specializes in liquid bulk, dry bulk, project cargo and RoRo (roll-on/roll-off of wheeled freight like trucks)[13]. Furthermore it hosts European Distribution Centers of fashion, automotive, pharma and high tech companies.

Amsterdam Airport Schiphol is the third largest cargo airport in Europe[14] handling over 1.4 million tonnes in 2020. The cargo activities support over 30.000 direct and indirect jobs and add 2.7 billion in economic value[15]. The connectivity of Schiphol (one of the best connected airports in the world) is a unique selling point for the attraction of foreign businesses to the Netherlands and the competitiveness of the Dutch exporting industries such as floriculture and high tech. The airport area also hosts many logistics facilities with a global or European service area. International companies that deliver time critical goods, in aerospace, automotive, medical devices, pharmaceuticals, spare parts, high tech and e-commerce either have their own distribution center or outsource it to specialized third party logistics service providers.

Companies that are active in the port and airport regions would benefit from increased connectivity between these locations by a reliable, high-speed and sustainable mode of transport like hyperloop. Also, in the context of a future European hyperloop network, it would allow these companies to greatly expand their range, improve their efficiency and reduce their carbon footprint.

2.3.3 Expand the reach of Holland's Greenports

The Dutch export of agricultural goods is estimated at €95.6 billion for 2020 making the Netherlands the second largest exporter of agricultural products in the world. Most of these products are either produced or transported through the region. The Ports of Rotterdam and Amsterdam play a major role in the import of agricultural products from overseas to the European market and the region's four greenports (West-Holland, Aalsmeer, Duin- en Bollenstreek and Boskoop) are significant specialized production hubs. The Royal FloraHolland auctions in Naaldwijk, Rijnsburg and Aalsmeer are world-class trading hubs for floriculture and horticulture. As physical trading is an important part of the process, these facilities create significant flows of goods with customers, suppliers and between them. Westland and Barendrecht are major international hubs for fruits and vegetables, consolidating locally produced and overseas products that are delivered to the European hinterland creating sizeable flows of goods within the region and to markets all across Europe.

As fresh products like flowers, plants, fruits and vegetables have limited shelf life, time-to-market is crucial. A modality that may improve speed and efficiency of transport within the region and towards their national and international markets would bring significant economic gains to these industries.

2.3.4 Major logistics and fulfilment location

Aside from fresh products, the region is also a major exporter of other time-sensitive and high value products such as fashion, high tech, pharma, medical devices, automotive, aerospace and spare parts. The Netherlands is a favorite location for European Distribution Centers as it ranks high in terms of international connectivity which draws activities of multinational companies. Nonetheless, the Netherlands has lost its top ranking in the World Bank Logistics Performance Index (from 2nd in 2014 to 6th in 2018), a sign that the top position of the Netherlands as a logistics leader is not self-evident. When the Cargo-hyperloop Holland route is extended internationally, this would improve the connectivity of the region, possibly resulting in increased logistics performance of the Netherlands and enhance the business climate for manufacturing and logistics activities.

11 PCU value of 2.3 for trucks have been assumed based on Traffic Modelling Guidelines, TfL, 2010
12 https://www.portofrotterdam.com/en/experience-online/facts-and-figures
13 https://www.portofamsterdam.com/en/business/cargo-flows
14 https://www.statista.com/statistics/434381/airfreight-volumes-in-europe-by-airport/
15 https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2019/11/18/economische-betekenis-luchtvracht-schiphol/economische-betekenis-luchtvracht-schiphol.pdf

2.4 Transport infrastructure development in the Amsterdam – Rotterdam corridor

The challenges of providing adequate transit capacity for the Amsterdam – Rotterdam corridor are widely recognized on the national and regional level. Over the last decade there have been several road expansion projects initiated and realized to provide additional capacity of A4 motorway and adjacent roads (Table 1). Up to 2019, four significant investments have been completed, amounting to €2.9 billion. The completion of these projects eliminated some bottlenecks along the corridor, but, despite the scale of the investments, they have not resolved the major congestion issues. Further €2.0 billion worth projects are already in the realization phase to improve the connectivity of the areas adjacent to A4, but they are not expected to improve capacity of the main A4 artery, and thus the major congestion problems remain unresolved and are to be tackled by the investments planned for the future.

#	Project Name	Year of Realization	Status	Costs [million €]
1	A15 Maasvlakte - Vaanplein	2016	Completed	2,053
2	A9 omlegging Badhoeverdorp	2017	Completed	300
3	N201 Waterwolftunnel	2017	Completed	291
4	N222 Veilingroute	2019	Completed	259
5	Rijnlandroute	2022	Realization	581
6	Maasdelta Tunnel	2024	Realization	1,300
7	N211 Wippolderweg	2025	Realization	47
8	A4 Haaglanden – N14	2023 – 2026/2028	Planning	676
9	A4 Burgerveen – N14	2026	Planning	231
10	MIRT onderzoek corridor Zuid	N/A	Planning	N/A

Table 1: Road transport investment projects along the Rotterdam – Amsterdam corridor

The two projects for A4 widening currently in the planning phase amount to about €1 billion and focus only on sections within the Haaglanden area and near Leiden. Further plans will be made within the MIRT program as a result of the recent strategic MIRT study[16], which should lead to the design of a strategic program for the development of the Corridor South[17], including the Amsterdam – Rotterdam section, in the coming years.

Within the main conclusions of the Corridor South study, it is recognized that an efficient and sustainable use of the transport and spatial infrastructure is crucial for the competitive position of Dutch business in Europe and that opening up the main seaport nodes of Amsterdam, Rotterdam, Moerdijk and Vlissingen/Terneuzen is important for the development of the Dutch economy and society. However, it is also acknowledged that spatial constraints and growing volumes of cargo transport require an integrated, multimodal and innovative approach to the congestion challenges experienced by the corridor and that the reactive expansion of the road network will not be either a sufficient or sustainable solution to address them. Therefore, the study recommends exploring new solutions, including investigating the potential of pipeline-based transport. Hyperloop is a unique solution which responds to all the recommendations from this study, integrating multimodal and integrated approach with the benefits provided by space-efficient and sustainable tube-based infrastructure.

16 Freight Transport Corridor South (ARA Corridor) – Exploratory study into the need for an integrated approach, Panteia, 2020

17 The Freight Transport MIRT Corridor Zuid runs from North-Holland via South-Holland to West-Brabant and Zeeland, where it connects to several European TEN-T Corridors, such as North Sea – Mediterranean.

3. Cargo-hyperloop Holland Project

3.1 Project objectives

The Cargo-hyperloop Holland project is defined to address all the challenges presented in the previous chapters of the report, and the objectives of the project are directly linked to resolving the major issues faced by the Amsterdam – Rotterdam corridor. The project aims to:

- Reduce levels of road traffic and congestion on A4 between Amsterdam and Rotterdam by providing additional modality;
- Reduce carbon and other emissions from transport to support achieving the sustainability goals on regional and national level
- Deliver the future economic growth for North and South Holland by improving accessibility and connectivity between logistics and industrial centers in the region;
- Initiate the development of the European hyperloop network by implementing a pilot hyperloop project
- Improve reliability of transport and transport times for shippers in North and South Holland
- Deliver savings and improve efficiency of other transport infrastructure development schemes in the region

3.2 Project scope

The focus of this project is on the busiest domestic freight corridor between the cities of Rotterdam and Amsterdam. It hosts major Dutch export industries like horticulture and floriculture and the logistics complex around it. Connecting producers, traders, buyers and logistics nodes on this corridor with a hyperloop, offers the potential to drastically reduce transport with existing modalities and significantly increase the speed and reliability of delivery. This would mean a gross reduction in maintenance costs for existing infrastructure and would alleviate the congestion problem. Also, a significant improvement of the air quality and a reduction of CO_2 emissions in the heavily populated area could be achieved. The latter would be a major step for the transport sector in achieving its ambitions towards achieving the climate agreement goals.

The scope of the Cargo-hyperloop Holland project covers the development of the Cargo-hyperloop Holland corridor between Amsterdam and Rotterdam (Figure 3). The Cargo-hyperloop Holland corridor is defined as an integrated infrastructure and logistics project adding a new hyperloop modality to the existing transport solutions in the corridor. The project comprises of the following components:

- Development of the hyperloop linear infrastructure between Aalsmeer / Amsterdam Schiphol Airport and Maasvlakte / Barendrecht
- Development of the hyperloop hubs for cargo in 12 locations along the corridor, identified in cooperation with wide stakeholders community
- Provision of hyperloop vehicles for cargo to be operated in the corridor.
- Provision of transport services related to the operation of hubs and vehicles along the corridor.

The Cargo-hyperloop Holland project is expected to be completed by the end of 2028, with 2029 being the first operational year.

Figure 3: Cargo-hyperloop Holland corridor – project location

4. Hyperloop System

4.1 Overview

4.1.1 Hyperloop System Overview

The hyperloop is an electrically powered mode of land transportation with vehicles travelling through a network of low-pressure tubes, capable of high-speed and driverless operations, offering continuous capacity for transporting passengers and cargo towards their destinations without intermediate stops. The hyperloop infrastructure can be built above ground, on ground level or underground. Vehicles that resemble small aircraft travel inside the tube, either separately or in short trains of coupled vehicles.

The hyperloop system is a combination of existing technologies from different industries into a new mobility concept. Instead of rail technologies as wheels on tracks, the system uses magnetic forces for levitation, guidance and propulsion.

Air resistance and noise emission become a major factor with increased speeds. Hyperloop system solves this by operating pressurized vehicles inside a low-pressure tube. The low-pressure environment reduces the air resistance and the energy consumption and allows propelling vehicles to maximum speeds of up to 700km/h. The hyperloop has the following key characteristics:

- High capacity. Over 20.000 passengers[18] or 20,000 half pallets of cargo[19] per hour per direction at 700 km/h
- High transit speeds. Operational speeds ranging from 100 km/h for local links to 700km/h for major international links,
- Low energy consumption. 38 Wh/passenger/kilometer at 700 km/h, and 15 Wh/tonne/kilometer at 200 km/h
- Low maintenance. Magnetic levitation and propulsion without friction and switching without moving components minimize wear and tear
- Zero operational emissions. Electric powertrain by renewable energy sources produces zero operational emissions
- Minimized infrastructure footprint. The small footprint of the elevated infrastructure allows the hyperloop to follow existing infrastructure and reach and integrate with transport hubs.
- Lower costs than any other comparable transport option

The hyperloop system uses the same infrastructure for passenger and cargo transport. The differences between cargo and passenger hyperloop are mainly observed in vehicle characteristics and hub operations. Within this report, the main focus is on the cargo application of the hyperloop, and thus, the hyperloop system description provided in the subsequent chapters of the report is focused on hyperloop for cargo. Specifications are subject to further development in the Hyperloop Development Program and standardization through JTC20.

18 This assumes no cargo being transported at the same time

19 This assumes no passengers being transported at the same time

4.1.2 Hyperloop for Cargo

The hyperloop for cargo is a comprehensive logistics solution[20] for moving small and medium, standardized, and configurable shipment units. As the shipments of small and medium cargo units are an emerging challenge for the logistics market which have not yet been fully addressed by the transport industry, the hyperloop for cargo is a complementary solution addressing this niche and releasing operational stress on the existing cargo transport modes.

The cargo application of hyperloop is addressed primarily towards a range of time-sensitive, demand-sensitive and high-value products, such as fresh food, horticultural products, pharmaceuticals, e-commerce, fashion, electronics, and high technology equipment. The hyperloop solution directly addresses the current and future challenges of these industries by:

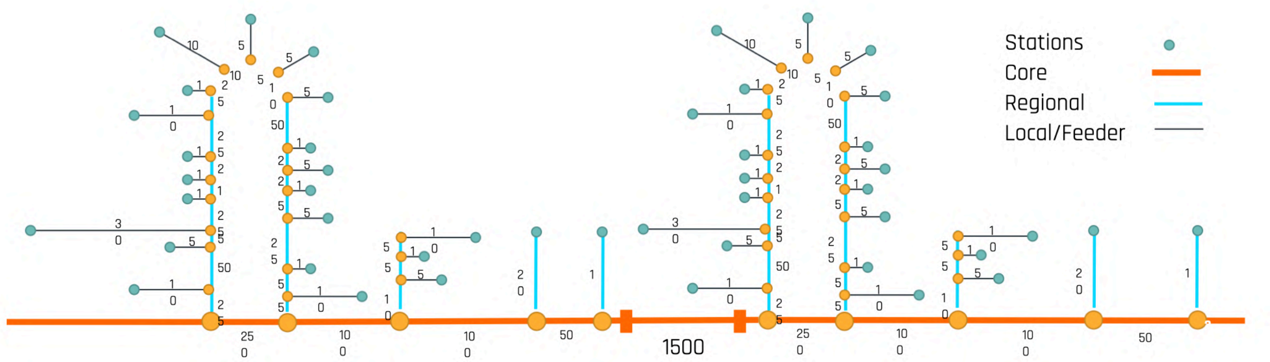
- Radically improving agility and efficiency of logistics operations for just-in-time and on-demand deliveries of small and medium sized shipments and packages, while minimizing their costs and carbon footprint
- Unlocking new market opportunities and economies of scale for time-sensitive and demand-sensitive products (reducing market access times, increasing geographical coverage, enabling new types of services and products)
- Enabling cost-effective transition to digital and automated logistics operations to increase responsiveness to demand volatility and changing customer requirements (logistics as a service, automated fulfilment, packaging modularization, physical internet)

Hyperloop also brings benefits for other market segments, by creating opportunities for supply chain optimization and automation, increasing the coverage of existing logistics facilities, and reducing the need for capital investments in new or expanded facilities.

4.2 Network

The hyperloop network comprises of links and nodes. The same links are used by both passengers and cargo, while nodes are passenger stations or cargo hubs.
The (cargo) hyperloop links are categorized into core, regional and local (feeder links) with varying specifications (Figure 4).

Figure 4: Example network showing the different types of elements within the comprehensive network. The numbers are the distances in km. Note that the network has been compressed at the 1500 km link, and in reality there would be many more regional network branches within the compressed link.



20 A comprehensive logistics solution is defined as a set of transport and logistics services increasing efficiency of the supply chain by providing high quality transport services with seamless interfaces between transport networks, and adaptable processes enabling integration of logistics operations within the supply chain.

- Core links: the highest strategic corridors linking the most important long-distance metropolitan areas at high-speed of up to 700 km/h. The core links do not connect to any nodes directly, but branch off into regional links. The typical distance between junctions on core links is 100 – 500 km.
- Regional links: the regional links directly link local nodes and feed into the core network. The typical distance between nodes is 3 – 300 km, with max speed of up to 300 km/h.
- Feeder (or 'Local') links: the capacity required in a link within the regional network is not always high enough to warrant a double tube for opposite unidirectional flow in each tube. Sometimes sufficient capacity can be achieved by alternating flows in opposite directions through the same tube. These links generally have the same specifications as the regional network, except that they consist of a single tube with means to buffer vehicles. These links are substantially lower cost than regular double-tube links.

The cargo hubs the locations where cargo can be (un)loaded from the hyperloop. There is no one-size fits all solution for cargo hubs, but they can broadly be divided in four categories: regional gateways, local hubs, urban hubs or direct facility connections.

- Regional (or 'Gateway') hub: located at a regional business / logistics park often close to a multi-modal connection, services a larger catchment area, a variety of cargo types and is accessible for heavy and light vehicles.
- Local hub: primarily services one local business / logistics / industrial park with a sufficient cargo potential.
- Urban hub: services a city and is typically located on the city edge to allow emission free last mile delivery into the city. Focus on spatial integration such as a limited physical footprint and accessibility for light (electric) vehicles.
- Direct facility connection: connects directly into a cargo generating facility with limited footprint inside the facility

4.3 Links

The hyperloop linear infrastructure consists of tubes connected with each other with expansions joints. The network operations are enabled by linking the tubes with lane switches.

4.3.1 Tubes

The hyperloop tubes are 2.5 m diameter and can be elevated, at grade or underground depending on the alignment requirements. Most of the tubes are at grade to minimize visual intrusion of the environment (Figure 5).

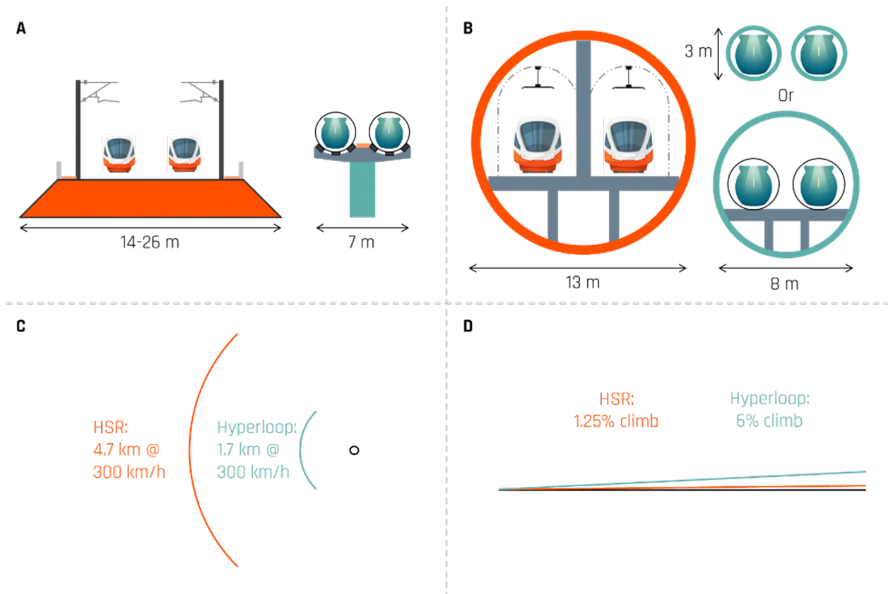


Figure 5: Hyperloop infrastructure – spatial comparison with high-speed rail

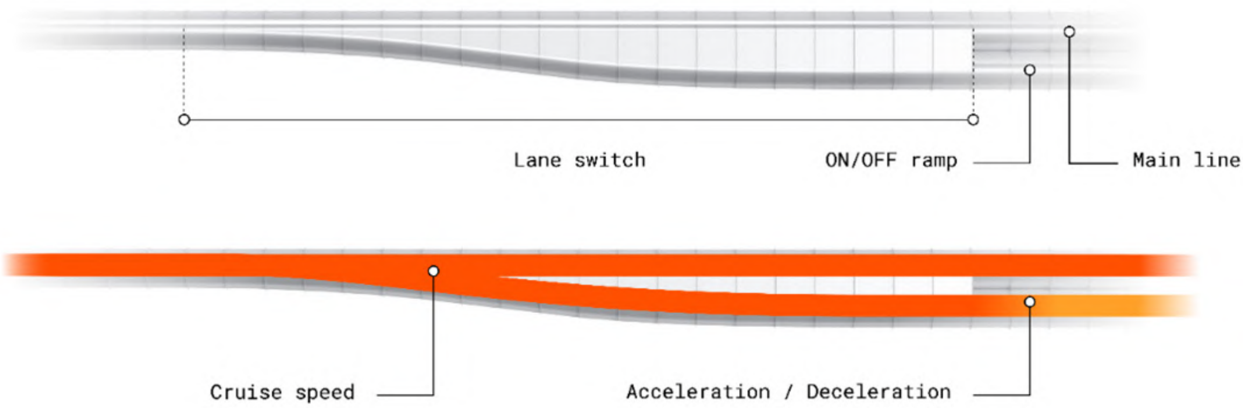
4.3.2 Expansion joints

Approximately every 60 meters, an expansion joint absorbs temperature-induced expansion of the tubes while safely holding them together. This increases the operational temperature range of the infrastructure.

4.3.3 Lane switches

The lane switch which splits one tube into two parallel ones, allowing the vehicles to switch from one track to another without slowing down.

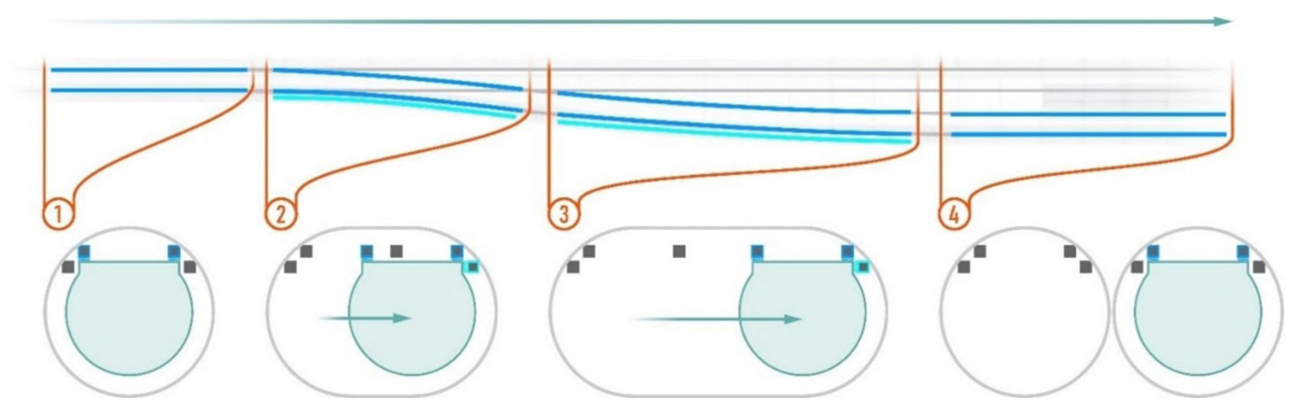
Figure 6. Diagram of lane switch



Being able to switch to a different track at high speeds is a feature that enables the hyperloop to supply direct connections between cities, without hampering the other vehicles on the route. The length of a switch designed for high speeds has a maximum length of 300 m.

Hyperloop magnetic levitation layout, enables infrastructure that operates without mechanical switches, and it is achieved this by means of electromagnetic forces which require no moving parts.

Figure 7. Lane switch overview



The high-speed switch consists of 4 stages:

1. The vehicles travel through the main track at cruise speed.
2. The guidance magnet in the switching side (marked in light blue) gently pulls the vehicle towards the switching side. As the tracks diverge, the vehicle remains aligned to the levitation tracks on the switching side. The tube extends in the lateral direction.
3. The vehicle remains engaged by the guidance track. The levitation tracks are now completely separated.
4. The vehicle leaves the switch and enters a new tube. The switch is complete.

Furthermore, the high-speed magnetic switch can operate continuously without any interruption, potentially giving the infrastructure the ability to handle multiple vehicles per second.

4.3.4. Double and single tube

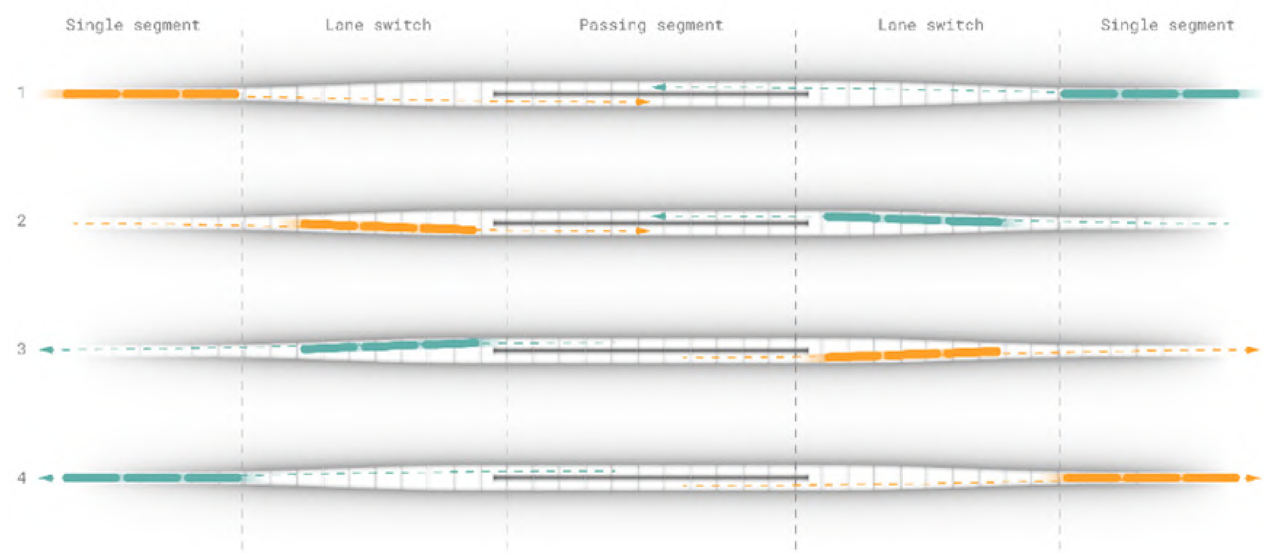
Hyperloop tubes can be operated either as a single or double tube infrastructure, depending on the expected volumes of traffic at each route segment.

Double tube infrastructure allows the continuous passing of vehicles in both directions, greatly increasing the capacity. Regional or core connections will be part of multiple origin-destination routes and therefore deal with higher and more variable volumes. When the network is expanded, the volume should be scalable. Hence, regional and core connections are being designed for a high throughput of 20.000 pallets per hour per direction.

In essence, a tube allows vehicles to move in either direction. A single tube line uses this feature to handle bidirectional traffic at low traffic volumes, by alternating flows in opposite directions through the same tube. On longer stretches, a single tube is alternated with a double tube to allow vehicle to pass each other when traveling in opposite directions.

The bidirectional operations of the single tube line with passing segments are fully automated. Coupled vehicles travel in opposite directions inside single tube segments and as they approach the passing segments, each set of vehicles switches lanes to the right, entering a dedicated passing segment (*Figure 8*). After passing each other, the vehicles switch again into the single tube infrastructure and continue their journey in a single tube line.

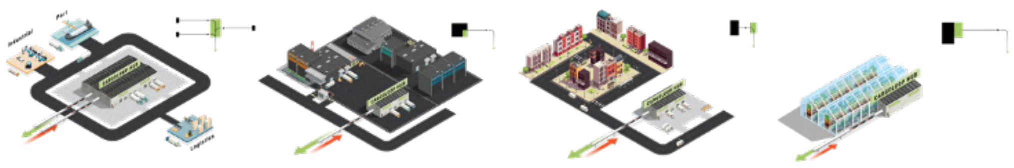
Figure 8. Top view of passing segments



4.4 Hubs

The hyperloop cargo hubs are designed to provide necessary services to enable seamless integration of hyperloop into the existing logistics processes. All hubs provide a basic set of loading/unloading and staging services, larger hubs also provide added value services such as container destuffing, palletizing and sorting. The hub layouts and functionalities differ depending on the size of the catchment area, the type of cargo and the type of environment it is placed in (urban, industrial, greenfield / brownfield).

Figure 9: Various types of hubs for cargo and their characteristics

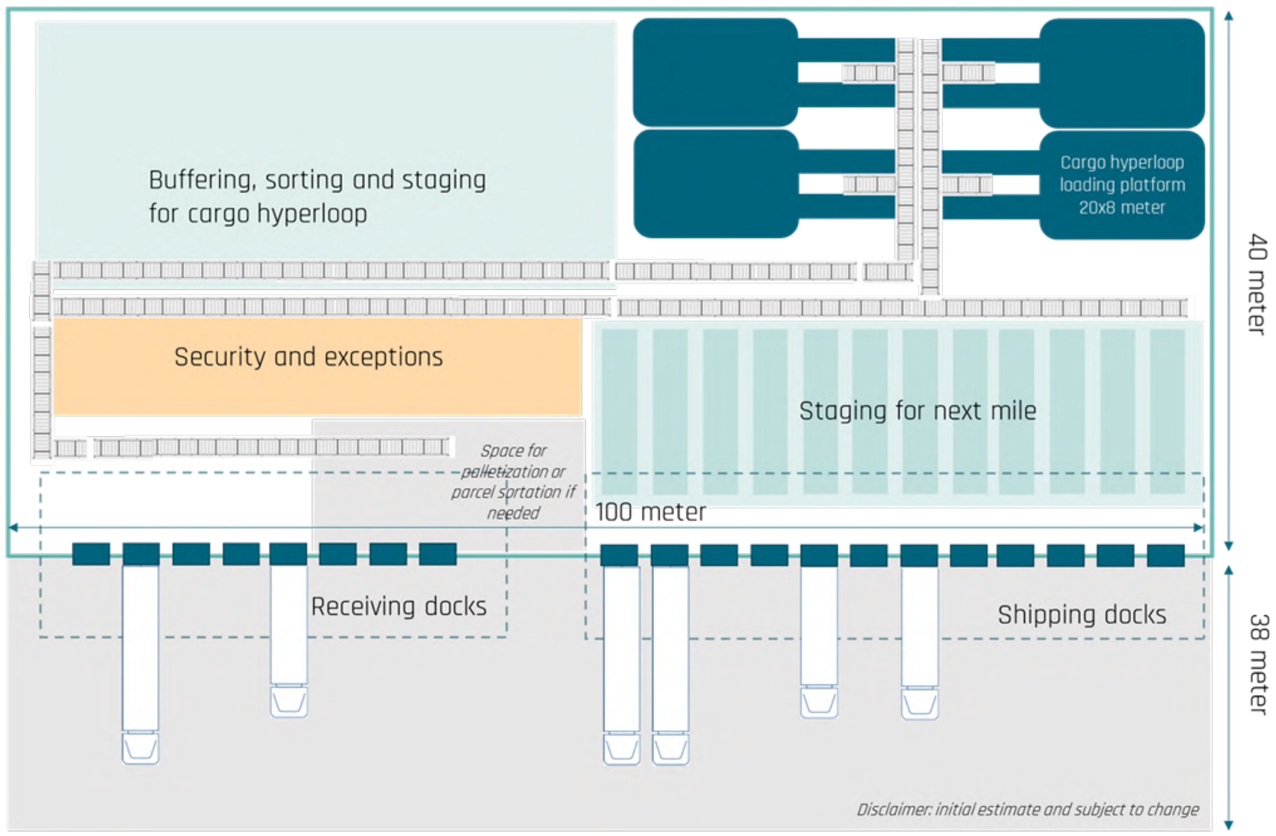


	Regional Hub	Local Hub	Urban Hub	Direct Connection
Catchment area	oooo	o	oo	o
Footprint	ooo	oo	oo	o
Throughput	oooo	oo	o	oo
Traffic around hub	ooo	o	oo	o

Hyperloop cargo hub functionalities necessary to conduct basic operations of cargo transshipment between a truck and a hyperloop vehicle include (Figure 10):

- **Cargo unloading from a truck**. Products arriving at the hub by truck from different destinations are unloaded from the inbound trailers in the receiving docks. Depending on the size of the items to be unloaded and the way they are packaged, the operation can be done manually or automatically (e.g. robotic arm). Bulk goods might need to be palletized while being unloaded, and multireference loads must be sorted.
- **Cargo check-in.** After unloading from a truck, the cargo is transported by a conveyor to a check-in gate. The check-in process aims to verify the integrity of the data regarding the incoming cargo, by checking cargo identity and destination, and whether the cargo complies with the dimension and weight requirements of hyperloop system. The control consists of weighting the products, visually checking or scanning the product dimensions, and verifying the data from cargo labels and tags with the data from the cargo hyperloop system database. All the non-compliant cargo items are considered as exceptions and processed separately.
- **Buffering, sorting and staging for departure.** The cargo which is successfully checked-in (excluding exceptions) is directed, depending on the service type, towards the express bypass, the hyperloop staging area or the overnight buffer area (optionally). The cargo directed to the staging area is sorted by destination, placed in dedicated staging lanes and awaits for the hyperloop route to become available.
- **Loading onto the hyperloop vehicles.** When the hyperloop route becomes available, the cargo is transported to the hyperloop platform and loaded into the hyperloop loading bay. The loading bay awaits on a platform for the hyperloop vehicle to arrive and is loaded into the vehicle. It is expected that the full loading process can take 1-1.5 minutes to complete.
- **Forming a vehicle sequence.** Loaded vehicles are combined into short trains of coupled vehicles in the delta sections of the hub. It is expected that the full loading process can take 3-6 minutes to complete.
- **Unloading from the hyperloop vehicles**. When a hyperloop vehicle arrives at the hub, the loading bay is removed from the vehicle into the hyperloop platform. Cargo is unloaded from the loading bays on the platforms and transported by a conveyor to a check-out gate. It is expected that the full unloading process can take 1-1.5 minutes to complete.
- **Cargo check-out.** At the check-out gate, the cargo ID and final destination is verified and the cargo is directed to a dedicated staging lane for outbound shipping.
- **Cargo loading onto a truck.** The cargo is loaded onto trucks from a dedicated staging line in the shipping docks. The loading process is either manual or automatic.

Figure 10: Hyperloop cargo hub operational components and functionalities. Draft layout of a regional hub of approx. 4000 m2 on a 7.500 m2 plot



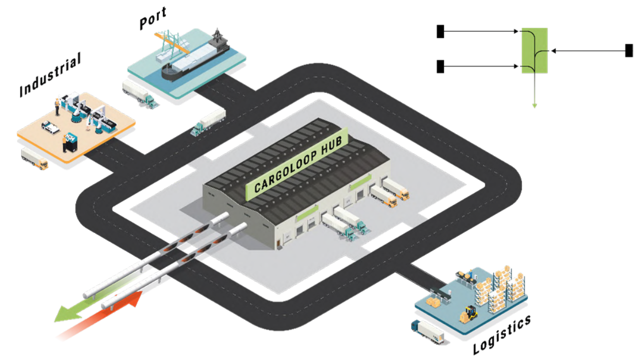
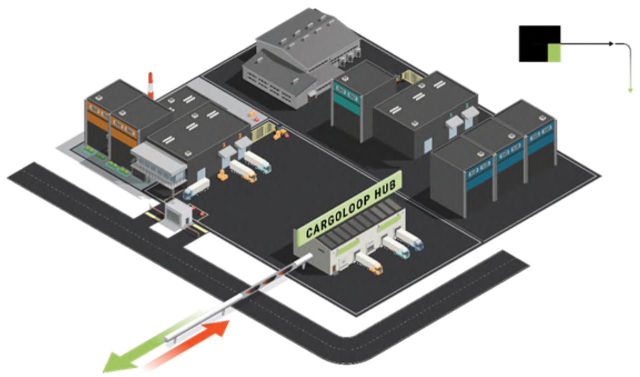


Figure 11: Regional hyperloop cargo hub

4.4.1. Regional (or 'Gateway') hubs

Regional hubs are large facilities with 4-8 hyperloop (un)loading platforms which can accommodate high throughput of cargo (1,000 - 2,000 pallets per hour). They are located at regional business or logistics parks, often close to multi-modal connections, service large catchment areas, and a variety of cargo types. They are accessible for heavy and light vehicles.

Regional hubs provide space for all basic hub functionalities and also for value added activities, such as container destuffing, palletizing and sorting.



4.4.2 Local hubs

Local hubs are medium facilities with 2-4 hyperloop (un)loading platforms which can accommodate cargo throughput of 500 – 1,000 pallets per hour. They service one business/logistics/industrial park and can be connected to adjacent facilities (like sorters) with automated conveyors. They are accessible for heavy and light vehicles. Local hubs provide space for all basic hub functionalities.

Local hub
Draft example layout

Number of Cargo hyperloop platforms: 2

Max throughput:
- 450 pallets per hour in
- 450 pallets per hour out

Building 1.800 m2
Plot 4.000 m2

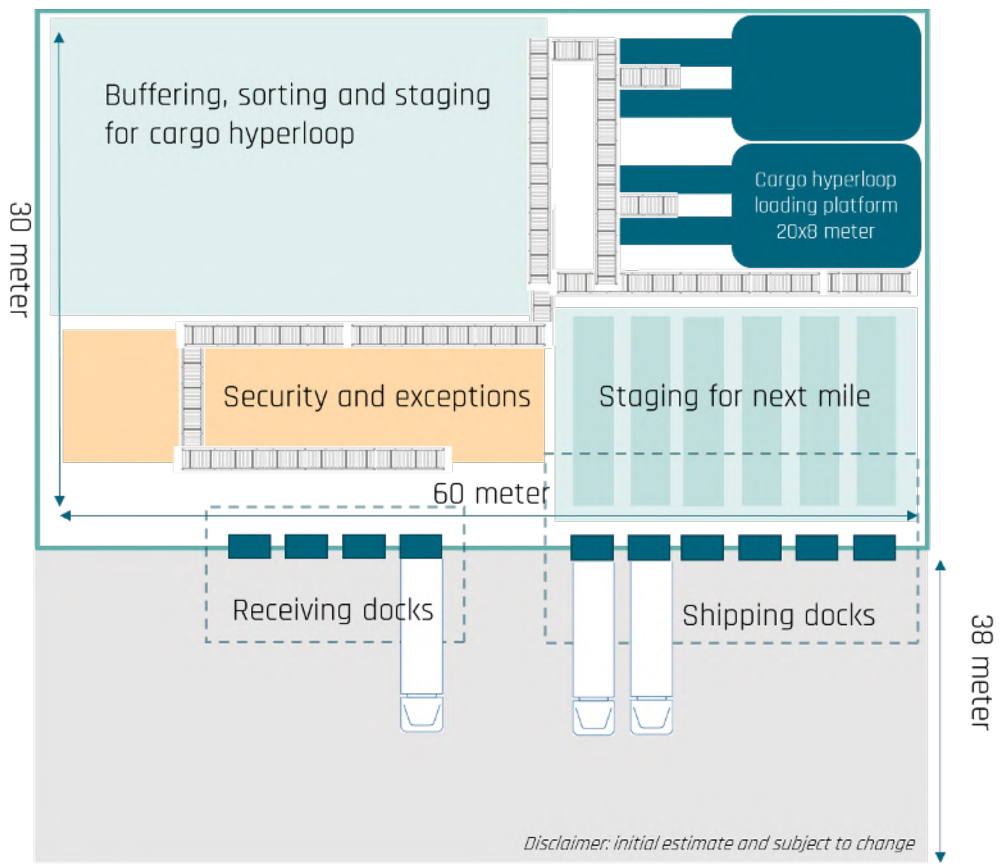


Figure 12: Local hyperloop cargo hub

4.4.3. Urban hubs

Urban hubs are small facilities with one hyperloop (un)loading platform which can accommodate cargo throughput of up to 7,000 parcels per hour. They are located at the edge of the a city or urban area that is being served to allow emission free last mile delivery. Their design is focused on spatial integration and a limited physical footprint, and they are accessible for light last-mile vehicles only. Urban hubs provide space for all basic hub functionalities, added value functionalities are possible depending on space available.

Figure 13: Urban hyperloop cargo hub

4.4.4. Direct facility hubs

Direct facility hubs are small facilities with one hyperloop (un)loading platform which can accommodate cargo throughput of 250+ pallets per hour. They are located directly at a cargo generating facility and integrated with its logistics processes, so no additional handling or transport is necessary. Their design and functionalities are tailored to provide services required by the facility they serve. These hubs are not accessible by third parties.

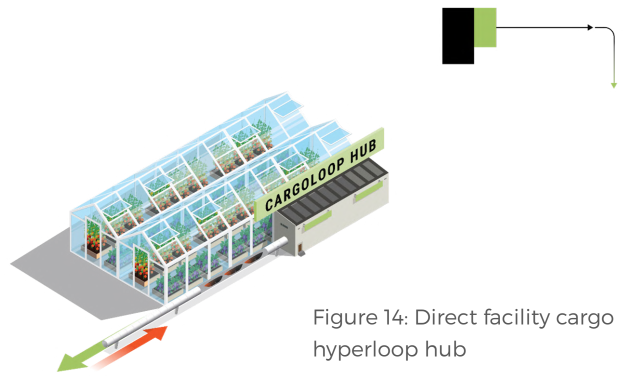


Figure 14: Direct facility cargo hyperloop hub

4.5 Vehicles

Hyperloop vehicles for cargo are designed specifically to move cargo through hyperloop tubes at high speeds and with limited energy use. The vehicle consists of two nose/tail segments which hold the vehicle subsystems connected by a rigid central structure (Figure 15). The nose/tail segments feature hinges to allow the vehicle to turn in tubes with tight corner radii. A central, detachable cargo bay locks into place in the middle.

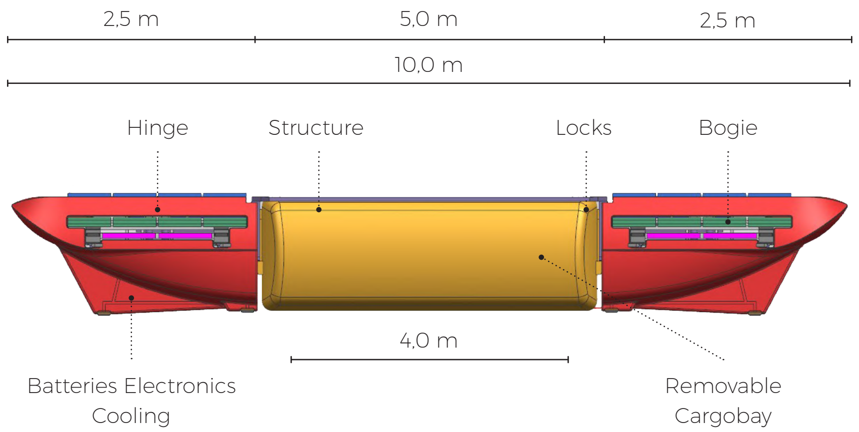


Figure 15: Hyperloop vehicle for cargo

The vehicle is made from lightweight material that gives several advantages. Firstly, the lighter the vehicles are with respect to the infrastructure, the lower the vibrations. A low vehicle weight minimizes infrastructure requirements and therefore costs. Secondly, a lower amount of energy and a smaller motor is required to bring the vehicle to speed, decreasing the costs of the vehicles.

The hyperloop vehicle for cargo is tailored for medium and small-sized shipments, and its cargo bay provides cargo envelope of 4.0 x 1.2 x 1.2 meters, with maximum payload of 2,500 kg. The cargo bay length differs from cargo envelope dimensions as it includes room to maneuver or use skids or internal containers for example for parcels. Considerations are made to also introduce another type of vehicle, featuring a smaller cargo bay of 2.4 x 1.2 x 1.2 meters (with 1,500 kg of maximum payload) to allow more agility and flexibility for express shipments.

The cargo space can be arranged to transport various types of cargo using either dedicated containers or pallets. The vehicle can hold all basic types of pallets (Euro pallet, block pallets or UK pallets), in various configurations. In the example below (Figure 16), a four meter nominal cargo bay length allows 5 Euro pallets or 4 block pallets. Between these pallets, there is a clearance of 7.5 cm to allow pallets that are not perfectly stacked to be loaded into the cargo container.

The height of the cargo containers is equal to the width, allowing space optimization in the circular infrastructure and allowing a pallet height of 1.20. According to market research, this will be able to facilitate 99% of the packaging units and already in road transport about half of the stacked pallets do not exceed this height. Users of the system should be aware of the height limitation and stack their pallets not higher than 1.20m.

4.6. System Operations

The hyperloop system for cargo operates as a part of the logistics environment and is integrated with other transport modes (predominantly road transport) to form an end-to-end delivery process (Figure 17). The delivery process starts with picking up cargo from different locations and delivering it by truck to the hyperloop departure hub where it is unloaded, sorted and loaded onto hyperloop cargo vehicles. The vehicles transport cargo to the arrival hub where the reverse process takes place (unloading hyperloop vehicles, sorting and loading trucks) and the cargo is delivered by trucks to its final destinations.
The hyperloop system for cargo allows for different service types: express, standard (fast) and overnight service.

- The express service has the highest priority in processing through the hyperloop cargo hubs and the hyperloop network. The cargo is not buffered but goes directly from the in-bound truck to the hyperloop vehicle at the departure hub (Figure 18) and directly from the vehicle to the truck at the arrival hub (Figure 19).

Figure 16: Example of pallet configuration in the cargo hyperloop vehicle

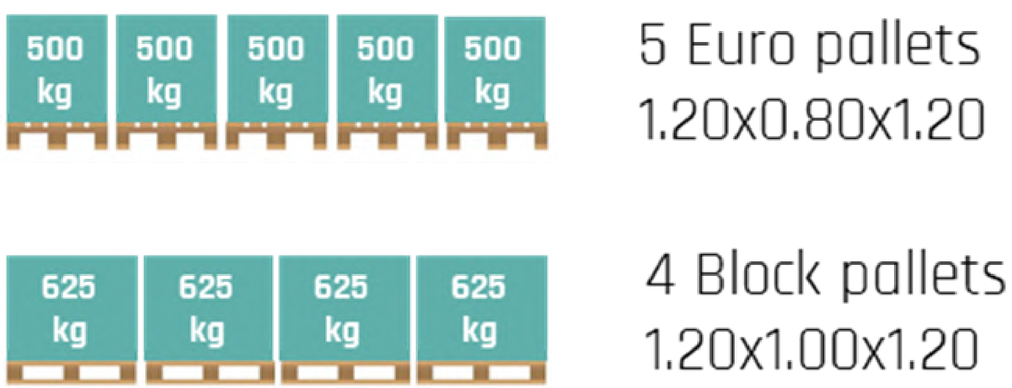
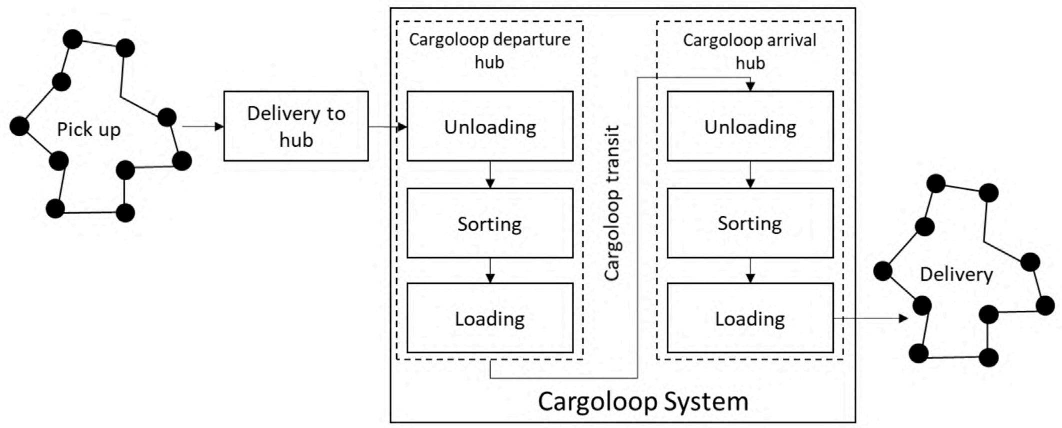


Figure 17: Cargo hyperloop system operations in the delivery process



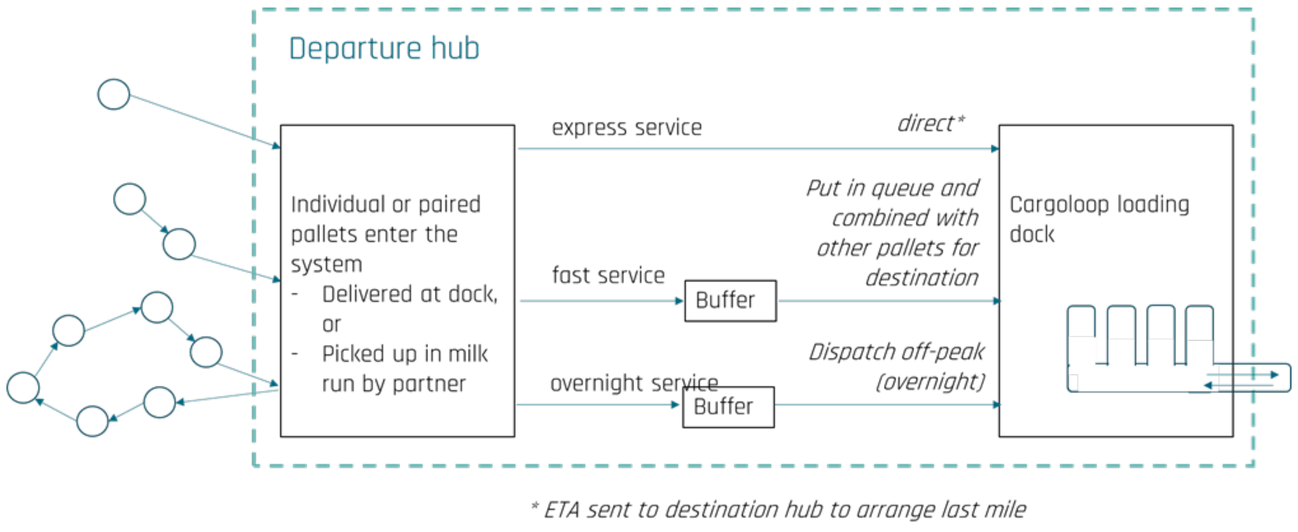


Figure 18: Hyperloop cargo hub - departure operations

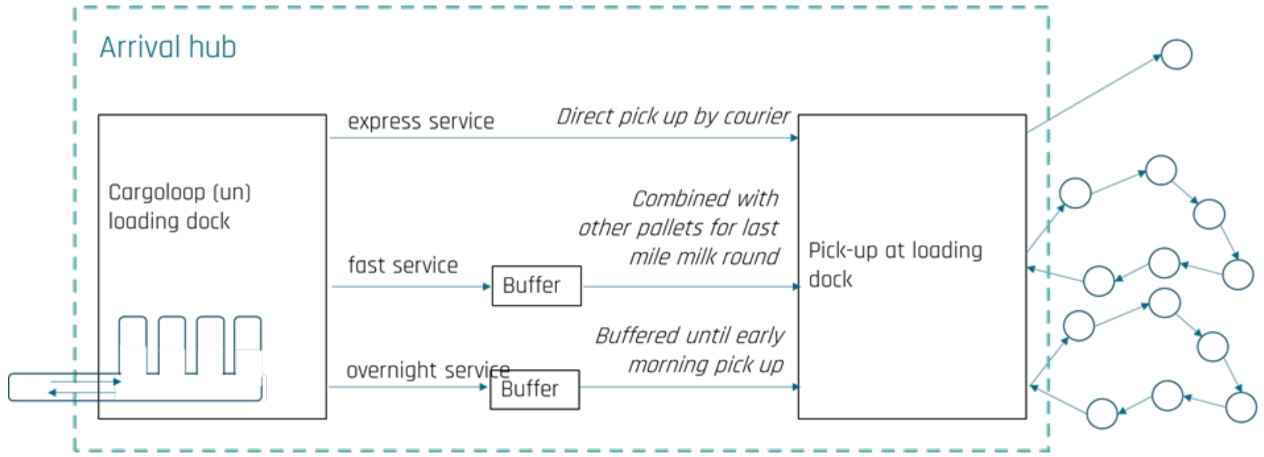


Figure 19: Hyperloop cargo hub - arrival operations

- The standard (fast) service has the second priority. The cargo is buffered in the hyperloop cargo hubs awaiting to be combined with other pallets transported to the same destination, and for a route to the arrival hub to become available and ready (Figure 18). At the arrival hub, the reversed process is applied: the cargo is buffered and sorted awaiting for the truck to pick it up and deliver to its final destination (Figure 19).

- The overnight service is arranged to provide off-peak or overnight delivery. The cargo is buffered in the hyperloop cargo hubs awaiting for the off-peak or overnight delivery window, when it is sorted, combined with other pallets and transported to the arrival hub (Figure 18). At the arrival hub the cargo is buffered, sorted and awaits the morning truck to pick it up and deliver to its final destination (Figure 19).

It is expected that the system will be operational 24/7, to provide different types of services presented above. However, from a practical perspective of system operations, a maintenance window of 2 hours has been assumed for hub operations, leaving 22 hours for cargo handling and loading/unloading operations. Based on the existing freight flow patterns observed on the road networks in Europe[21], the majority of cargo handling operations (90-95%) is conducted during the working days, and within 4-16 peak hours of a day. On average, one peak hour accounts for 7-10% of daily traffic. Considering that, it has been assumed for further analyses that the system is available 24/7, with 95% of traffic attributable to 240 working days per year, and 80% of daily throughput attributable to 8 peak hours a day. Due to the relatively small payload of each vehicle, it has been assumed that all vehicles entering the system are fully loaded, with 10% of empty vehicles circulating in the network for the purpose of repositioning between the hubs.

Although the intent is for the hyperloop to seamlessly integrate into the existing operating environment as much as possible, in order to take full advantage of its certain capabilities, the users will need to make some changes to their logistics processes:

- The shipments intended to be transported with the cargo hyperloop system need to be arranged into half-pallets or other shipment units with dimensions fitting the cargo envelope of the hyperloop. Containerized cargo will be palletized at the hyperloop hub before being transported to its destination. Destuffing containers will be included in the hyperloop hub services.

- For the shippers who currently use the door-to-door road transport system, switching to hyperloop would require additional first and last mile services. The first/last mile connections complementing the hyperloop services can be either organized by the hyperloop users or integrated first/last mile services offered by hyperloop affiliated partners can be used to ensure full compliance with hyperloop standards of handling quality, speed and reliability.

- The companies wishing to integrate hyperloop cargo hubs withing their existing facilities would need to define the level of automation they are willing to adopt for the hyperloop cargo hub.

- Lean hyperloop cargo hub infrastructure and small footprint requires that the first and last mile services are conducted in a timely fashion to reduce the time their vehicles spend at the hub.

- Hyperloop corridors with high density traffic (core network) will require reinforcement of the electric grid by utility companies to accommodate the electricity needs of the system.

- Emergency response procedures need to be developed to reflect specifics of the cargo hyperloop system.

In a practical example of the operational environment, shippers would need to review their packaging policies to make sure that the shipments fit the cargo envelope of the hyperloop. They would also need to define the level of automation of the hyperloop hub to ensure best integration with their operations. Unless the departure and arrival hubs are fully integrated with their warehousing facilities, they would also need to consider the first and/or last mile services to complement the hyperloop operations.

Also, the utility companies would need to be engaged at the infrastructure development stage (feasibility study and design phase) to assess whether there is a need for electric grid reinforcement. Hyperloop vehicles will either be charged at the hubs or wirelessly through a distributed charging system integrated with the tube infrastructure. For the purpose of this report it is assumed that the vehicles would be charged at the hubs, and each hub would require a dedicated substation powering the vehicle charging system. The capacity of each substation dedicated to vehicle charging would be proportionate to the size of the hub and range from 0.25 MVA for one-platform hubs to 2 MVA for eight-platform hubs[22].

21 Market needs for Cargoloop capabilities, Hyperloop Development Program, 2021

22 Vehicle charging requirements are preliminary results based on the conceptual design of the system. These requirements will be revised and updated after the next stages of system development.

4.7. System Costs

4.7.1. Construction costs

Costs of the hyperloop system implementation include capital expenditures on infrastructure (linear infrastructure and hubs), vehicles, and other costs, such as planning, procurement and engineering (Table 2). At this stage of the system development the costs are estimated with the accuracy level of 50%[23].

- The costs of linear hyperloop infrastructure built at grade amount to €8.5 million per km of a double tube line, including substructure, superstructure (guideway) and necessary communication, power, control and electronic systems. When built underground, the costs can increase by 75-500%, depending on the tunnelling technology.
- The costs of a cargo hyperloop hub comprising of one loading/unloading platform requires €3.7 million of expenditure. This represents a simplest direct connection hub integrated into an existing logistics facility. A local hub would require an investment of €7.3 million and a regional hub would cost up to €12.1 million for an 8-platform hub. These estimations exclude costs of equipment and space potentially needed for added value services such as sorting and logistics offices.
- The costs of cargo hyperloop vehicles amount to €188,000 per vehicle.
- Other costs such as planning, procurement and engineering have been estimated as a percentage of the linear infrastructure construction costs and amount to 6.0% of linear infrastructure CAPEX.
- Land acquisition costs have not been included in this estimations as it is assumed that the limited amount of space required by the hyperloop infrastructure can be provided by the public sector free of charge.

23 The costs estimates have been verified by an independent reviewer (Balance), also with the accuracy levels of 50%.

CAPEX category (in million €)*	**Cost per 1 unit**
Linear infrastructure [1 km of double tube line]	8.5
Guideway (superstructure)	7.0
Power, Control, Communication and Electronics	0.6
Substructure	1.0
Hub [1 loading/unloading platform]	3.7
Buildings	0.6
Loading/unloading system	0.1
Other systems	3.0
Vehicle [1 vehicle]	0.2
Cargo vehicle	0.2
Other costs [% of linear infrastructure CAPEX]	5.96%
Planning	0.37%
Procurement	0.13%
Engineering	3.62%
Construction management	1.80%
Marketing and communication	0.04%

* Totals might not add up due to rounding

Table 2: Capital expenditures for the hyperloop system, linear infrastructure at grade

Input	**Value**	**Unit**	**Source**
SG&A variable cost as percentage of revenues	4%	%	SAI Books
Energy consumption at 200km/h	15	Wh / tonne / km	Hardt
Energy costs (non-households in NL)	0.10	€ / kWh	Eurostat
Vehicle maintenance variable cost per year as percentage of vehicle value	4.50%	%	(Levinson, Mathieu, Gillen, & Kanafani, 1996); Hardt
Insurance of assets variable cost per year as percentage of value of assets	0.4%	%	Pianoo
Infrastructure maintenance fixed cost as per centage of direct construction costs	0.15%	%	(Levinson, Mathieu, Gillen, & Kanafani, 1996) ; Hardt

Table 3: Operational and maintenance costs of the hyperloop system

4.7.2. Operational and maintenance costs

Operational and maintenance costs of the hyperloop system comprise of several cost components:

- Selling, general and administrative expenses (SG&A costs), expressed as a percentage of revenues generated by the hyperloop system.
- Energy cost, expressed in nominal values and derived from a combination of energy consumption and energy costs
- Vehicle maintenance costs, expressed as percentage of the value of the vehicles in operation
- Asset insurance costs, expressed as percentage of the value of the vehicles and infrastructure in operation
- Infrastructure maintenance costs, expressed as percentage of direct construction costs of the hyperloop infrastructure.

The first four cost categories are variable costs and the infrastructure maintenance cost are fixed costs. Except of energy consumption costs, all costs have been estimated based on a review of international literature on other modes of transportation. The energy consumption costs are based on the vehicle concept developed by Hardt. The summary of the costs assumptions for each cost category is presented in Table 3.

5. Cargo-hyperloop Holland Corridor Alignment

5.1. Cargo hyperloop hubs

Hyperloop hubs play an important role as entry and exit points of the cargo into the hyperloop system and ensure integration with other modes of transportation. Locations of the hubs along the Cargo-hyperloop Holland corridor (Table 4) have been identified in cooperation with a wide stakeholders community to ensure that the corridor connects the major logistics locations and provides hyperloop access points to production and distribution facilities of main types of goods produced in the area. Out of 12 hubs identified along the corridor, five will serve as regional hubs, providing services for larger areas and remaining seven will be local, focused on serving specific logistics facilities. For half of the hubs, the major product types expected to be handled are time sensitive, best-fit products, including horticultural and fresh food products.

For the purpose of this report it is assumed that each hub will be accompanied by a power substation to provide electricity for charging hyperloop vehicles (see chapter 4.6), and the capacity of each substation would be proportionate to the size of the hub and range from 0.25 MVA for one-platform hubs to 2 MVA for eight-platform hubs. Considering the number and size of the hubs along the corridor, the capacity required to power the Cargo hyperloop Holland corridor is estimated at about 17 MVA. In comparison, a rail corridor in Netherlands of a similar length requires about ten times more power of approximately 175 MVA (substations with a capacity of 2.5 - 12 MVA placed at a distance of 6 km[24]), and a 150 km long high-speed rail corridor requires 480 – 540 MVA (substations with a capacity of 60 MVA placed at a distance of ca 20 km[25]).

Cargo-hyperloop hub	Municipality	Hub function	Major product types
ABC Westland	Westland	Local	Best fit – time sensitive goods
Atlaspark	Amsterdam	Local	Other - Products that are physically suitable
Auction Flowers Aalsmeer	Aalsmeer	Regional	Best fit – time sensitive goods
Auction Flowers Naaldwijk	Westland	Local	Best fit – time sensitive goods
Auction Flowers Rijnsburg	Katwijk	Regional	Best fit – time sensitive goods
Barendrecht Reyerwaard	Barendrecht	Regional	Best fit – time sensitive goods
City distribution center Badhoeverdorp	Amsterdam	Local	Other - Products that are physically suitable
Honderdland	Westland	Local	Best fit – time sensitive goods
CER Maasvlakte	Rotterdam	Regional	Other - Products that are physically suitable
PostNL IMEC	s-Gravenhage	Regional	Other - Products that are physically suitable
Schiphol Cargo	Haarlemmermeer	Local	Other - Products that are physically suitable
Schiphol Trade Park	Haarlemmermeer	Local	Other - Products that are physically suitable

Table 4: Cargo-hyperloop Holland hubs

5.2. Linear infrastructure

The alignment of linear infrastructure of the corridor has been developed based on the following assumptions resulting from the hyperloop technical concepts:

- The hyperloop infrastructure is predominantly constructed along existing infrastructure: highways, rail, bridges and tunnels unless there is not enough public space available.
- Single and double tube segments are used, depending on the volumes of traffic expected on each segment of the corridor.
- The horizontal and vertical alignment of the infrastructure ensures that during a turn the vertical acceleration does not exceed 1.1G, lateral acceleration does not exceed 0.1G[26], and the lateral and vertical jerk does not exceed $0.5 m/s^3$[27].
- The hyperloop infrastructure can be constructed at ground level, elevated (viaduct) or below ground. Construction at ground level is preferred unless the environment/landscape does not allow so. Underground or elevated segments are planned only where necessary (Table 5).
- The technologies for construction of each of the underground segments will be determined at the feasibility stage. For further analyses a mix of excavation and micro tunnelling has been assumed (Table 6), with excavation method used for short segments (up to 2,000 meters), and micro tunnelling applied to longer segments (above 2,000 meters).
- Given the acceptable longitudinal and lateral accelerations, the maximum slope of hyperloop infrastructure is 10%. A limit of 8% slope has been assumed in the alignment of the corridor to stay safely within the limit. Each underground segment is accompanied by two transition segments linking it with the surface level segments.
- Tilting the vehicles during cornering allows for higher later accelerations and as a result tighter corner radii. The hyperloop vehicles are tilted by a combination of canting of the tracks up to 9.5° and tilting the vehicle suspension by up to 9.5°, for a superelevation tilt of 19°. Table 7 shows the minimum design radii for various speeds given the maximum permitted total superelevation.

24 Analysing the business case for introducing a 3 kV traction power supply in Dutch railways, ProRail, 2014
25 Powering the world's high-speed rail networks, ABB
26 The parameter G refers to Earth's gravity.
27 Federal Railway Authority, High-speed Maglev system design principles,2007

Underground segments	Elevated segments
· crossing with transport infrastructure (road, rail, bike etc) · approaching urban areas sensitive to noise · approaching buildings and other public/private property of cultural importance · traversing highly urbanized areas · traversing facades of private properties and hence restricting access to them · Along existing tunnels	· crossing inland waterways · underground and at grade segments are not feasible · elevated infrastructure can also be selected when there is existing elevated infrastructure (bridges/viaducts).

Table 5: Alignment assumptions for the underground and elevated segments of the corridor

Tunnelling method	Segment type	Length [km]	% of the underground segments
Micro tunnelling (segments up to 2,000 meters)	Single tube	7.7	24%
	Double tube	-	0%
Excavation (segments below 2,000 meters)	Single tube	15.5	48%
	Double tube	9.0	28%
Total length of underground segments		32.1	100%

Table 6: Tunnelling methods used for underground segments construction

Speed [km/h]	100	150	200	300	400	500
Minimum radii [km]	0.2	0.4	0.7	1.6	2.8	4.4

Table 7 Minimum radii for various speeds at total maximum superelevation of 19°

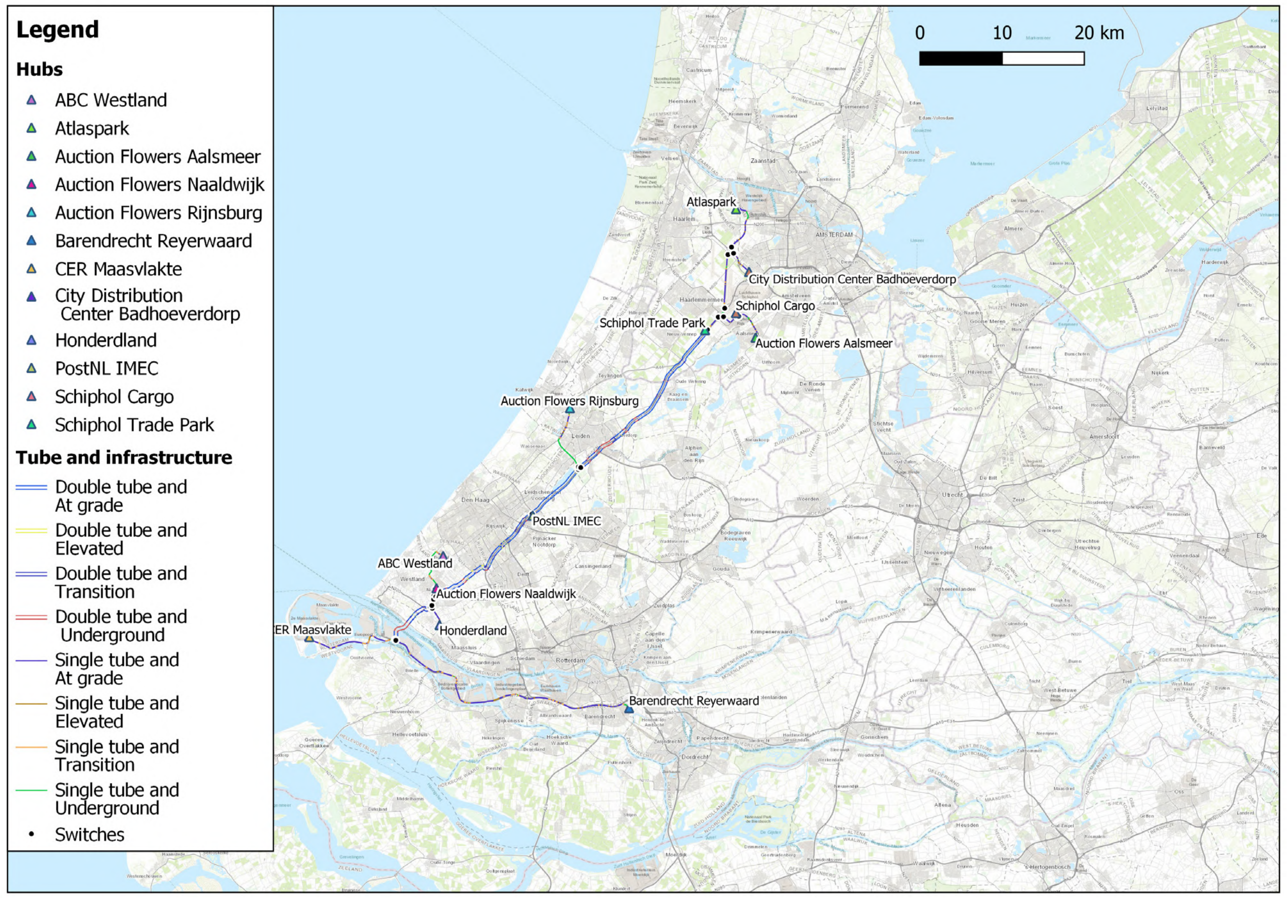


Figure 20: The Cargo-hyperloop Holland corridor – hubs and alignment

The alignment developed based on these assumptions and guidelines is presented in Figure 20. The total length of the corridor is 149km, with 26 switches located at junctions leading to hubs. 67% of the corridor is designed at grade, 5% elevated, 21% underground and 7% as transition segments. Most of the corridor is designed as a single tube line (64% of the corridor length), 36% is planned to have a double tube configuration. Specification of the alignment and its segments is provided in Table 8.

The alignment of the Cargo hyperloop Holland corridor has been evaluated to identify risks associated with potential conflicts with existing infrastructure, protected areas and planned developments[28]. The major risks are related to conflicts with future A4 widening and an additional runway planned for the Schiphol airport. The conflict with A4 widening has been resolved by adjusting the alignment. The plans for an additional runway will be further discussed with the Schiphol airport and the government.

The alignment allows for maximum speed of up to 400km/h on close to 50% of the route. At the remaining segments, the speed is limited to 200km/h, 150km/h or 100km/h, due to spatial integration requirements. Figure 21 shows an overview of the achievable speeds along the Cargo hyperloop Holland corridor.

Figure 21 Velocity along the corridor

28 The corridor alignment has been verified by Antea.

	Maasvlakte – Barendrecht	Maasvlakte – Westland	Greenports	Corridor
At grade [km]	36.8	17.0	44.3	99.6
Elevated [km]	3.9	1.6	2.7	8.1
Transition [km]	2.5	2.6	4.0	9.8
Tunnel [km]	3.2	8.4	15.0	32.1
Switch [-]	-	5	7	26
Local Hubs	-	3 (Auction Flowers Naaldwijk, ABC Westland, Hon derdland)	3 (Auction Flowers Naalwijk, Schiphol cargo, Schiphol Trade Park)	7
Regional Hubs	2 (CER Maasvlakte, Barendecht Reyer waard	1 (CER Maasvlakte)	2 (Auction Flowers Aalsmeer, Auction Flowers Rijnsburg)	5
Single Tube [km]	45.3	22.4	19.3	95.7
Double tube [km]	-	7.2	46.6	54.0

Table 8 Allignment details per researched segment

6. Demand Assessment

6.1. Assessment scenarios

Demand projections for Cargo-hyperloop Holland corridor have been prepared for four scenarios:

- **Single section scenario** (Figure 22). In this scenario all three sections of the Cargo-hyperloop corridor are considered separately as single pilot sections. The demand projections are prepared for each of the sections separately as if they were the only sections to be implemented, without any other parts of the hyperloop network to follow. Each section is assumed to be completed by the end of 2028, with 2029 being the first operational year.

- **Single corridor scenario** (Figure 23). In this scenario the Cargo-hyperloop Holland corridor is considered as a whole, and the demand projections are developed for the whole corridor. No other parts of the future hyperloop network are considered to impact the demand projections of the corridor. The construction of the corridor is assumed to be realized in three years, between 2026 and 2028, with 2029 being the first operational year.

- **Dutch hyperloop network scenario** (Figure 24). In this scenario the Cargo-hyperloop Holland corridor and its sections are considered as a part of the future Dutch hyperloop network. The demand projections include the network effect resulting from increased number of connections being able to use the Cargo-hyperloop Holland corridor as the Dutch network is expanded and developed. After the construction of the Cargo-hyperloop Holland corridor by 2029, it is assumed that the corridor operations will be evaluated and after a year of successful operations the construction of the next sections of the Dutch network will begin to be gradually finalized by 2040.

- **European hyperloop network scenario** (Figure 25). In this scenario the Cargo-hyperloop Holland corridor is considered as a part of the European hyperloop network. The demand projections include the network effect generated by the European network. The network effect is expected to become noticeable with the completion of the Dutch network (and its international gateways) in 2040, and to gradually increase between 2040 and 2050, when the majority of the European hyperloop network is completed.

6.2. Demand segments

For cargo, hyperloop is a transport and logistics solution addressed primarily towards a range of time-sensitive, demand-sensitive and high-value products, such as fresh food, horticultural products, pharmaceuticals, e-commerce, fashion, electronics, and high technology equipment. For the purpose of the demand assessment, these products are divided into three categories reflecting how closely the cargo hyperloop meets their supply chain requirements:

- **Best-fit products - time sensitive goods** that require urgent transportation or guaranteed delivery times, for which Hyperloop could generate the highest added-value by reducing their lead/transit times. These products

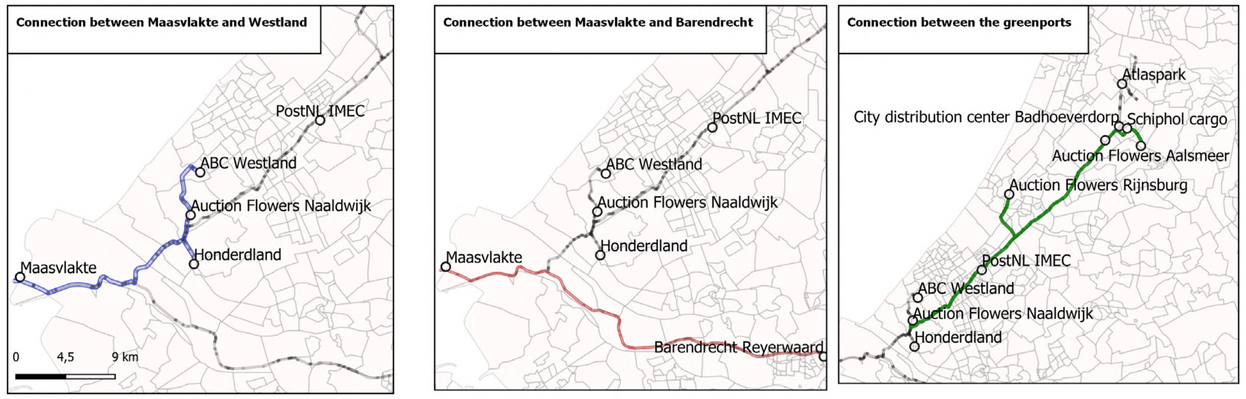


Figure 22: Single section scenario

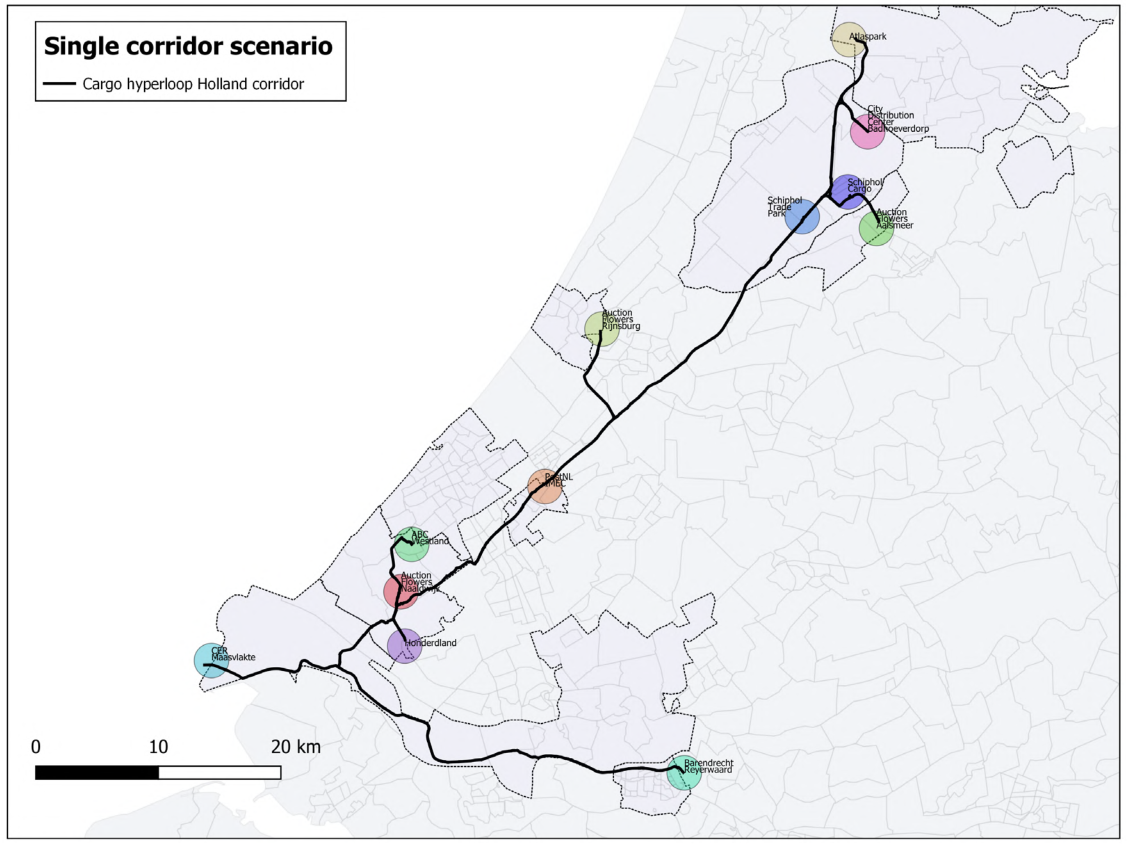


Figure 23: Single corridor scenario

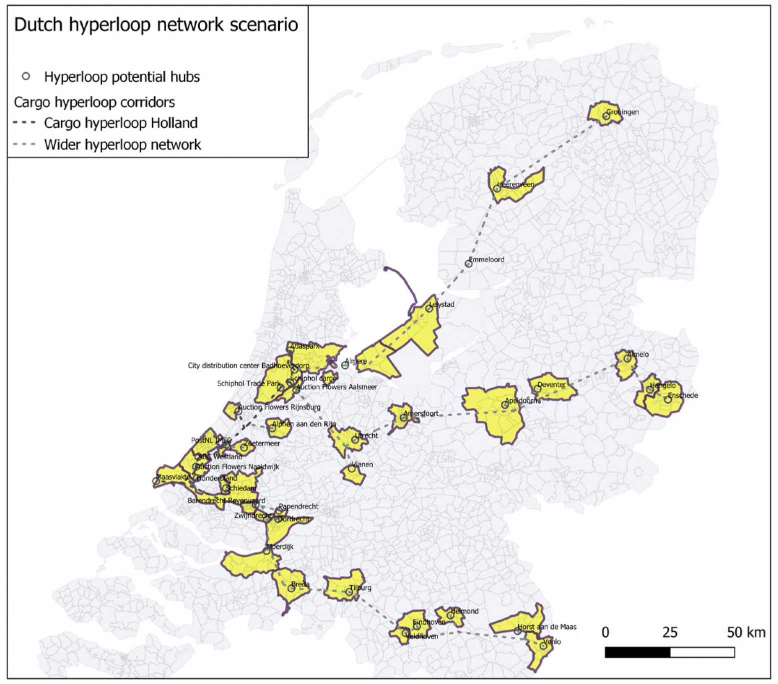


Figure 24: Dutch hyperloop network scenario

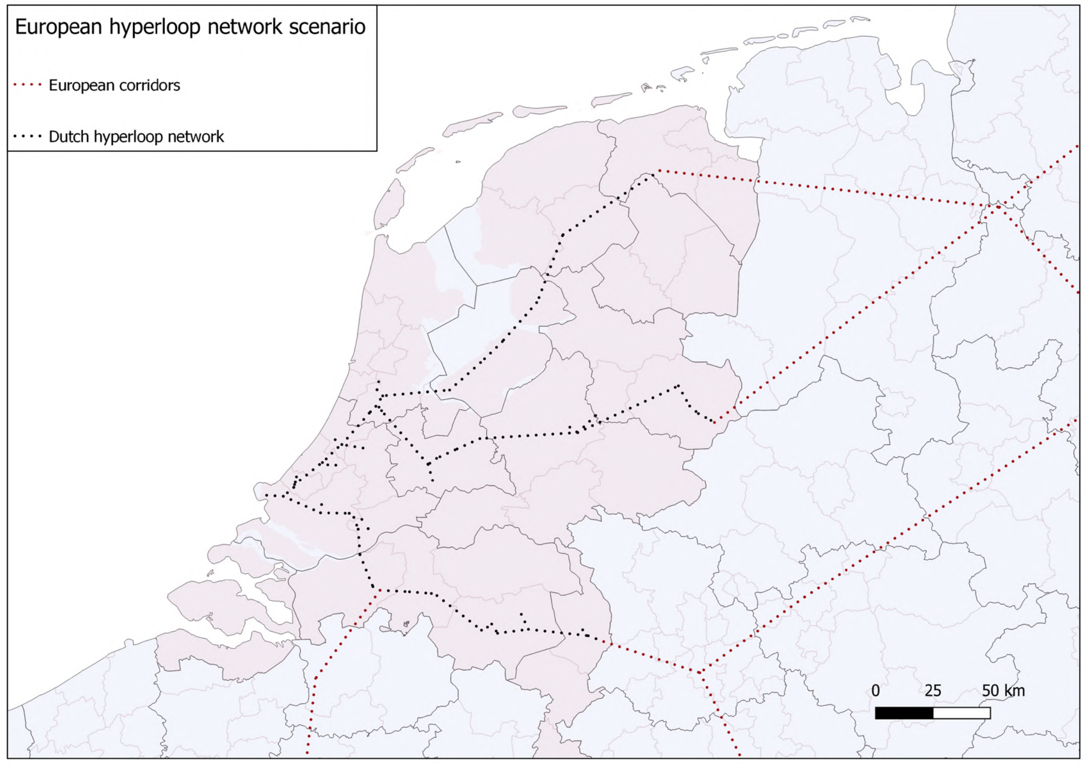


Figure 25: European hyperloop network scenario

include fresh food perishable produce, horticultural products, pharmaceuticals, spare parts for automotive industry, high-tech, space industry, aircraft industry or other machinery industry with a just-in-time production workflow, e-commerce products within the logistics chain of e-commerce providers[29]

- **Good-fit products-high value products** which have higher than average profit margins and could benefit from reduced transit times while being able to absorb some increase in the costs of transportation. The high added value of Hyperloop for these products results primarily from decreasing their market response time[30]. These products include electronics, high technology equipment, high-end clothing, jewelry, footwear and accessories.

- **Other products – products physically suitable for Hyperloop** which could benefit from using Hyperloop provided that the logistics model of Hyperloop brings them either a market advantage or direct financial savings[31].
These products include processed food, bottled beverages, tobacco products, household products (excluding these within the logistics chain of e-commerce providers), chemicals (e.g. cosmetics and other consumer products, fine and specialty chemicals – adhesives, sealants, coatings, cleaning chemicals, catalysts)

For each of these categories, the demand volumes of products are assessed separately and different assumptions are made for the modal shift to hyperloop in the future.

6.3. Data sources

The demand assessment for the Cargo-hyperloop Holland corridor used two sources of data about cargo flows:

- CBS data[32] were used for the distribution of the cargo flows in the corridor for all cargo types except for the horticultural products (live plants and flowers). The most recent dataset as of 2018 created by CBS has been used.

- A dedicated dataset has been used[33] for horticultural flows between flower auctions of Royal FloraHolland. The CBS data for live plants and flowers between hubs adjacent to flowers auctions has been replaced with this dataset. The horticultural flows have been rebased from their original year (2009) to 2018 based on the Royal FloraHolland commercial growth indicators[34].

29 Various products transported between fulfilment and distribution centers of e-commerce providers.
30 Time between a change in consumer demand and delivery of the new/adjusted product to the market.
31 Recipients of products in this category focus more on on-time delivery than on short transit time. This category also includes backhauling products which fit well on the route and are only introduced to optimise costs of operations.

32 Cargo demand in tonnes per year between origin destination pairs (municipality level) in the Netherlands
33 Coordination and optimization of the inter-auction transport of floricultural products at FloraHolland, J.D.G. Dat (Diederik), 2010
34 Annual reports of Royal Flora Holland, https://www.royalfloraholland.com/en/about-us/facts-and-figures/annual-reports

6.4. Current cargo flows

6.4.1. Methodology

The current cargo flow volumes and patterns were analyzed from three different perspectives:

- **The origin-destination analysis**. The origin-destination cargo flows along the Cargo-hyperloop Holland corridor were determined to inform the assessment of section and corridor-based scenarios. This analysis was conducted for all cargo segments: best-fit, good-fit and supplementary products.
- **The area-based analysis**. The areas adjacent to the Cargo-hyperloop Holland corridor representing the highest attraction, generation and distribution flows of cargo[35] were identified. The flows between these locations, and to/from the rest of Netherlands and Europe, were analyzed to determine the potential of the demand for the Cargo-hyperloop Holland corridor and inform the assessment of network-based scenarios.
- **The modal analysis**. The cargo flows volumes on the road network along the Cargo-hyperloop Holland corridor were identified to inform the conversion of the results into truck-units.

6.4.2. Cargo flows along the Cargo-hyperloop Holland corridor (origin-destination analysis)

The total cargo flows between the locations adjacent to the Cargo-hyperloop Holland corridor across all demand segments amount to 6.5 million tonnes per annum. Decomposition of the cargo flows according to cargo segments shows that best and good-fit products represent more than 55% of total cargo flows (3.6 million tonnes), and the remaining 45% represents other products (2.9 million tonnes). Further decomposition has been conducted for the best-fit and supplementary products to identify the products which are most important for the Cargo-hyperloop Holland corridor and its sections.

- Within the best and good-fit products category, the top products are live plants and flowers with 33% of total flow in this category (2.2 million tonnes) and fresh fruits and vegetables with15.4% share (1.0 million tonnes).
- Within the other products, the top products are beverages, food products and tobacco products, representing together about 11% of the cargo flows (0.7 million tonnes).

The origin-destination patterns have been determined for these top products and their respective categories to identify major transport connections and inform the quantitative assessment of the demand for Cargo-hyperloop Holland corridor and its sections.

- In the best-fit category, the major flows recorded along the Cargo-hyperloop Holland corridor are found between Amsterdam, Westland, Aalsmeer, Katwijk, Rotterdam and Barendrecht (Figure 26). For live plants and flowers, top connections are between the flower auction locations in Westland, Katwijk and Aalsmeer. For fruits and vegetables, the major flows are recorded between Rotterdam and Westland, Barendrecht. Machines, machine tools and parts are transported mostly between Haarlemmermeer, Amsterdam, Rotterdam.
- In the good-fit category, the major flows are recorded between Haarlemmermeer - Amsterdam, Haarlemmermeer-Rotterdam and Amsterdam – 's-Gravenhage (Figure 27). For brown goods the main flow is found between Haarlemmermeer and Amsterdam. Thick flows of electronic machinery and apparatus are located between Rotterdam - Amsterdam and Amsterdam - 's-Gravenhage. Regarding medical, precision and optical instruments, watches and clocks, most cargo is transported between Haarlemmermeer - Amsterdam and Haarlemmermeer - Rotterdam.
- In the other products category, the main routes are more dispersed along the Cargo-hyperloop corridor (Figure 28). For beverages, the main connections are: Rot-

35 Production flow: aggregated cargo movements departing from a specific location; attraction flow: aggregated cargo movements arriving at a specific location; distribution flow: cargo movements within the same municipality (same origin and destination); demand potential: the amount of cargo that travels from and to a specific location.

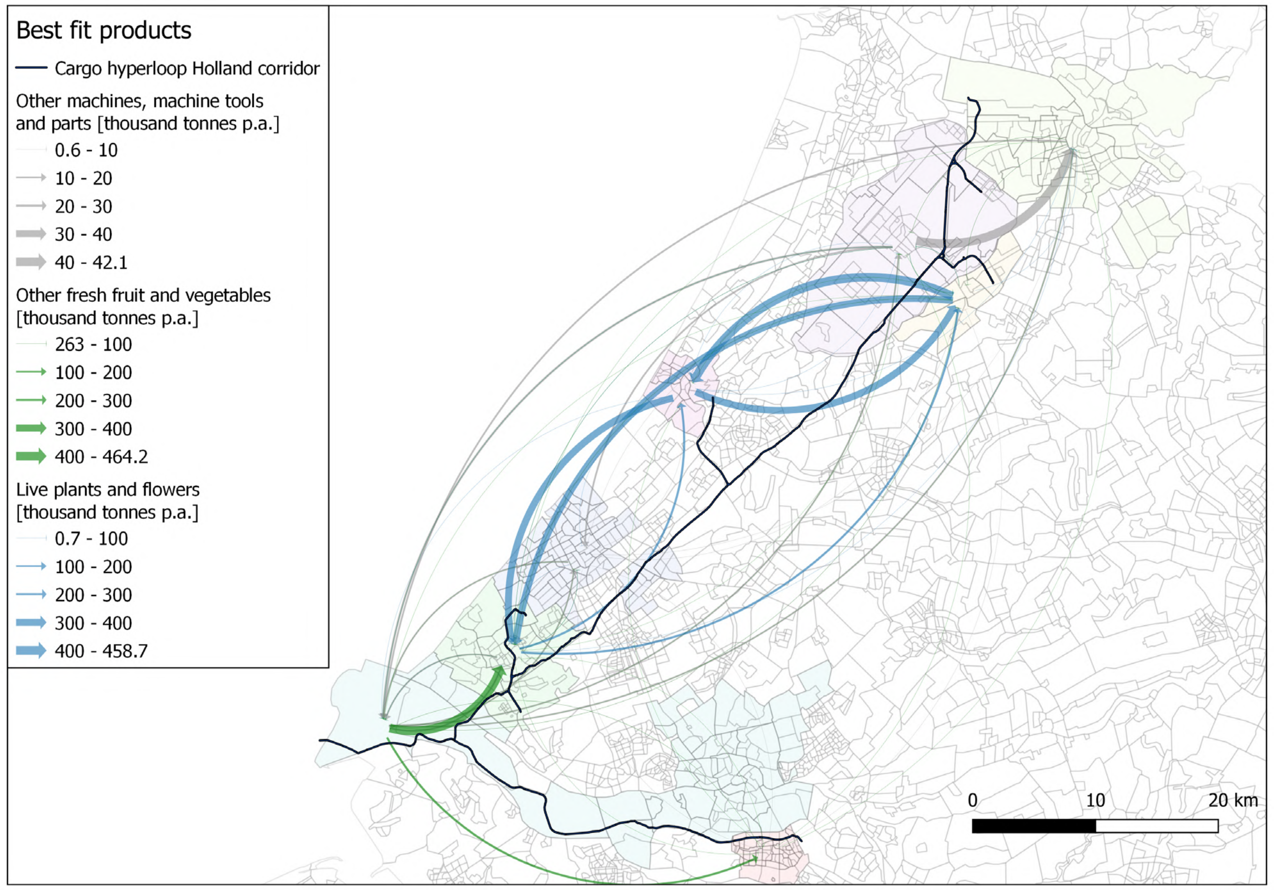


Figure 26: Origin-destination patterns for the best-fit products

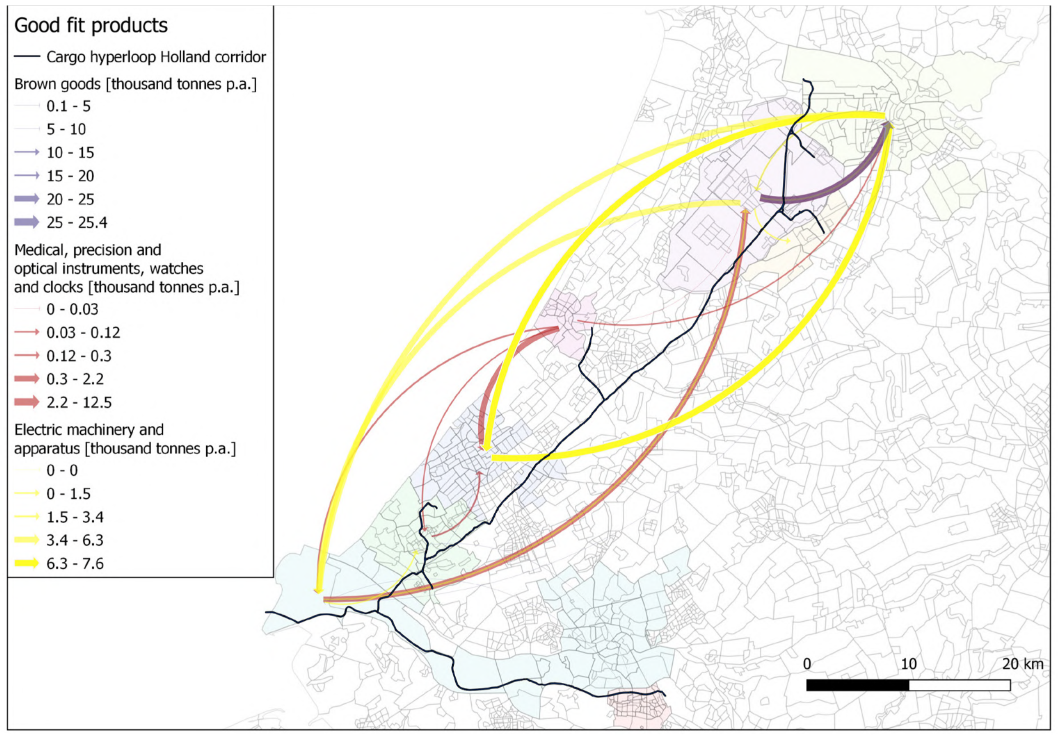


Figure 27: Origin-destination patterns for the good-fit products

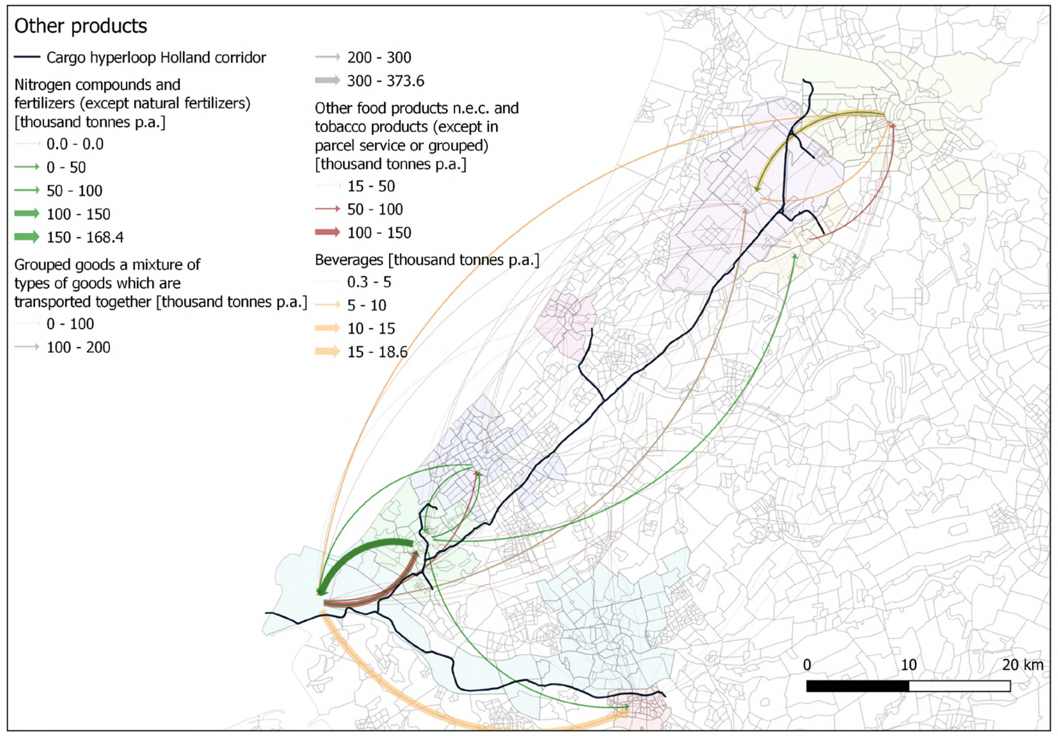


Figure 28: Origin-destination patterns for the other products

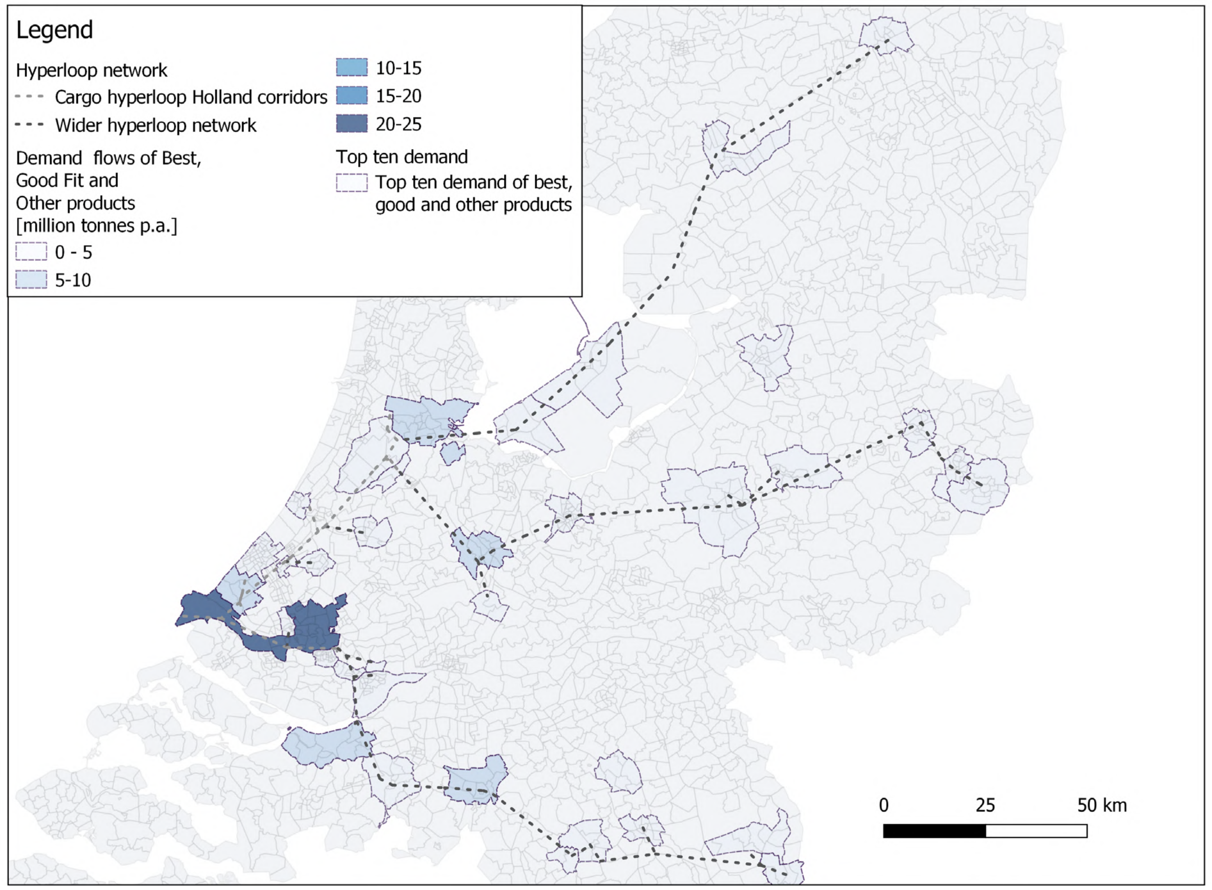


Figure 29 Dutch hyperloop network and the top ten cargo flow centers in the Netherlands

terdam-Barendrecht, Rotterdam-Haarlemmermeer, Amsterdam-Haarlemmermeer. For food products and tobacco, the top routes are 's-Gravenhage-Rotterdam, Westland-Rotterdam, Aalsmeer-Amsterdam.

6.4.3. Cargo flows to/from the rest of Netherlands and Europe (area based analysis)

The analysis of current cargo flows between the locations adjacent to the future Cargo-hyperloop Holland hubs and the rest of Netherlands and Europe has been conducted to estimate the network effect to be expected when the corridor is implemented and becomes a part of the wider Dutch and European hyperloop network. The total cargo flows of all products suitable for transporting using the hyperloop system (best-fit, good-fit and other products as defined in chapter 6.2) were considered in this assessment to represent the potential demand for hyperloop.

In 2018, the total cargo flows between future Cargo-hyperloop Holland hub locations and the rest of Netherlands amounted to 25.4 million tonnes. These flows can only be accommodated by the Cargo-hyperloop Holland corridor in conjunction with introducing the wider Dutch hyperloop network. Implementation of this network will allow the Cargo-hyperloop Holland corridor to become a major link connecting eight of the top ten areas with the highest cargo flows in the Netherlands (Figure 29).

Considering only the areas to be connected by the future Dutch hyperloop network, the cargo flows between them and the Cargo-hyperloop Holland hubs account for 11.6 million tonnes as of 2018. This gives the future Dutch hyperloop network coverage ratio[36] of 45.7%, and adds 5.1 million tonnes to the 6.5 million tonnes of potential demand for the Cargo-hyperloop Holland corridor (79% more cargo flows comparing to the volumes recorded between the locations along the Cargo-hyperloop Holland corridor).

As the hyperloop network extends beyond Netherlands and connects the Cargo-hyperloop Holland corridor with the rest of Europe (Figure 30), the potential demand for the corridor will increase even more. The cargo flows between the locations along the Cargo-hyperloop Holland corridor and other European countries account for 4.7 million tonnes. Assuming the same hyperloop network coverage ratio as in Netherlands (45.7%), this translates into additional 2.1 millions of tonnes of additional cargo flows as of 2018.

In total, implementing the wider Dutch and European hyperloop networks will produce a significant network effect for the Cargo-hyperloop Holland corridor and, as of 2018, generate additional 7.2 million tonnes of cargo flows on top of 6.5 million generated solely by the corridor. This confirms that the assessment of the network-based scenarios and considering the network effect are essential to realistically predict the utilization of the Cargo-hyperloop Holland corridor. The impact of the future generic growth of cargo flows will be discussed in the next chapters of the report.

6.4.4. Conversion to truck-units (the modal analysis)

The cargo flow analysis for the Cargo-hyperloop Holland corridor is based solely on road traffic, and the data used for creation of origin-destination matrices for the corridor include only road transport of products. Therefore, the results of the analysis can be expressed in the number of trucks per day[37] as well as in tonnage.

The cargo transported in Netherlands is moved by light and heavy duty freight vehicles (LGVs and HGVs respectively). The effective capacity of an average LGV is assumed at 13 tonnes[38], and the capacity of average HGV is assumed at 30 tonnes[39]. Corrected by the Netherlands load factor of 40%[40], the average payload of an LGV is 5.2 tonnes and of an HGV is 12 tonnes. This is in line with the Eurostat data showing average road freight vehicle load for Netherlands of 12.5 tonnes[41]. Therefore, for the purpose of this assessment, average truck unit load of 12 tonnes has been assumed.

36 Hyperloop network coverage ratio in a selected area represents the proportion of flows between the locations connected with the hyperloop network in total origin-destination cargo flows within the area.

37 260 working days withiin a year were taken into consideration

38 Cost Figures for Freight Transport, Panteia, 2020

39 Cost Figures for Freight Transport, Panteia, 2020

40 https://www.eea.europa.eu/data-and-maps/indicators/load-factors-for-freight-transport/load-factors-for-freight-transport-1

41 Road freight transport by journey characteristics 2018, Eurostat

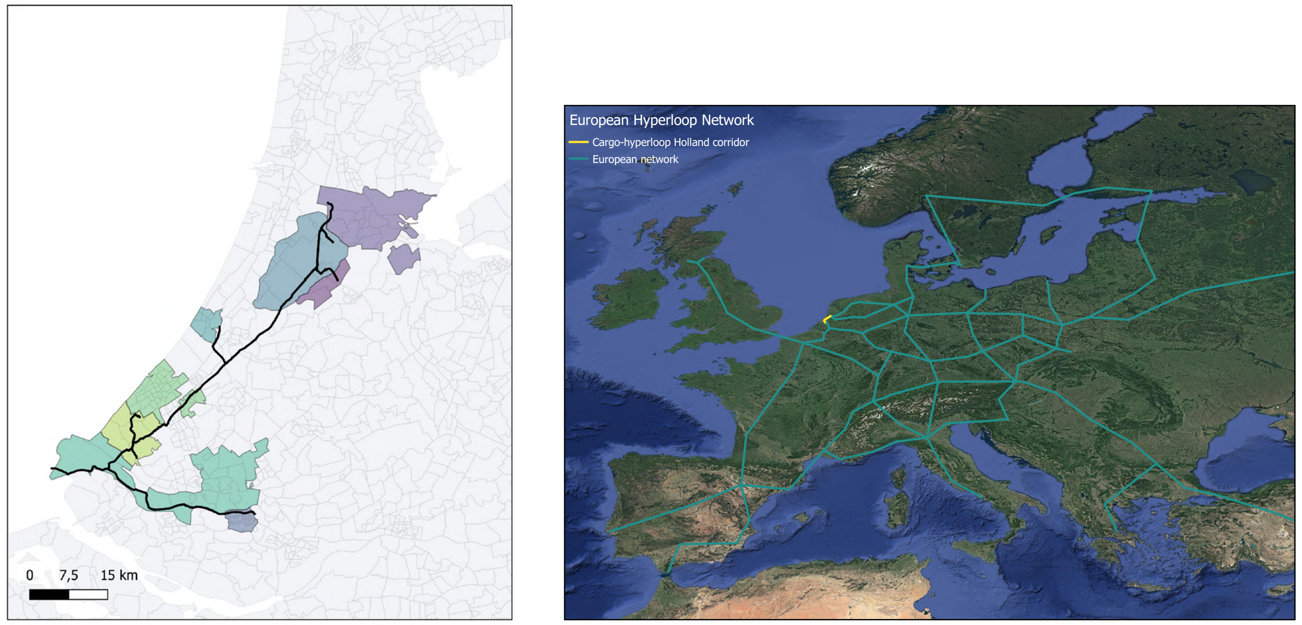


Figure 30 Cargo-hyperloop Holland corridor as a part of the European hyperloop network

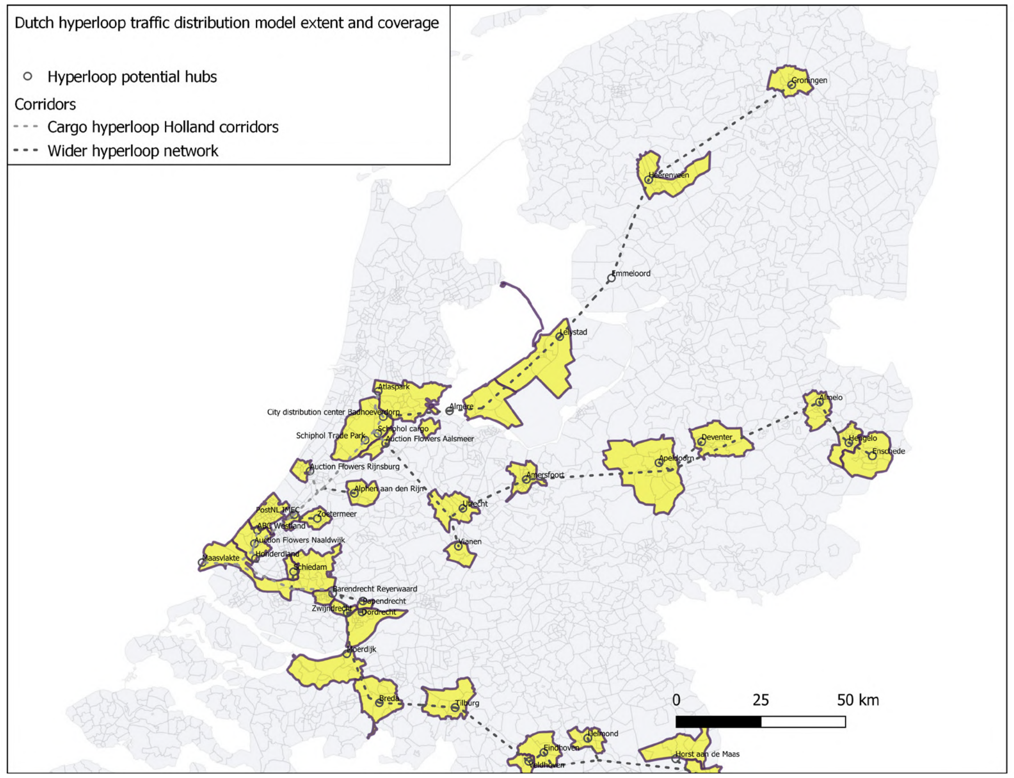


Figure 31: Dutch hyperloop traffic distribution model extent and coverage

6.5 Demand projections and distribution

6.5.1 Methodology

Demand projections for the Cargo-hyperloop Holland corridor were prepared for the period of 2029 – 2058, covering 30 years since the first operational year of Cargo-hyperloop Holland corridor. The demand projections for the corridor were prepared for 2030, 2040 and 2050, considering 2029 as a ramp-up period when the market adjusts to hyperloop as the new modality and its services. The growth rates used to project the current volumes (as of 2018) to the 2030, 2040 and 2050 volumes were sourced from the WLO scenarios for freight transport via road produced by the Dutch Central Planning Office[42], as the most reflective of the circumstances of the project. Due to the lack of available data to use for the periods after 2050, the same annual growth as for the period from 2030 to 2050 has been used.

WLO proposes two scenarios, high and low, with the high scenario showing annual growth rates of 1.1% - 1.3% and low scenario assuming growth rates between 0.2% and 0.4%. At the same time, the province of Zuid-Holland reports that truck transport in the region is growing with a CAGR of 5%[43]. Therefore, the high WLO scenario has been selected as reference values for demand projections (Table 9).

Table 9 Growth rates 2018 – 2060 of cargo volumes

	Annual growth '18-'30	**Annual growth '30-'60**
Growth rates for cargo volumes	1.1%	1.3%

Source: WLO Mobiliteit goederenvervoer en zeehavens referentiescenarios en aanvullende onzekerheidsverkenningen 2010-2030-2050 PBL/CPB

42 WLO Mobiliteit goederenvervoer en zeehavens referentiescenarios en aanvullende onzekerheidsverkenningen 2010-2030-2050 PBL/CPB

43 https://www.zuid-holland.nl/onderwerpen/ruimte/visie-ruimte/greenport-west/@17946/pitch-corridor-a4/

Table 10: Modal shift ratios for hyperloop product segments

Product Group	**Modal Shift**
Horticultural and other Best-Fit Products	80%
Good-Fit Products	30%
Other Products	5%

Source: Hyperloop for cargo, time and reliability elasticities, Hyperloop Development Program, 2021

The implementation of the Cargo-hyperloop Holland corridor is expected to unlock huge opportunities for its users to reduce transit time and improve reliability, and result in shifting a portion of the cargo traffic from other transport modes (mainly roads) to hyperloop, but to fully utilize this potential, future user will need to revise some of their logistics processes (see chapter 4.6). It is expected that not all potential users of the hyperloop system will adopt these changes. As hyperloop has not been introduced into the market, there are no reference values for modal shift from other modalities to hyperloop, Therefore, for the purpose of this study, the assumptions have been made based on the results of the research on time and reliability elasticity for hyperloop product segments conducted within the Hyperloop Development Program.
The demand distribution analysis was conducted for four assessment scenarios described in chapter 6.1.:

1. Single section scenario
2. Single corridor scenario
3. Dutch hyperloop network scenario
4. European hyperloop network scenario

For the first three scenarios, a traffic distribution model has been developed to facilitate allocation of the origin-destination flows to specific sections of the corridor. The extent of the model included the Cargo-hyperloop Holland corridor alignment and the envisaged outline of the Dutch hyperloop network (Figure 31). The model allocated cargo flows to the hyperloop links based on the location of hyperloop hubs, the origin-destination matrices of cargo flows between hub catchment areas for 2030, 2040 and 2050, and hyperloop network infrastructure parameters (length of the network sections and their speed profiles).

For the European hyperloop network scenario, the traffic distribution analysis has been conducted based on the Dutch hyperloop network model. The European flows from/ to the Cargo-hyperloop Holland hubs have been added to the traffic distribution model using even distribution across the international gateway points of the Dutch hyperloop network.

6.5.2. Single section scenario

In this scenario all three sections of the Cargo-hyperloop corridor were considered separately as single pilot sections. The demand projections were prepared for each of the sections separately as if they were the only sections to be implemented, without any other parts of the hyperloop network to follow.

Section 1: Maasvlakte - Barendrecht
In 2030, the total flow of goods between Maasvlakte and Barendrecht, across all product categories, will amount to 0.53 million tonnes. Out of this flow, the hyperloop is expected to capture 48% of cargo, equivalent to 0.3 million tonnes or 80 trucks per day removed from the road network. By 2050, the volume transported by the hyperloop is estimated to increase to 0.33 million tonnes annually (equivalent to 104 trucks per day).

Section 2: Maasvlakte - Westland
In 2030, the total flow of goods between Maasvlakte and Westland, across all product categories, will amount to 2.0 million tonnes. Out of this flow, the hyperloop is expected to capture 35% of cargo, equivalent to 0.7 million tonnes or 221 trucks per day removed from the road network. By 2050, the volume transported by the hyperloop is estimated to increase to 0.9 million tonnes annually (equivalent to 286 trucks per day).

In 2030, the highest volume of cargo is expected between Maasvlakte' s hub and the hyperloop junction leading to the Westland hubs, with 221 trucks removed daily from this busy stretch of A15 motorway.

Section 3: Naaldwijk - Rijnsburg - Aalsmeer - Amsterdam Schiphol Airport
In 2030, the total flow of goods between the greenports in Naaldwijk, Rijnsburg and Aalsmeer and Amsterdam Schiphol Airport, across all product categories, will amount to 2.0 million tonnes. Out of this flow, the hyperloop is expected to capture 77% of cargo, equivalent to 1.59 million tonnes or 510 trucks per day removed from the road network. By 2050, the volume transported by the hyperloop is estimated to increase to 2.0 million tonnes annually (equivalent to 660 trucks per day).

The highest volumes of cargo in 2030 are expected between Rijnsburg, Schiphol Airport and Aalsmeer hubs, with 340-383 trucks removed daily from this busy stretch of A4 motorway.

6.5.3. Single corridor scenario

In this scenario the Cargo-hyperloop Holland corridor is considered as a whole, and the demand projections are developed for the whole corridor. No other parts of the future hyperloop network are considered to impact the demand projections of the corridor.

The demand captured by the Cargo-hyperloop Holland corridor in this scenario is estimated at 3.4 million tonnes of cargo in 2030, and 4.4 million tonnes in 2050. This amounts to reduction of road traffic by 1,091 trucks per day in 2030 and 1,412 trucks per day in 2050.

6.5.4. Dutch hyperloop network scenario

In this scenario the Cargo-hyperloop Holland corridor is considered as a part of the future Dutch hyperloop network. The demand projections include the network effect resulting from increased number of connections being able to use the Cargo-hyperloop Holland corridor as the Dutch network is expanded and developed.

The demand captured by the Cargo-hyperloop Holland corridor in this scenario is estimated initially at 3.4 million tonnes of cargo in 2030, and gradually growing up 5,6 million tonnes in 2040 when the Dutch hyperloop network is completed and 6.3 million tonnes in 2050.

Under the consideration that the first additional links become operational in 2033 and the Dutch network is expected to be realized by 2040, the combined effect of growth and network effect corresponds to a CAGR of 5,93% for that period.

In this scenario the number of trucks removed daily from the Dutch roads will increase from 2,726 trucks per day in 2030 to 4,460 trucks in 2040, and 5,075 trucks in 2050.

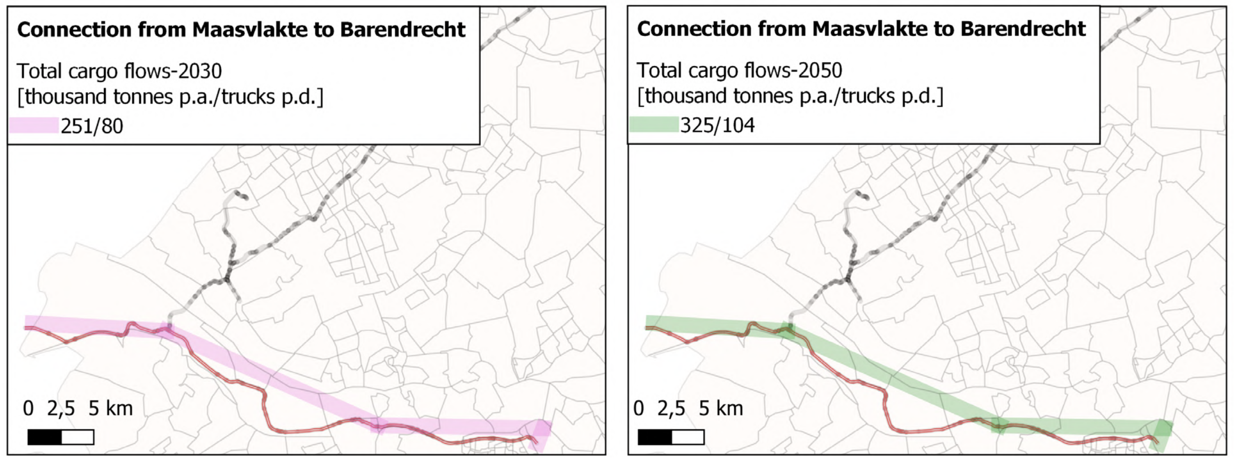


Figure 32: Single section scenario - cargo volumes for Maasvlakte – Barendrecht section

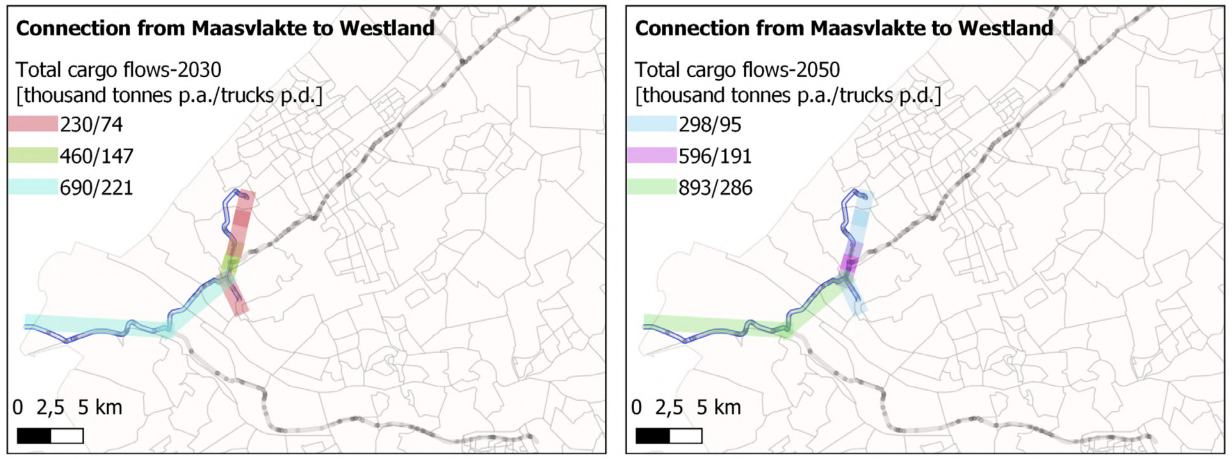


Figure 33: Single section scenario - cargo volumes for Maasvlakte – Westland section

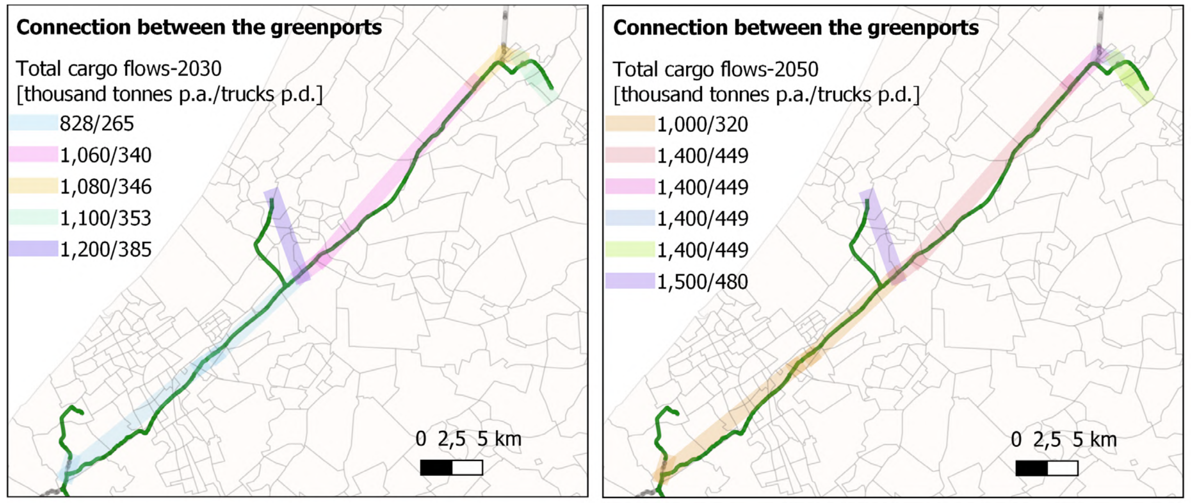


Figure 34: Single section scenario - cargo volumes for Naaldwijk - Rijnsburg - Aalsmeer - Amsterdam Schiphol Airport section

6.5.5. European hyperloop network scenario

In this scenario the Cargo-hyperloop Holland corridor is considered as a part of European network for passengers and cargo. The demand projections include the network effect generated by the European hyperloop network cargo and passenger flows generated for the corridor.

The cargo demand captured by the Cargo-hyperloop Holland corridor in this scenario is estimated initially at 3.4 million tonnes of cargo in 2030, and gradually growing up to 5.6 million tonnes in 2040 when the Dutch hyperloop network is completed and 7.9 million tonnes in 2050 when the European network becomes fully operational.

Considering that the international links related to the 2.3 million tonnes additional cargo flows for Cargo-hyperloop Holland will become operational between 2040 and 2050, the combined effect of growth and network effect corresponds to a CAGR of 3.50% for that period.

In this scenario the number of trucks removed daily from the Dutch roads will increase from 1,091 trucks per day in 2030 to 1,784 trucks in 2040, and 2,517 trucks in 2050.

6.5.6. Summary and conclusions

The development of the Cargo-hyperloop Holland corridor will provide a new opportunity for the logistics sector to use a sustainable and fast mode of transportation. However, the demand attracted by the corridor is heavily dependent on availability of the network connecting logistics centers in Netherlands and Europe, and will grow with the hyperloop network expansion.

In 2030, when the Cargo-hyperloop Holland corridor is completed as the first hyperloop corridor in Europe, it is expected to attract 3.4 million tonnes of cargo. In 2040, with the completion of the Dutch hyperloop network, the volume transported along the corridor will rise to 5.6 million tonnes. The demand will continue to grow as the European networks is expanded, to reach 7.9 million tonnes in 2050.

The Cargo-hyperloop Holland corridor will also play an important role in relieving congestion on the Dutch road network. In the first fully operational year[44], in 2030, the corridor will allow to remove 1,091 trucks daily from the A4 motorway between Rotterdam and Amsterdam and adjacent roads. With the network expansion, the importance of the corridor as an alternative to road transport will grow even more, and by 2050, the corridor is expected to capture an equivalent of 2,517 trucks per day.

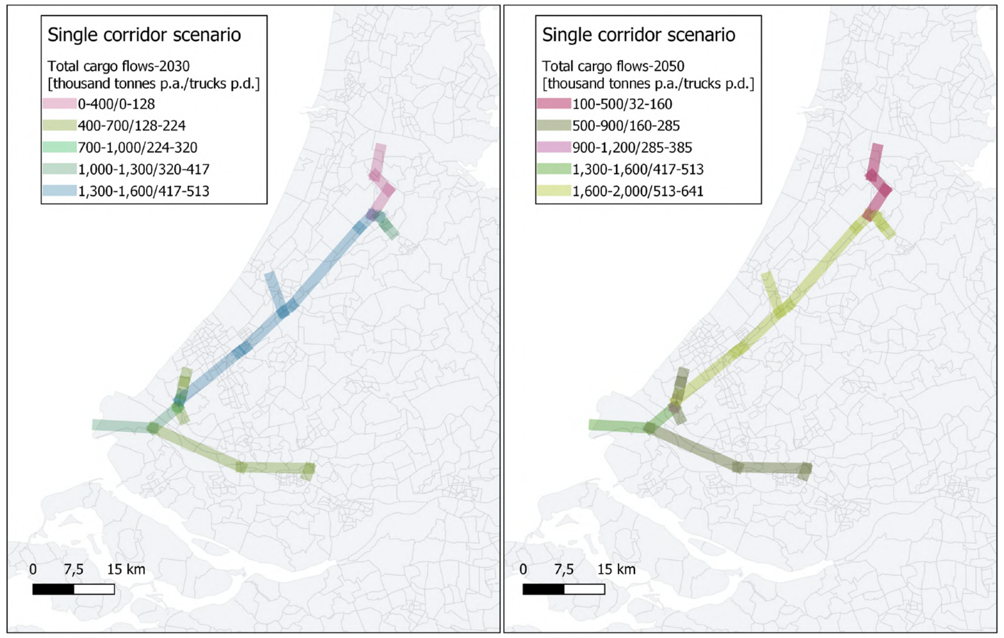


Figure 35: Single corridor scenario - cargo volumes for Cargo-hyperloop Holland corridor in 2030 and 2050

44 After one-year ramp-up period

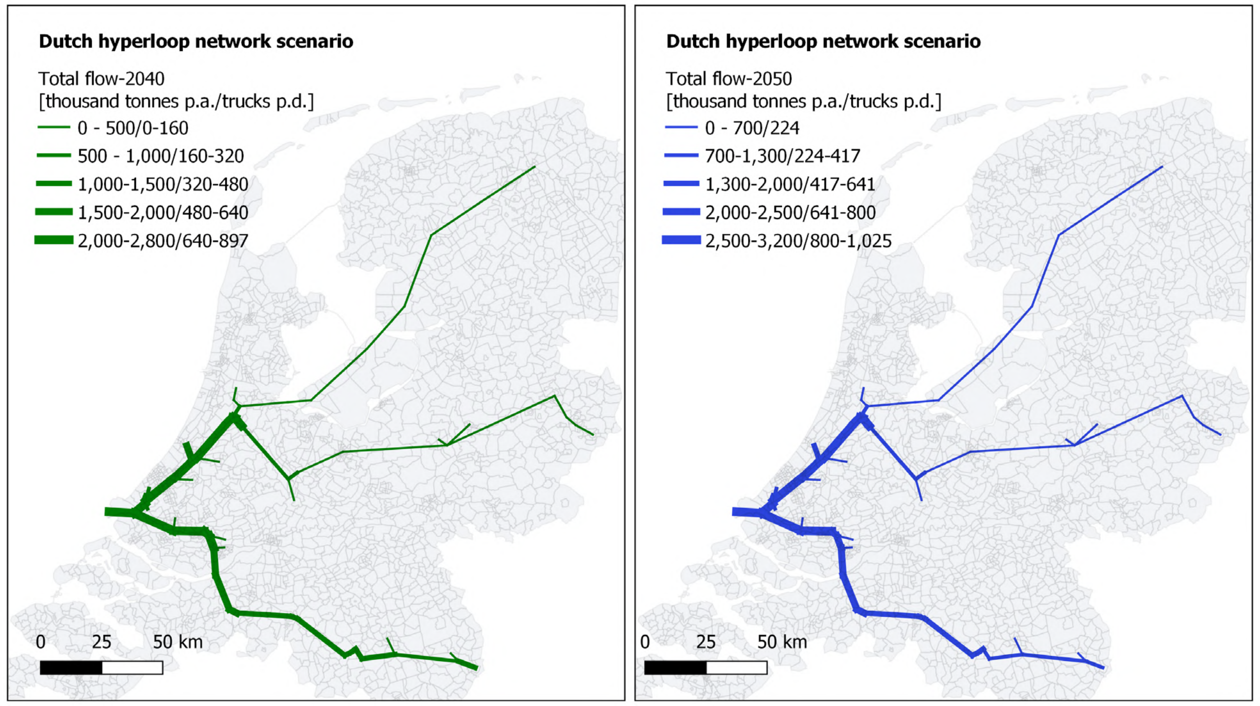


Figure 36: Dutch hyperloop network scenario – cargo volumes for Cargo-hyperloop Holland corridor in 2040 and 2050

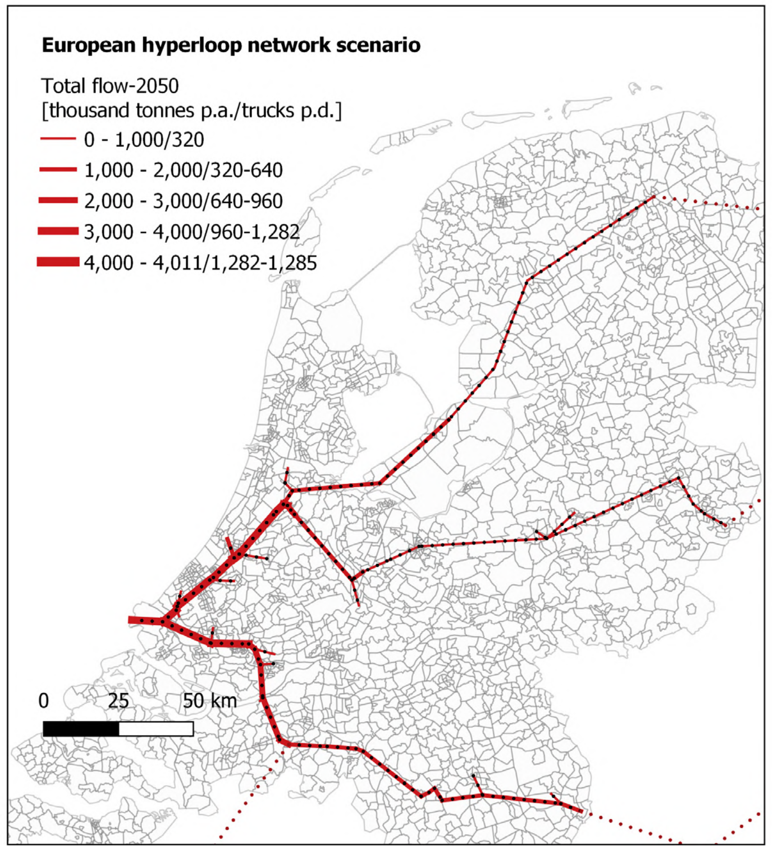


Figure 37: European hyperloop network scenario – cargo volumes for Cargo-hyperloop Holland corridor in 2050

7. Economic Assessment

7.1. Methodology

Implementation of the Cargo-hyperloop Holland corridor will generate a range of economic impacts, from purely financial impacts (costs and revenues) to impacts on users, environment and wider economy. As the project is likely to have large public sector involvement, a social cost benefit analysis has been performed to assess these impacts[45]. In the context of CBA, constant prices at 2021 price level have been used. While Dutch CBA guidelines recommend an assessment horizon of 100 years for transport projects, an assessment horizon in line with EU practice of 30 years has been selected, to ensure comparability with other publicly funded transport infrastructure projects (rail and road projects[46]). Going beyond 30 years would lead to even greater uncertainty with regard to factors such as growth and economic development.

The economic impacts generated by the corridor will differ depending on the corridor utilization level and demand attracted to the corridor, so economic assessment follows the scenario approach defined for demand assessment (chapter 6.1.) and the same scenarios are considered and compared:

1. Single section scenario, three different sections
2. Single corridor scenario
3. Dutch hyperloop network scenario
4. European hyperloop network scenario

In the social cost benefit analysis, the positive as well as negative impacts of the project are assessed and economic values are derived in order to weigh the cost and benefits against each other. Wherever possible, publicly acknowledged values have been used or estimations have been made. The following impacts have been considered:

- **Financial impacts**, including capital expenditure, operational and maintenance costs and operational revenues generated from the project.
- **Impact on users**, including time and reliability gains experienced by users who switch from road transport to hyperloop.
- **Impact on carbon emissions**, including emissions from construction and operations of the project as well as emissions avoided by shifting cargo from road transportation to hyperloop.
- **Other external impacts**, such as reduction in noise, air pollution, accidents, etc, generated by shifting cargo traffic from road transport to hyperloop.
- **Impacts on employment**, including direct, indirect and induced jobs created by the investment in the Cargo-hyperloop corridor. Those impacts will not be included in the main evaluation as it is typically excluded in Dutch CBAs. However, results including the impact on employment will be reported separately.

Wider economic impacts other than indirect and induced employment, have not been considered in the cost benefit assessment. However, it should be expected that the implementation of the project will result in the following economic effects:

- Property value increase that can typically be seen when transportation infrastructure is being built, as improved connectivity corresponds to a higher attractiveness of properties, e.g. logistics facilities close to or directly connected to hyperloop hubs.
- The impact on Dutch respectively European GDP due to the realization of this project, which is expected to be positive due to a diverse engagement of smaller and larger sized companies from different sectors in the realization of the project as well as the benefits related to the existence of the system as an additional transport option.

45 A dedicated financial and socioeconomic model has been developed by Hardt and verified by independent experts (Royal HaskoningDHV)

46 https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

7.2. Impact Assessment

7.2.1. Financial impacts

For the assessment of the financial impact it is important to note that inflation has not been considered and constant prices at 2021 price level (if available) have been used in line with standards in social cost-benefit analysis. Furthermore, taxes on generating profits of the project have not been included in the analysis. In addition, financing costs such as interest payments on debt have not been considered in this analysis either as the financial scheme has not been determined yet and can otherwise only be speculative.

Development and capital expenditures have been estimated using values as well as cost percentages from chapter 4.7.1 in combination with the route specifications as given in chapter 5. Costs for land acquisition as well as for visual pollution of the environment have not been accounted for. The corresponding result can be found in Table 11.

Cost Items (in million €)[47]	Maasvlakte – Westland Connection	Maasvlakte – Barendrecht Connection	Greenports Connection	Corridor (NL (and EU) network context)
Linear infrastructure	335	223	743	1390
Hub	27	12	30	47
Other costs	20	13	44	80
Grand Total	**382**	**235**	**817**	**1473**
Costs per km	13.2	5.2	13.9	9.8

Table 11 Overview of costs for the different scenarios

47 Total values might deviate due to rounding

In addition to the linear infrastructure and the hubs, the number of vehicles needed to fulfill demand during peak hours needs to be derived. Thus, the following values have been used as further detailed in chapter 4.6.

The following number of vehicles and that would be needed over the project lifetime to cope with the demand during peak hours on peak days and the associated costs for a given scenario can be found in Table 13 below. In the long-term the project would require more than 600 vehicles.

Operational expenditures have been estimated using the parameters as described in chapter 4.7.2. The corresponding results for the different scenarios over the project lifetime can be found in Table 14 below. It shows that hyperloop can be operated very cost effectively.

Revenues have been estimated using demand numbers from chapter 6.4, growth numbers from chapter 6.5.1 and applying the network effect as described in chapter 6.5.4 and 6.5.5. In order to derive the revenues, a price level for the transported volumes is assumed. In Europe, shippers paid an average rate of €1.58/km for road freight services in Q2 of 2020[48], which corresponds to an average price of €0.13/t/km at an average truck unit load of 12 tonnes as described in chapter 6.4.4. However, market research performed within this study indicates that higher prices can be charged for transport services of for certain product types targeted within this study on these shorter distances. For example, in the context of the Greenports connection for the transport of a flower trolley between the auctions, an average price of €8.51 is being charged. At an average distance of 43km and an average weight of 0.3 tonnes per trolley this translates to a price of €0.66/t/km, which is 5 times the average rate seen in Europe. Panteia[49] estimated between €0.14/t/km and €0.35/t/km, depending on the truck used, for transport in the Netherlands. The difference in costs is likely due to the difference in distance travelled within the Netherlands respectively across Europe.
Nevertheless, for this study the average price of €0.25/t/km has been used. This price is excluding additional costs for first and last mile but it does include handling at the hyperloop hubs as this is part of the service offering.

48 https://www.upply.com/hubfs/TI%20Webinar/Ti-Upply_The-European-Road-Freight-Rate-Benchmark_Q2-2020.pdf

49 https://www.kimnet.nl/publicaties/formulier-en/2020/05/26/notitie-kostenkengetal-len-voor-het-goederenvervoer---wegvervoer-verschi-jningsvorm

Input	Value	Unit
Operating time per day	22	h
Peak hours per day	8	h
Peak days per year	240	days
Amount of daily demand during peak hours	80%	%
Amount of yearly demand during peak days	95%	%
Loading Time	0.03	h
Unloading Time	0.03	h
Waiting Time	0.10	h
Factor empty trips	10%	%
Average speed	180	km/h
Vehicle costs	188	€ 000s
Capacity per vehicle	2.5	t
Vehicle useful life	30	Years
Vehicle buffer as percentage of total vehicles	5%	%

Table 12 Input parameters for determining amount of vehicles needed

	Maasvlakte – Westland	Maasvlakte – Barendrecht	Greenports	Corridor only	Corridor with NL network	Corridor with NL and EU network
Amount of vehicles	61	25	156	364	521	646
Costs of vehicles (real alues, in million €)	11.5	4.7	29.3	68.4	97.9	121.4

Table 13 Amount of vehicles needed over project life and associated costs for different scenarios

(real values, in million €)	Maasvlakte – Westland	Maasvlakte – Barendrecht	Greenports	Corridor only	Corridor with NL network	Corridor with NL and EU network
SG&A variable cost	6.9	3.8	24.1	58.8	79.2	89.7
Energy variable cost	1.2	0.7	4.1	10.0	13.5	15.3
Maintenance vehicles variable cost	2.9	1.2	7.3	16.8	22.6	25.6
Insurance of assets variable cost	47.9	27.6	103.4	194.6	197.0	198.2
Infrastructure maintenance fixed cost	16.3	9.5	34.8	64.7	64.7	64.7
Total opex	**75.1**	**42.7**	**173.6**	**345.0**	**377.0**	**393.5**
Average annual opex	2.5	1.4	5.8	11.5	12.6	13.1

Table 14 Overview of operational expenditures over the project lifetime for the different scenarios

(real values, in million €)	Maasvlakte – Westland	Maasvlakte – Barendrecht	Greenports	Corridor only	Corridor with NL network	Corridor with NL and EU network
Revenue – Best-fit products	158.9	90.9	600.2	1,381.8	1,794.0	2,039.0
Revenue – Good-fit products	0.3	0.5	0.8	17.3	47.3	54.2
Revenue – Other products	12.3	4.1	1.2	72.0	138.1	148.8
Total revenue	**171.5**	**95.4**	**602.2**	**1,471.1**	**1,979.4**	**2,242.0**
Average annual revenue	5.7	3.2	20.1	49.0	66.0	74.7

Table 15 Overview of revenue streams over project lifetime for the different scenarios

7.2.2. Impact of CO_2 Emissions

For the calculation of CO_2 emissions and the related economic impact, the following approach has been followed. An estimation for the CO_2 emissions related to the production and construction of the hyperloop infrastructure and its operations has been made to account for the environmental impact of the project implementation.

Based on estimations by Hardt, the impact related to the construction of the infrastructure can be accounted for as to be seen in Table 16. It is based on the technological concept that has been used within this study and using current as well as estimated future CO_2 levels for the production of concrete and steel. It has to be noted that the research and development is ongoing, which might lead to different choices for materials being used, thus, impacting the related CO_2 emissions. The baseline scenario will be used in the analysis.

To assess the CO_2 emissions during operations, the energy consumption of the system has been used as the main driver. The energy consumption of the system has been estimated at 15 Wh per tonne-km at the speed level chosen for this study[50]. The emissions have then been derived from the CO_2 emissions related to the production of energy based on the energy mix in The Netherlands. A factor for improvement of the CO_2 emissions related to the energy production has been applied as further described later on.

According to the European Environment Agency, the CO_2 emissions related to electricity production based on the energy mix of The Netherlands account for 390 g CO_2 per kWh as of 2019[51]. In order to account for the expected improvement of energy production, the WLO climate and energy reference scenarios[52] have been used to derive an improvement factor for the energy sector using the values as depicted in Table 17 below. While population and GDP grew during the period from 2008 to 2018, energy demand declined by 5% partially due to a 15% improvement in the energy efficiency of the economy[53]. Nevertheless, The Netherlands is home to a large concentration of energy and emission-intensive industries and remains heavily reliant on fossil fuels. From 2008 to 2018, the share of fossil fuels in total primary energy supply (TPES) declined only slightly, from 92% to 90%. Energy from renewable sources accounted for only 7.4% of total final energy consumption (TFEC) in 2018, the third-lowest share among IEA member countries and well below the IEA median of 12.1%. However, renewable energy deployment is progressing rapidly. The renewable contribution to TFEC increased by 50% between 2008 and 2018. Due to the imperative need for decarbonization of the energy sector as well as availability of technologies and political undertakings on Dutch and EU level, it is likely to assume that the energy production will become more sustainable in the coming decades at a high rate.

Thus, the CAGR can be estimated at -6.88% for the period from 2013 to 2030 and -6.07% for the period from 2030 to 2050 reflective of the high scenario.

The reduction of CO_2 emissions can be derived from the freight transport that is being shifted from trucks to the hyperloop. The European Environment Agency has last reported a value of 139.8g CO_2 per tonne-km for road based transport in 2014[54]. Looking at historic values from 2000 up until 2014, the CO_2 emissions related to trucking have improved with a CAGR of -0.68%. Again using the WLO climate and energy reference scenarios to derive an improvement factor for the sector of land based transport and using the values as depicted in Table 18 below, a CAGR of -0.88% can be estimated for the period from 2013 to 2030 and -1.48% for the period from 2030 to 2050 for the high scenario. Those values have ultimately been used in the model to account for the CO_2 related improvements in the trucking industry. This is reflective of an increase in improvement of the trucking industry compared to historic developments, which is driven by to technological advancements for internal combustion engines as well as electric vehicles. However, a faster rate of improvement is uncertain. The European Commission's strategy for sustainable and smart mobility, unveiled in December 2020, set an objective of having 80,000 zero-emission trucks on the road by 2030. ACEA estimates around 6.2 million medium and heavy commercial vehicles are currently in operation in the EU while only 0.04% of these vehicles are zero emission[55].

The corresponding results can be found in Table 19. It shows that all assessed scenarios, except for the Maasvlakte-Barendrecht connection, will lead to a reduction of CO_2 emissions over the project life. The corridor is expected to reduce more than 500 thousand tonnes of CO_2 in the long-term.

Plotting the Net CO_2 emissions over time as seen in Figure 38, it shows that break even would occur as early as 2041 for the scenarios for the corridor including the network effects for the Dutch network.

In order to assess the economic value related to the negative and positive impact of emission and reduction of CO_2, the latest publicly acknowledged values for CO_2 pricing in the Netherlands as depicted in Table 20 below have been used.

However, the latest official values for CO_2 emissions price does not reflect the latest developments in climate policies. A 1.5-degree

Table 16 Values for CO_2 emissions related to production and construction of single-tube hyperloop infrastructure

('000 ton CO_2 per km of single tube hyperloop infrastructure)	Best Case	Baseline	Worst Case
CO2 emissions	0.4	1.6	2.7

Table 17 Excerpt from dataset WLO Klimaat en Energie referentiescenarios en aanvullende onzekerheidsverkenningen 2013-2030-2050 PBL/CPB

CO_2 emissions per sector (illustrative image)		Low		High		2 degree central		2 degree decentral	
Year	2013	2030	2050	2030	2050	2030	2050	2030	2050
Electricity production	47	23	15	14	4	13	-1	20	-1

Source: WLO Klimaat en Energie referentiescenarios en aanvullende onzekerheidsverkenningen 2013-2030-2050 PBL/CPB

Table 18 Excerpt from dataset WLO Klimaat en Energie referentiescenarios en aanvullende onzekerheidsverkenningen 2013-2030-2050 PBL/CPB

CO_2 emissions per sector (illustrative image)		Low		High		2 degree central		2 degree decentral	
Year	2013	2030	2050	2030	2050	2030	2050	2030	2050
Road transport and other transport	36	29	25	31	23	30	18	26	14

Source: WLO Klimaat en Energie referentiescenarios en aanvullende onzekerheidsverkenningen 2013-2030-2050 PBL/CPB

50 Speed profile of the corridor is provided in chapter 5
51 https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-3/assessment-1
52 https://www.wlo2015.nl/rapporten-wlo/klimaat-en-energie
53 https://www.iea.org/reports/the-netherlands-2020
54 Specific CO_2 emissions per tonne-km and per mode of transport in Europe — European Environment Agency (europa.eu)
55 https://www.euractiv.com/section/transport/news/electric-truck-technology-close-to-challenging-diesel-study/

Table 19 CO2 Emissions over project lifetime

(in '000 ton CO2)	Maasvlakte – Westland	Maasvlakte – Barendrecht	Greenports	Corridor only	Corridor with NL network	Corridor with NL and EU network
CO_2 emissions during production and construction	58.7	72.0	180.8	326.4	326.4	326.4
CO_2 emissions during operations	0.9	0.5	3.3	8.0	10.3	11.2
CO_2 emission saving	68.6	38.1	240.9	588.5	783.2	879.7
Net CO_2 Emissions	**-8.9**	**34.3**	**-56.8**	**-254.0**	**-446.5**	**-542.1**

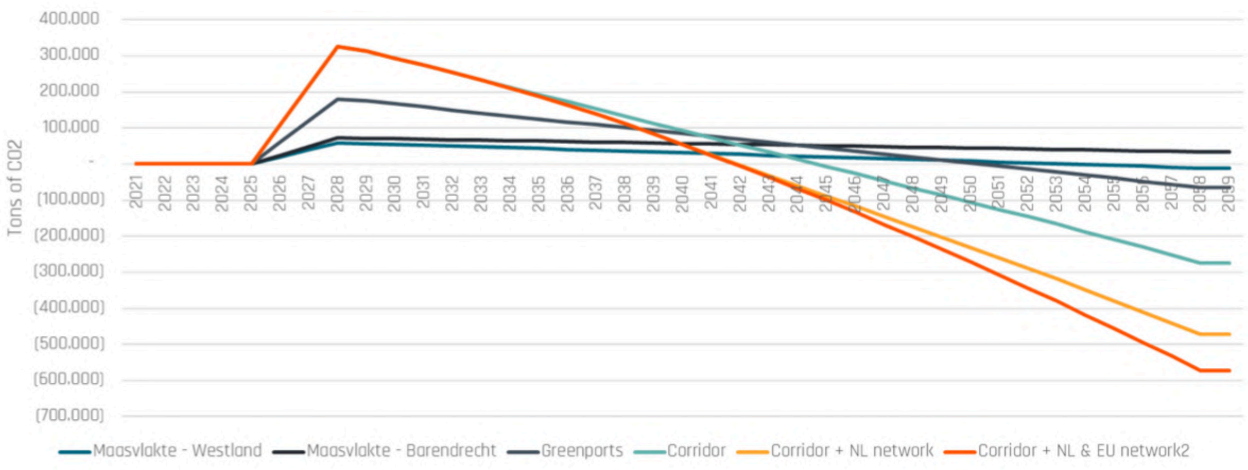


Figure 38 CO_2 emissions over time for the different scenarios

Table 20 Efficient and ETC-price of one ton CO2 (in € per ton) in the two WLO scenarios and the two-degree uncertainty exploration

(€ per ton CO2)		2015	2030	2050
High	Efficient price	48	80	160
	ETC-price	5	40	160
Low	Efficient price	12	20	40
	ETC-price	5	15	40
2 Degree Celsius	Efficient price	60 – 300	100 – 500	200 – 1000
	ETC-price	5	100 – 500	200 – 1000

Source: WLO-klimaatscenario's en de waardering van CO2- uitstoot in MKBA's, 2016

target has not yet been set. The emission reduction for the ambitious scenario is still at 40% for 2030 (now 55%) and 65% for 2050 (now >95%). Nevertheless, several sources[56,57] predict a CO_2 price by 2030 that will be above the high scenario, but lower than the upper limit of the range set in the 2-degree scenario. For the purposes of this study, a value of €100 per tonne CO_2 will be used from 2030 gradually increasing to €200 per ton CO_2 as of 2050, which corresponds to the lower boundary of values given for the 2-degree scenario. From 2020 onwards the average daily closing price €24.29 per tonne CO_2 for the year 2020 will be used[58].

Due to the expected increase in CO_2 price over time, all cases would lead to positive economic impact related to CO_2 emission savings (Table 21).

There is an opportunity for adding solar panels to the tube infrastructure on sections that are above the ground, which would allow for the system to generate its own clean energy. However, neither the costs related to the installation of solar panels nor the associated benefits stemming from the possible energy production have been assessed within this study.

7.2.3. Impact on shipping industry / users

Benefits for users of hyperloop who will benefit from **shorter delivery times and higher reliability**. The benefits associated with time savings and improved reliability depend on product characteristics, their value, shelf life and perishability, and therefore differ by product type. The values have been derived using elasticity values for the different product types[59] and the corresponding bonus values can be found in Table 22 for an average speed of 180km/h.

- It is worth noting that these benefits for users can potentially be capitalized as these gains could be translated into higher transport prices leading to higher revenues and therefore improving the financial business case. The pricing at this moment only considers the current cost price.

According to Dutch and European CBA practice, value of time increases over time and has to be accounted for reliability and time bonuses. According to estimates from Rijkswaterstaat value of time increases with a CAGR of 0.6% respectively 0.9%[60]. An average of the two scenarios of 0.75% growth annually has been used in the analysis. It has to be noted that although this growth factor has been estimated corresponding to the impact of value of time on people, while time and reliability bonuses have been determined corresponding to the value of time of goods (e.g. shelf life). it is an acknowledged practice to use the recommended growth factors also for cargo related time impacts.

The corresponding values for the different scenarios can be found in Table 24. The corridor is expected to generate more than €2 billion (in real values) in economic benefits to the users of the hyperloop system in the long-term.

7.2.4. External impact

Benefits related to reducing negative external impacts of road transportation such as accidents, air pollution, noise, congestion, well-to-tank emissions, habitat damage as well as avoided costs (e.g. for repair of roads) were considered in the assessment. These benefits result from shifting cargo from road transport to hyperloop. For these impacts the calculations were based on external costs related to road freight transport. As the hyperloop system is not expected to generate any negative external impact in any of these categories (e.g. no noise emissions), the total value of external impacts of road transport attributable to volumes shifted to hyperloop are accounted for as benefits for the hyperloop system[61,62]. The values that have

56 Europe CO₂ Prices May Rise More Than 50% by 2030, EU Draft Shows - Bloomberg

57 Analyst: EU carbon price on track to reach €90 by 2030 – EURACTIV.com

58 https://www.spglobal.com/platts/en/market-insights/latest-news/coal/120320-analysts-see-eu-carbon-prices-at-eur56-eur89mt-by-2030

59 Hyperloop for cargo, time and reliability elasticities, Hyperloop Development Program, 2021

60 https://www.rwseconomie.nl/kengetallen/kengetallen-bereikbaarheid-map

61 https://op.europa.eu/en/publication-detail/-/publication/9781f65f-8448-11ea-bf12-01aa75ed71a1/language-en/format-PDF/source-search

62 https://op.europa.eu/en/publication-detail/-/publication/7ab899d1-a45e-11e9-9d01-01aa75ed71a1

Table 21 Economic value of CO_2 emissions for the different scenarios

(Impact in real values, in million €)		Maasvlakte-Westland	Maasvlakte-Barendrecht	Greenports	Corridor	Corridor with NL network	Corridor with NL and EU network
CO2 emissions impact	Project Lifetime	6.6	0.8	24.9	69.3	103.4	121.9
	Average annual	0.2	0.0	0.8	2.3	3.4	4.1

Table 22: Time and Reliability bonus values for hyperloop product segments

Product Group	Time Bonus(€ per tonne-km)	Reliability Bonus(€ per tonne-km)
Best-Fit Products	0.10	0.13
Good-Fit Products	0.10	0.05
Other Products	0.00	0.00

Source: Hyperloop for cargo, time and reliability elasticities, Hyperloop Development Program, 2021

Table 23 Value of Time in Road Traffic, per person for freight

(in € per hour)	2010	2020	2030	2040	2050
Low	45.16	46.54	49.66	53.44	57.27
High	45.16	47.32	52.06	58.41	64.54

Source: Kengetallen Bereikbaarheid, Rijkswaterstaat, 2010

Table 24 Impact on shipping industry / users for different scenarios

(Impact in real values, in million €)		Maasvlakte-Westland	Maasvlakte-Barendrecht	Greenports	Corridor	Corridor with NL network	Corridor with NL and EU network
Time Bonus	Project Lifetime	75.7	43.5	286.1	665.9	881.2	1,007.3
	Average annual	2.5	1.5	9.5	22.2	29.4	33.6
Reliability Bonus	Project Lifetime	98.4	56.4	371.6	859.2	1,127.3	1,288.4
	Average annual	3.3	1.9	12.4	28.6	37.6	42.9
Total impact on shipping industry / users	Project Lifetime	174.1	99.9	657.6	1,525.1	2,008.6	2,295.7
	Average annual	5.8	3.3	21.9	50.8	67.0	76.5

Table 25 Unit and values for assessing different sources of impact for hyperloop

Impact / Benefit	Value(Reference year, 2016)	Value (adjusted to 2021)	Unit	Region	Note
Accident	0.013	0.014	€ / t / km	EU	Average costs, HGV
	0.001	0.001	€ / t / km	EU	Marginal costs, HGV, motorway
Air Pollution	0.008	0.008	€ / t / km	EU	Average costs, HGV
Noise	0.006	0.006	€ / t / km	EU	(Weighted) average costs, HGV
Congestion	0.002	0.002	€ / t / km	EU	Average costs, HGV – inter-urban, delay & deadweight loss costs
	0.069	0.074	€ / t / km	EU	Social marginal costs, HGV, motorway, congested
Habitat Damage	0.002	0.002	€ / t / km	EU	Average costs, HGV
Well-to-tank Emissions	0.002	0.002	€ / t / km	EU	Average costs, HGV
Avoided Infrastructure Costs	0.029	0.031	€ / t / km	NL	Average motorway infrastructure costs for HGVs
	0.008	0.009	€ / t / km	NL	Marginal motorway infrastructure costs for HGVs

Source: Handbook on the external costs of transport; European Commission, 2019; Overview of transport infrastructure expenditures and costs, European Commission, 2019

Table 26 Overview of external impact for different scenarios

(Impact in real values, in million €)		Maasvlakte-Westland	Maasvlakte-Barendrecht	Greenports	Corridor	Corridor with NL network	Corridor with NL and EU network
Accident	Project Lifetime	3.0	1.6	10.4	25.3	53.8	68.5
	Average annual	0.1	0.1	0.3	0.8	1.8	2.3
Air Pollution	Project Lifetime	5.6	3.1	19.8	48.3	64.9	73.5
	Average annual	0.2	0.1	0.7	1.6	2.2	2.5
Noise	Project Lifetime	4.2	2.3	14.7	35.9	48.3	54.7
	Average annual	0.1	0.1	0.5	1.2	1.6	1.8
Congestion	Project Lifetime	37.8	21.0	132.6	324.0	328.9	331.4
	Average annual	1.3	0.7	4.4	10.8	11.0	11.0
Habitat Damage	Project Lifetime	1.4	0.8	4.8	11.8	15.8	17.9
	Average annual	0.0	0.0	0.2	0.4	0.5	0.6
Well-to-tank emissions	Project Lifetime	1.1	0.6	3.9	9.5	12.6	14.1
	Average annual	0.0	0.0	0.1	0.3	0.4	0.5
Avoided Infrastructure Costs	Project Lifetime	10.1	5.6	35.5	86.7	150.5	183.5
	Average annual	0.3	0.2	1.2	2.9	5.0	6.1

Table 27 Estimated employment effects (for €1bn invested)

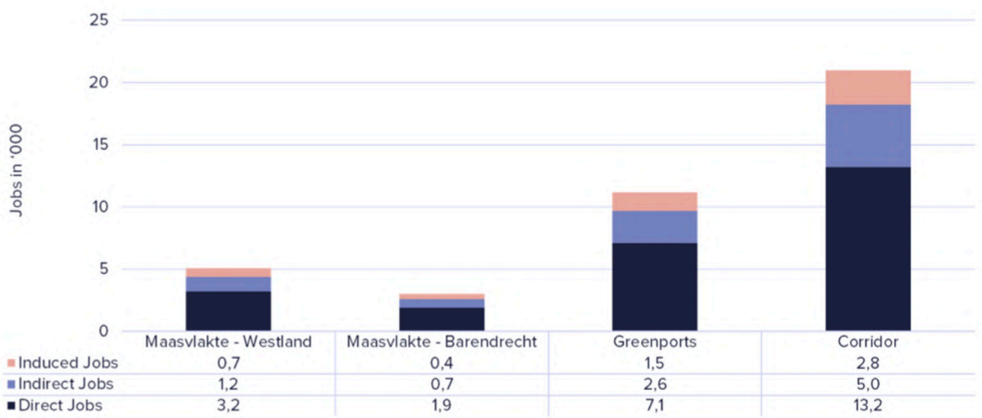
(Jobs in '000)	Direct	Indirect	Direct & Indirect	Induced	Total
Road (construction)	8.8	3.3	12.1	1.9	14.0
Rail	8.1	3.0	11.1	1.7	12.9
Hyperloop as average between Road and Rail	8.5	3.2	11.6	1.8	13.4

Source: Transport Research & Information Note - The Employment Benefits of Investment Projects, National Roads Authority, 2013

Table 28 Overview of economic value of impact on employment for the different scenarios

(real values in million €)	Maasvlakte-Westland	Maasvlakte-Barendrecht	Greenports	Corridor (with NL (and EU) network)
Impact on employment	69.3	40.8	150.9	282.3

Figure 39 Overview of jobs created for different scenarios



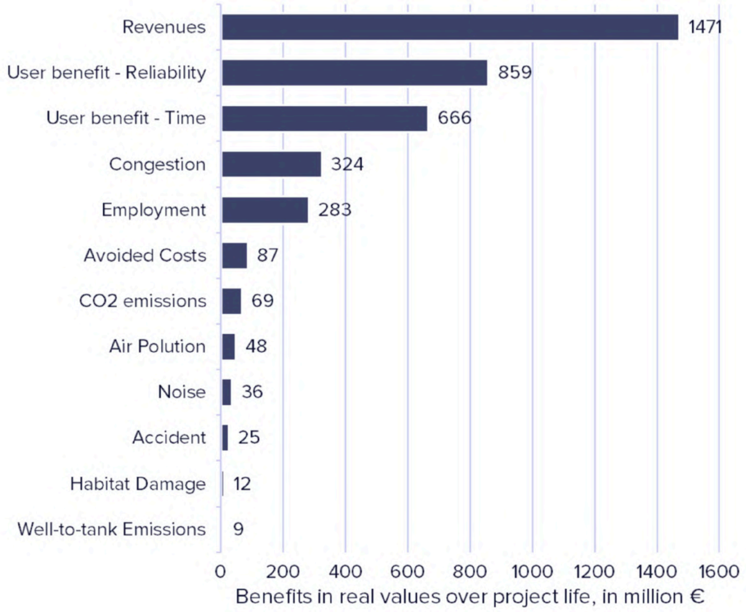


Figure 40 Overview of benefits for corridor only scenario

been used can be found in Table 25. For noise, habitat damage and well-to-tank emissions no marginal cost factor has been identified due to a lack of available data on the type of trucks and the respective composition for the traffic assessed within this project. The same improvement factor for road transportation as described in chapter 7.2.2 has been applied to the well-to-tank emissions impact. Values have been adjusted to 2021 price levels using historic inflation rate data for the European Union respectively The Netherlands. Whenever, average as well as marginal cost values had been available, marginal cost values had been applied to the existing traffic that would be shifted to hyperloop and average cost values had been applied to the traffic considered as new traffic due to growth as this additional growth will have to be accommodated for example through building new infrastructure as the existing one is at its capacity limits. The corresponding results can be found in Table 26.

7.2.5. Impact on employment

As no commercial hyperloop projects has been realized yet, estimations for hyperloop have to be made using values from existing industries and projects. Using an average of the estimated employment effects for every €1 billion of investment for road construction and rail projects[63] as seen in Table 27 below, the impact on employment due to the realization of this hyperloop project has been derived.

The corresponding amount of jobs created for the different scenarios can be found in Figure 39.

Using the median gross income for employees in the Netherlands, which is € 36,500 annually as of 2021 according to the Dutch Central Planning Office[64], the economic impact has been estimated.

For the corresponding economic impact on employment only indirect and induced jobs have been considered as direct jobs will be accounted for through a correction of the construction costs to social costs by means of applying shadow wage factors. The results can be found in Table 28.

63 https://www.tii.ie/tii-library/strategic-planning/transport-research-and-information-notes(trins)/The-Employment-Benefits-of-Investment-Projects.pdf

64 Salary, minimum wage and payslips in the Netherlands (iamexpat.nl)

One might argue that the shift of freight transportation from trucks to hyperloop has a negative impact on the Dutch and European economy as it would reduce the need for drivers, thus, reducing employment. However, the trucking industry is currently experiencing a heavy shortage of drivers. Thus, the effects on the trucking industry have not been estimated and accounted for in this study and it is not possible to say whether the effects would ultimately be positive or negative for this industry.

In conclusion, the impact on employment is estimated at generating between 3 thousand and 20 thousand jobs depending on the assessed scenario, which translates to an economic value between €40 million and €280 million for the different scenarios.

7.2.6. Summary

Taking a closer look at the distribution of benefits for the corridor only scenario as seen in Figure 40, it becomes clear that user benefits account for the largest share of benefits with 39% followed by revenues with 37%. Thus, a majority of the benefits are directly attributed to the usage of the hyperloop system, while only a minority of the benefits (24%) are related to other areas of economic impact. Similar structure of benefits is followed by other scenarios, except for Maasvlakte – Barendrecht section, where the CO_2 emissions during construction outweigh the benefits of removing trucks from the roads.

7.3 Evaluation of economic performance

7.3.1. Model Assumptions

The analysis has been performed using prices at 2021 price level excluding VAT. VAT has been excluded due to the foreseen delivery method of this project within a public-private partnership wherein a separate SPV is expected to be formed, which could then redeem the VAT.

The concept of shadow prices is being applied to reflect the social opportunity cost of goods and services in the social cost benefit analysis. Therefore, a share of labor for the investment costs (capital and development expenditures)

Table 29 Discount rates for WLO scenarios

	WLO Low	Standard	WLO High
Discount rate – general	1.85%	2.25%	2.65%
Discount rate – fixed, sunk costs	1.2%	1.6%	2%
Discount rate – strong non-linear income	2.5%	2.9%	3.3%

Source: Discount rates for WLO scenarios, Rapport discontovoet, 2020

Table 30 Overview of project impact for the different assessment scenarios over project lifetime

(Present values in million €*)	Maasvlakte – Westland	Maasvlakte – Barendrecht	Greenports	Corridor only	Corridor with NL network	Corridor with NL and EU network
Scenario	**A**	**B**	**C**	**D**	**E**	**F**
Benefits	234.0	129.2	847.1	2,034.6	2,637.8	2,936.8
Revenues	103.2	57.4	362.5	885.5	1,168.7	1,302.6
Economic Impact	130.7	71.8	484.6	1,149.1	1,469.1	1,634.2
Costs (at shadow prices)	363.8	210.1	788.6	1,488.9	1,523.7	1,543.9
CapEx + DevEx	321.3	185.9	690.5	1,294.3	1,312.6	1,325.1
OpEx	**42.5**	**24.2**	**98.1**	**194.7**	**211.0**	**218.8**
B/C Ratio	**0.64**	**0.61**	**1.07**	**1.37**	**1.73**	**1.90**
ENPV	**-129.8**	**-80.9**	**58.5**	**545.7**	**1,114.1**	**1,392.9**
ERR	**-2.91%**	**-3.13%**	**0.50%**	**2.30%**	**3.98%**	**4.53%**

Table 31 Overview of project impact for the different assessment scenarios over project lifetime including residual value

(Present values in million €*)	Maasvlakte – Westland	Maasvlakte – Barendrecht	Greenports	Corridor only	Corridor with NL network	Corridor with NL and EU network
Scenario	**G**	**H**	**I**	**J**	**K**	**L**
Benefits	234.0	129.2	847.1	2,034.6	2,557.0	2,845.5
Costs (at shadow prices)	363.8	210.1	788.6	1,488.9	1,429.1	1,447.3
Residual value	80.3	46.5	171.7	320.5	324.6	330.3
B/C Ratio	**0.83**	**0.79**	**1.37**	**1.74**	**2.20**	**2.42**
ENPV	**-49.5**	**-34.4**	**230.3**	**866.1**	**1438.7**	**1,723.2**
ERR	**-0.79%**	**-0.94%**	**1.58%**	**3.03%**	**4.46%**	**4.95%**

* Total values might deviate due to rounding

of 50% is assumed[65]. Based on the latest cost insights it is estimated that operations are less labor intensive, thus, a share of labor for the operating costs of 40% is assumed. While The Netherlands has a rather low unemployment rate and therefore would justify applying a shadow wage factor of 0.99, it is expected that the project would also attract workers from neighboring regions with higher unemployment rates. Therefore, in the European context of this project, a shadow wage factor of 0.8 has been used for investment costs and operational expenditures[66,67]. When using the WLO scenarios, the working group "Discontovoet" proposes the discount rates as shown in Table 29. The standard discount rate has been used in the baseline scenarios.

As infrastructure as well as vehicle purchases during operations are expected to have a remaining value after the assessment period of 30 years, evaluations are given with residual value included. For infrastructure a lifetime of 60 years has been assumed and for vehicles a lifetime of 30 years. The remainder of the value after depreciation is used as residual value.

65 Labor costs include direct labor and subcontractors. Source: Major infrastructure projects: costs and productivity issues, Deloitte, 2014

66 http://fiorio.economia.unimi.it/res/Del%20Bo%20Fiorio%20Florio%20Article%202011_1_17.pdf

67 https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

7.3.2. Scenario Analysis

Using the outcomes and assumptions as described in previous chapters, the performance of the different scenarios from an economic point of view has been evaluated. The results can be found in Table 30.

Within the single section scenarios, only the Greenports connection shows a positive economic outcome. The corridor performs well even without the network effects with an economic value of approximately €500 million. This value more than doubles when considering the effects of a Dutch hyperloop network on the corridor and an additional uplift of 25% to the net economic value can be achieved through the expansion of the hyperloop network within Europe. The corridor shows strong economic performance even without considering residual value or wider economic benefits (e.g. impact on employment).

The economic value of the corridor (Scenario J) improves by approximately 59% (compared with scenario D) by taking into account the residual value of the assets.

Considering residual value as well as the impact on employment, all assessed scenarios demonstrate a B/C ratio that is higher than 1 and a corresponding positive economic net present value. The corridor on its own would lead to an economic value of more than €1 billion, while this value would increase to almost €2 billion in the long-term considering the expansion of the network.

Table 32 Overview of project impact for the different assessment scenarios over project lifetime including residual value and employment benefits

(Present values in million €*)	Maasvlakte – Westland	Maasvlakte – Barendrecht	Greenports	Corridor only	Corridor with NL network	Corridor with NL and EU network
Scenario	**M**	**N**	**O**	**P**	**Q**	**R**
Benefits	234.0	129.2	847.1	2,034.6	2,557.0	2,845.5
Costs (at shadow prices)	363.8	210.1	788.6	1,488.9	1,429.1	1,447.3
Residual value	80.3	46.5	171.7	320.5	324.6	330.3
Employment benefits	61.6	35.7	132.4	247.7	247.7	247.7
B/C Ratio	**1.04**	**1.01**	**1.59**	**1.95**	**2.41**	**2.62**
ENPV	**12.1**	**1.3**	**362.6**	**1,113.8**	**1,686.4**	**1,970.8**
ERR	**0.22%**	**0.04%**	**2.84%**	**4.47%**	**5.95%**	**6.42%**

* Total values might deviate due to rounding

8. Risk Assessment

8.1 Sensitivity Analysis

The following variables have been chosen for performing a sensitivity analysis:

- Linear infrastructure costs and hub costs as largest cost drivers within capital and development expenditures
- Volume for the different product types (which is synonymous in its effect with the modal shift for the different product types) as well as price as the drivers for revenues
- Insurance of assets as the largest cost driver within operational expenditures
- Time and reliability bonuses related to the impact on the shipping industry as the largest driver within economic benefits. Only done for best-fit products as those comprise the largest share within volume

Sensitivity analysis has only been performed for the corridor only scenario (D). The scenarios with the network effects have not been considered in this analysis as the corridor on its own reports a positive economic outcome. The results of the sensitivity analysis can be found in Table 33.
The results show that linear infrastructure costs, volume of best-fit products as well as price are critical variables and important drivers for the economic performance of the corridor.

8.2 Switching Values

In order to assess the level of risk related to the critical variables, the switching value at which the economic net present value would turn negative has been determined. The results can be found in Table 34.

The results show that quite high variations for critical values are possible that would still allow to break even economically. Thus, the results of the assessment can be considered rather robust.

8.3 Scenario Analysis

As the project is of an innovative nature and still in an early stage, a scenario analysis for a pessimistic and optimistic scenario has been performed. Whenever applicable and appropriate WLO Low or WLO High (respectively 2 Degree Scenario) values have been used.

The analysis shows that even when a multitude of factors would fall short of current expectations, the project would still almost reach acceptable levels of economic performance. However, just by including residual value, the B/C ratio would increase to 1.17 and even reach 1.40 when considering employment effects as well. This shows again, that the project at hand is rather robust. Furthermore, the optimistic case demonstrates that even when excluding residual value and employment benefits economic performance is even higher than for the baseline scenario (Scenario P) including those, which shows the enormous potential of the project.

Table 33 Results of sensitivity analysis for corridor only scenario

Variable	**Variation of ENPV**	
	+1% of variable	**-1% of variable**
Linear Infrastructure costs	-2.46%	2.46%
Hub costs	-0.08%	0.08%
Volume – Best-fit products	3.45%	-3.45%
Volume – Good-Fit Products	0.04%	-0.04%
Volume – Other Products	0.10%	-0.10%
Price	1.56%	-1.56%
Insurance of assets	-0.20%	0.20%
Time bonus – best-fit products	0.62%	-0.62%
Reliability bonus – best-fit products	0.81%	-0.81%

Table 34 Results for switching value analysis for corridor only scenario

Critical Variable	**Value for which ENPV = 0**
Linear Infrastructure	40.67%
Volume – Best-fit products	- 29.11%
Price	- 63.98%

Table 35 Results for scenario analysis

(Present values in million €)	**Corridor only - PESSIMISTIC**	**Corridor only**	**Corridor only - OPTIMISTIC**
Scenario	**S**	**D**	**T**
CHANGE OF VARIABLES			
Construction Costs	+20%		-20%
Volume	-10%		+10%
Average annual growth rate – volume	0.3%	1.2%	2.1%
CO2 emissions (ton CO2 per km of single tube hyperloop infrastructure)	2.7	1.6	0.4
Average annual Improvement rate – energy production	-3.12%	-6.48%	-8.66%
Average annual improvement rate – trucking	-2.48%	-1.18%	-1.00%
CO2 price (€ per ton CO2)	-20%		+20%
Time + Reliability bonus – annual growth rate	0.6%	0.75%	0.9%
Discount rate - general	1.85%	2.25%	2.65%
Discount rate – fixed, sunk costs	1.2%	1.6%	2%
Discount rate – strong non-linear income	2.5%	2.9%	3.3%
RESULTS			
Benefits	1,580.1	2,034.6	2,569.2
Costs *(at shadow prices)*	1,789.4	1,488.9	1,211.3
B/C Ratio	**0.88**	**1.37**	**2.12**
ENPV	**-209.3**	**545.7**	**1,357.9**
ERR	**-0.88%**	**2.30%**	**6.00%**

8.4 Risk Analysis

In the table below, several risks have been identified and evaluated. The probability as well as severity might change as the project progresses to later stages. Furthermore, it has to be noted that this list is not exhaustive and only lists the most relevant risks identified for the project at this moment.

Evaluation scale:
Probability: : A. Very Unlikely; B. Unlikely; C. About as likely as not; D. Likely; E. Very likely
Severity: I. No effect; II. Minor; III. Moderate; IV. Critical; V. Catastrophic
Risk level: Low; Moderate; High; Unacceptable

Table 36 Overview of different types of risk and their evaluation

Risk	Effect	Probability (P)	Severity (S)	Risk level	Causes	Prevention / mitigation measures
PLANNING AND ADMINISTRATIVE RISKS						
Obtaining Permits	Delay	C	III	Moderate	Types of permits needed still uncertain at this point	Early collaboration with authorities and local as well as national governments to ensure providing the right means for obtaining permits later on
Lack of au thority grant ing approvals	Delay	C	III	Moderate	No existence of designated hyperloop au thority	Early collaboration with authorities from other (transport) infra structure
LAND ACQUISITION						
Cost of land	Cost	C	III	moderate	Costs related to land acqui sition still uncertain at this point	Route alignment largely follows existing infrastructure. Early conversations with respective land owners
Delays of land acquisition	Cost, Delay	B	IV	moderate	Amount of land to be acquired still uncertain at this point	Early conversations with respective land owners
DESIGN						
Changes in the require ments	Cost, Delay	D	II	Moderate	Hyperloop is still in research and development phase	Key requirements have already been deter mined within this study together with the target users as well as engineering
Inadequate design cost estimates	Cost	D	II	Moderate	No commer cial hyperloop route has been realized yet, thus, no historic design cost estimates	Hyperloop by design is supposed to mini mize the need for large engineering design work as it is mostly modular pre installed infrastructure
CONSTRUCTION RISKS						
Inadequate construction cost estimates	Cost	D	IV	high	Hyperloop is still in research and development phase	Ongoing research and development is aimed at further minimizing future construction costs
Cost overruns (during con struction)	Cost	D	IV	High	Cost overruns typically happen with in infrastruc ture projects	Contingency above average could be foreseen to accom modate risks associ ated with pilot project
Inadequate construction quality	Cost	C	III	moderate	No commercial hyperloop route has been realized yet, thus, no reference re garding construc tion quality avail able	Large group of indus try is already en gaged within the Hyperloop Develop ment Program creat ing a knowledge base for building future hy perloop routes
Construction Delay	Cost, Delay	D	II	moderate	Construction de lays typically happen within in frastructure proj ects	Hyperloop by design is aimed at minimizing construction complex ity as it is mostly mod ular pre installed infra structure
Archeological findings	Cost, Delay	B	II	low	No historic site has been identi fied within route alignment study	Largely following ex isting infrastructure with known archeolog ical history
OTHER RISKS						
Traffic (demand) risk	% traffic	C	IV	high	Traffic study avail able, uncer tainties regarding long term fore cast and modal shift	More detailed traffic study in follow-up phases; potentially ne gotiating offtake agreements with large users
Public opposition	Delay	C	III	moderate	Hyperloop is a new modality	Early participation of public

9. Project Realization and Governance

9.1 Project delivery models

A range of project delivery model options for the Cargo-hyperloop Holland project are considered to organize and finance design, construction, operations, and maintenance of the corridor. These options vary in the degree of separation of roles and whether the role is fulfilled by the public or the private sector. The potential roles that are defined are:

- Acquire and own land – it is assumed that the acquisition and ownership of land to support the hyperloop system is in the hands of an entity owned by the Dutch Government in all cases.
- Design and build the hyperloop network – designing and implementing the guideway, substructure, specials, infrastructure-based communications/controls system and electrical infrastructure.
- Maintain the hyperloop system – maintaining the guideway, substructure, specials, infrastructure-based communications/controls system and electrical infrastructure.
- Operate the hyperloop system – controlling the movement of vehicles through the guideway.
- Operate vehicle services – the delivery of hyperloop transport services.
- Supply vehicles – the supply of hyperloop vehicles.

Some of these roles may be split up further or bundled. For the public/private sector allocation of roles, there are generally three delivery options – a private, public, or combined private-private approach. There are various sub-options possible within each option (Table 37). This list is not exhaustive but gives an overview of common combinations used in the market for other infrastructures.

Selecting the most effective option is usually based on the criteria of efficiency, risk allocation and competitiveness. Especially competition issues, including the role of contestability in the provision of hyperloop services, either through competition for concession rights or direct competition between service suppliers, are very often central to deciding about the final delivery model.

The public delivery models historically perform somewhat ineffectively. Absence of competition might prompt a less efficient and less client-centered result than models that allow private competition. For the Cargo-hyperloop Holland corridor, it is an option to start with a public-sector operator and privatize once the hyperloop has matured. However, this would forego the advantage of utilizing private sector skills, experience and incentives in the early stages. Therefore, a public delivery model (option 1) is not desirable.

The private delivery models transfer risks to the private sector. Various components make this sort of agreement tricky for an implementation of the Cargo-hyperloop Holland corridor:

- It is unlikely to be feasible to fund the whole corridor through private means, as it most likely will not provide sufficient financial return for private investors without the additional flows that the Dutch and European network extensions would provide.

Table 37: Overview of available delivery models (green: public, grey: private)

Delivery models	Acquire & own land	Design & build network	Maintain network	Operate network	Operate transport service	Supply fleet
1 Public						
1a Vertically integrated	Hyperloop Agency					
1b Vertically separated	Hyperloop Development Authority		Hyperloop Network Manager		Hyperloop Vehicle Operating Company(ies)	
2 Private						
2a Vertically integrated	Hyperloop Authority	Hyperloop "Design Build Finance Maintain Operate" concession(s)				
2b Vertically separated	Hyperloop Authority	Hyperloop "Design Build Finance Maintain" concession		Hyperloop "Operate" concession(s)		
3 Public-Private						
3a Public operator-maintainer	Hyperloop Agency					Hyperloop Fleet supplier
3b Public infrastructure manager	Hyperloop Infrastructure Agency				Hyperloop "Operations" concession(s)	
3c Public landlord-maintainer	Hyperloop Infrastructure Agency			Hyperloop "Operations" concession(s)		
3d Public landlord	Hyperloop Delivery Authority		Hyperloop "Operate/Maintain" concession(s)			

- Substantial public subsidizing would therefore be required; hence the public sector would need a mechanism to oversee that the hyperloop program meets public interests.
- Wider public interests imply a need to coordinate the hyperloop with state transport frameworks.

Thus, a private delivery model (option 2) is not appropriate.

The most promising option is a hybrid public-private model, where the delivery and ownership of the infrastructure is provided by the public sector, and the transport services are provided by private companies. The exact structuring and bundling of roles is to be determined in later studies.

9.2 Governance

Implementation of the hybrid delivery model suggested for the Cargo-hyperloop Holland corridor requires establishing a hyperloop agency/authority as the public counterpart to private developers, to play a similar role as ProRail for rail, Rijkswaterstaat for roads and waterways, and Gasunie for gas pipelines. The ministries that should be involved in setting up the Hyperloop Agency/Authority and selecting the Cargo-hyperloop Holland corridor delivery method are:

- Ministry of Infrastructure and Water Management (IenW)
  - In relation to the infrastructure governance and the impact on other infrastructures.
- Ministry of Economic Affairs and Climate (EZK)
  - In relation to the economic and environmental implications.
- Ministry of the Interior and Kingdom Relations (BZK)
  - In relation to the spatial planning implications.
- Ministry of Finance
  - In relation to the financial implications.

9.3 Funding sources

The corridor would likely need public funding to close the commercial funding gap. A public-private delivery model allows for a broad range of funding possibilities:

- Debt/Equity (Private or public)
- Up-front grants for the implementation of the infrastructure (public)
- Subsidized transport (public)
- Availability payments (public)

The justification of the funding could come from a combination of user revenues underpinning the financing and socio-economic benefits underpinning the government funding. Due to the innovative nature of the project as well as the wider economic benefits that are expected to be generated, the project is well suited to receive public funding, e.g. in the form of grants. Those can either come through national, regional or European schemes as well as a combination thereof. The following is a non-exhaustive list of potential public funding sources:

- **ELENA (EIB).** The ELENA (European Local Energy Assistance) Facility is implemented by the European Investment Bank (EIB). It aims at supporting the actions of public and private stakeholders in order to stimulate a broader utilization of innovative solutions. **Interreg.** The Interreg North-West Europe Programme is part of the European Cohesion Policy and is financed by the European Regional Development Fund (ERDF).
  Targets projects within North-West Europe that fall under one of the following themes: innovation, low carbon, resource and materials efficiency.
- **ERDF.** The European Regional Development Fund (ERDF) aims at strengthening economic, social and territorial cohesion in the European Union.
  The financial support is of shared responsibility among the European Commission and the authorities of the Member States.
- **InvestEU.** The InvestEU Programme aims at supporting sustainable investment, innovation in Europe.
- **InvestNL.** InvestNL is a private organization funded by public funds. It financially supports companies/projects that aim at making the Netherlands more sustainable and innovative.
- **Groeifonds.** The Nationaal Groeifonds supports projects in the areas of: knowledge development, research and innovation, infrastructure. The investments focus on opportunities of structural and sustainable economic growth.
- **MIRT.** Meerjarenprogramma Infrastructuur, Ruimte en Transport (MIRT) is the multi-annual program for infrastructure, space and transport by the Dutch government.

These or other similar sources could be used to provide funding for the nest stages of the project, from feasibility study to design and project realization.

9.4 Legal considerations

As hyperloop is a new mode of transportation, there are uncertainties on how to implement hyperloop under Dutch legislation. As these processes could take on long lead-times, a preliminary legal feasibility assessment was conducted to identify potential barriers early on.

The legal feasibility assessment focused mainly on whether hyperloop could be implemented following existing Dutch legislation, if amendments are deemed necessary, or that a completely new law is to be drafted. In this light, specific regulatory and legal enablers necessary to realize hyperloop were identified, within existing frameworks regulations for spatial planning and environment, for exploitation with or without concessions, and the potential of a "Law of Hyperloop".

9.4.1 Hyperloop in existing legislation

According to the current Dutch spatial planning and environmental regulations, it would be possible to accommodate the implementation of the Cargo-hyperloop Holland corridor infrastructure, by introducing hyperloop-specific governmental decrees. At least a period of 24 months should be reserved for the necessary regulatory processes to be completed, before the construction of the infrastructure could be commenced.

For the operational phase of the Cargo-hyperloop Holland, the safety and certification process of the hyperloop system has to be initiated and developed. An authority for managing the certification and safety issues needs to be appointed and collaborate closely with project partners for gaining the required expertise for the assessment of the safety and security. Based on the knowledge and expertise gained, certification process for the commercial exploitation will have to be developed. Existing legal framework and procedures only to a certain extent are applicable to the hyperloop system, and to obtain the necessary certification, new processes are necessary anyway. Thus, it is recommended that in order to overcome the difficulties in existing frameworks, new legislation is required, 'tailored' to hyperloop.

9.4.2 Hyperloop in new legislation: Law of Hyperloop

Introducing the 'Law of Hyperloop' is a favorable solution from various perspectives:

- In the past, a specific new legislation used to be created and adopted in circumstances similar to these related to the Cargo-hyperloop Holland corridor development, namely when the new technologies were introduced for which the existing legal framework had not been not conducive, and where the innovative development had been regarded as an opportunity to contribute to social objectives or policy objectives
- Recently, it has been declared at European level on behalf of the European Commission that new regulation will be created specifically for hyperloop networks. It is highly likely that the European institutions will want to regulate hyperloop networks as soon as the commercial operation becomes apparent. The standardisation process has already begun and the Joint Technical Committee has been stablished to define the hyperloop standards for Europe.

Therefore, it is recommended for the next stage of the Cargo-hyperloop Holland corridor development, to explore the possibilities for the 'Law of Hyperloop' in consultation with the Ministerie IenW and the Ministrie van BZK. The Ministerie van BZK will also have to be involved in the process of RIP and for the spatial planning aspects of a Law of Hyperloop. In addition, in consultation with the Dutch government, a collaboration with the European Commission could be initiated at an early stage, to discuss and agree the proposal to draft and adopt the 'Law of Hyperloop'.

10. Project realization schedule

The Cargo-hyperloop Holland project is realized in accordance with a general transport infrastructure development framework, with a decision-making process being iterated after each preparatory phase (Figure 41). The initial two steps (the concept study and the pre-feasibility study), have been completed so far, with results of the pre-feasibility study provided within this report. As the results of the pre-feasibility assessment are positive and have proven feasibility of the project at this stage, the project will move to the next realization step - the feasibility study.

At the feasibility stage, project partners responsible for the project implementation are defined and, supported by project promoters and stakeholders, undertake a detailed assessment to make the final go/no-go decision about the project implementation. The feasibility assessment deepens the analyses conducted at the previous stages as well as adds additional aspects such as the financing scheme development and environmental impact assessment. If the project is then deemed feasible with no major showstoppers, the project can be put forward through a proper procedure to initiate the design and construction phase.

In case of the Cargo-hyperloop Holland project, this procedure has yet to be determined, but it is expected that an adjusted version of *trace decision* process ("tracebesluit") will be applied by the Dutch government . In general, this process includes a tender set out by the government as well as acquiring initial permits. The winning consortium then starts design and engineering before entering the construction phase.

Construction of the Cargo-hyperloop Holland corridor is likely to be phased, as this project is expected to be built as the first commercial hyperloop route. The first phase would build out a smaller section of the corridor first as proof of operation and for certification purposes before building out the rest of the corridor.

The project planning as foreseen within this study can be found in Figure 42. During feasibility study phase a more substantiated planning will be made.

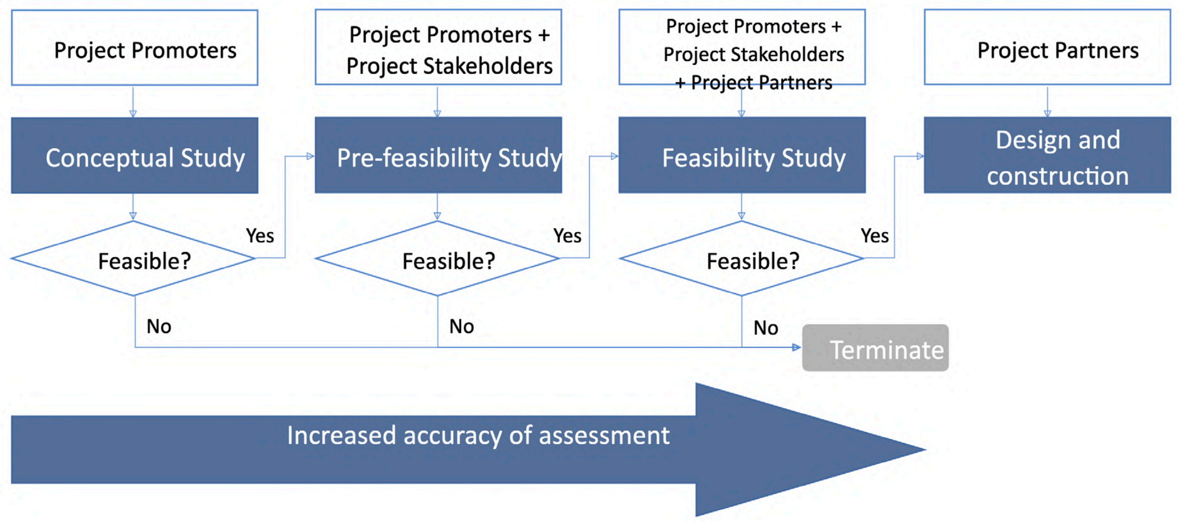


Figure 41: Transport infrastructure projects realization framework

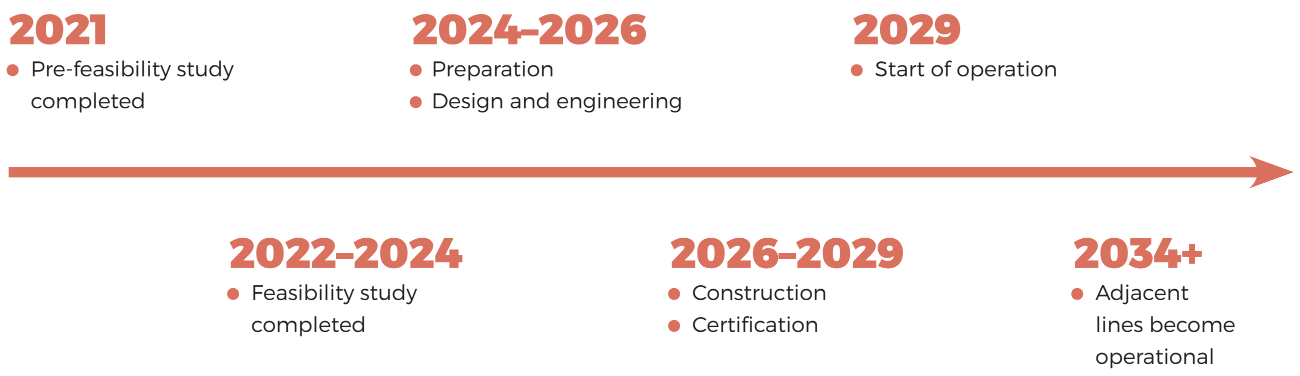


Figure 42 Project Timeline

11. Conclusions and next steps

The development of the Cargo-hyperloop Holland corridor will provide a new opportunity for the logistics sector to use a sustainable and fast mode of transportation, first on the regional scale, and then within national and European hyperloop networks. In 2030, when the Cargo-hyperloop Holland corridor is completed potentially as the first hyperloop corridor in Europe, it is expected to attract 3.4 million tonnes of cargo. In 2040, with the completion of the Dutch hyperloop network, the volume transported along the corridor will rise to 5.6 million tonnes. The demand will continue to grow as the European network is expanded, to reach 7.9 million tonnes in 2050.

The Cargo-hyperloop Holland corridor will also play an important role in relieving congestion on the Dutch road network. In the first fully operational year[68], in 2030, the corridor will allow to remove 1,091 trucks daily from the A4 motorway between Rotterdam and Amsterdam and adjacent roads (ca 10% of the truck traffic along the corridor in 2030), which is equivalent to over 2,500 passenger cars. With the network expansion, the importance of the corridor as an alternative to road transport will grow even more, and by 2050, the corridor is expected to capture an equivalent of 2,517 trucks per day (17 % of the 2050 truck traffic) or 5,800 passenger cars. In monetary terms, this will result in over €300 million benefits from relieving congestion by 2050.

The implementation of the Cargo-hyperloop Holland corridor will result in significant positive socio-economic impacts contributing to strategic European and national objectives.

- Competitiveness of the businesses in the region will be improved, as the introduction of Cargo-hyperloop Holland corridor will enable optimization of logistics processes and allow its users to achieve tangible gains in transit time and reliability. These benefits will range from €1.7 billion when the corridor is considered separately, to €2.5 billion for the corridor being a part of wider Dutch and European hyperloop networks.

- Carbon emissions from freight transport operations in the corridor have a potential to be reduced by 1 million tonnes in 2050. Considering the CO_2 emitted during construction, by 2050 the corridor implementation will result in net CO_2 reduction of up to 0.6 million tonnes. Further technical work with industrial partners are conducted to minimize hyperloop construction emissions and therefore bring even more positive net impacts.

- A whole new industry is developing around the hyperloop technology. The implementation of the Cargo-hyperloop Holland corridor will boost this industry with 18,000 jobs created in Netherlands and Europe directly and indirectly in relation to the construction works and further 3,000 jobs induced by the project in other sectors of the Dutch and European economy.

Achieving these benefits will require capital expenditures of €1.4 billion to deliver the corridor infrastructure, out of which €818 million will be spent on the greenports connection, €362 million on Maasvlakte – Westland section, and €235 million on Maasvlakte – Barendrecht section.

The resulting economic performance indicators confirm high economic value of the corridor, ranging from €0.5 billion in a single-corridor scenario to €1.9 billion for the corridor being a part of the wider Dutch and European hyperloop network (excluding residual value and impact on employment), with the benefits to costs ratio of 1.37 to 1.9 respectively. These positive economic results could be affected by changes in construction costs, demand volumes or revenues generated by hyperloop operations. Sensitivity analysis of the project confirmed that only drastic changes of these variables (by >30%) would result in negative results of the economic assessment, and considering the risks and uncertainties associated with the project, this outcome seems rather unlikely.

The alignment of the Cargo hyperloop Holland corridor has been validated by an independent external party
. In the alignment, the major risks were related to conflicts with future infrastructure developments (A4 widening and an additional runway for the Schiphol airport). The conflict with A4 widening has been alleviated by adjusting the alignment. The plans for an additional runway will be further discussed with the Schiphol airport and the government. The construction cost estimates for the corridor were also confirmed by an independent reviewer, with the accuracy levels of 50%. Further detailed work on the next stages of the project is necessary to select the most appropriate tunnelling technology to further optimize the capital expenditures of the project.

On the demand side, the corridor unlocks huge opportunities for its users to reduce transit time and improve reliability. To fully utilize this potential, future user will need to revise some of their current logistics processes:

- Containerized cargo will be palletized at the hyperloop hub before being transported to its destination. Destuffing containers will be included in the hyperloop hub services.

- The first/last mile connections complementing the hyperloop services can be either organized by the hyperloop users or integrated first/last mile services offered by hyperloop affiliated partners can be used to ensure full compliance with hyperloop standards of handling quality, speed and reliability.

It is expected that not all potential users of the hyperloop system will adopt these changes. However, as confirmed by the sensitivity analysis, even more than 29% decrease in the demand will still result in a positive economic case for the corridor.
The prices for hyperloop services and revenues generated by the project will be established to provide a competitive offer comparing to existing services, and to encourage modal shift to hyperloop and ensure project economic viability. As the most promising option for the project delivery is a hybrid public-private model, the government will play an essential role in implementation of the corridor and ensuring that an optimal price for hyperloop services is adopted. Public sector participation in the project delivery is also essential because most of the benefits generated by the project are not reflected in purely financial outcomes and their materialization will require a coordinated regional and national effort which is largely in a public sector domain.

Based on the economic results achieved for the corridor and its sections, the implementation of the full Cargo-hyperloop Holland corridor is recommended as it brings the full scope of economic benefits. However, the Greenports

68 After one-year ramp-up period

section could be considered as a shorter pilot as it is economically viable on its own.

The pilot route would bring limited benefits comparing to the whole corridor, but it would serve as a commercial demonstrator of hyperloop capabilities to build social support and public adoption for hyperloop, and provide lessons and learnings to be used for large-scale deployment. The pilot route, except for being economically viable investment, should also demonstrate the following hyperloop capabilities:

- multi-point networking capability to transport between any origin-destination pair,
- spatial integration of the hyperloop in diverse environment,
- efficient and swift construction of the hyperloop infrastructure,
- seamless integration with logistics processes and supply chains.

The Cargo-hyperloop Holland corridor and a potential pilot route will be the first hyperloop routes in Europe and a starting point to develop future continental network for cargo and passengers. From this perspective, both the corridor and pilot route infrastructure should be suitable for transporting both, goods and passengers, when the network is expanded. Further research is planned to examine the infrastructure requirements for passenger transport and additional financial impacts of making the infrastructure suitable for passenger transport and economic impacts resulting from providing passenger hyperloop services in the corridor.

Successfully proving the economic viability of the Cargo-hyperloop Holland corridor, the next steps will be focused on establishing government leadership for the project, initiating the necessary regulatory adjustments, and conducting further research on the technical aspects of the route, including passenger transport application, and its future role as a part of European hyperloop network.

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DÜMMEN ORANGE®
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BEST FRESH GROUP
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Gemeente Aalsmeer
Gemeente Amsterdam
Gemeente Rotterdam

gemeente Haarlemmermeer
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green port DUIN- EN BOLLENSTREEK
GREENPORT Aalsmeer

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