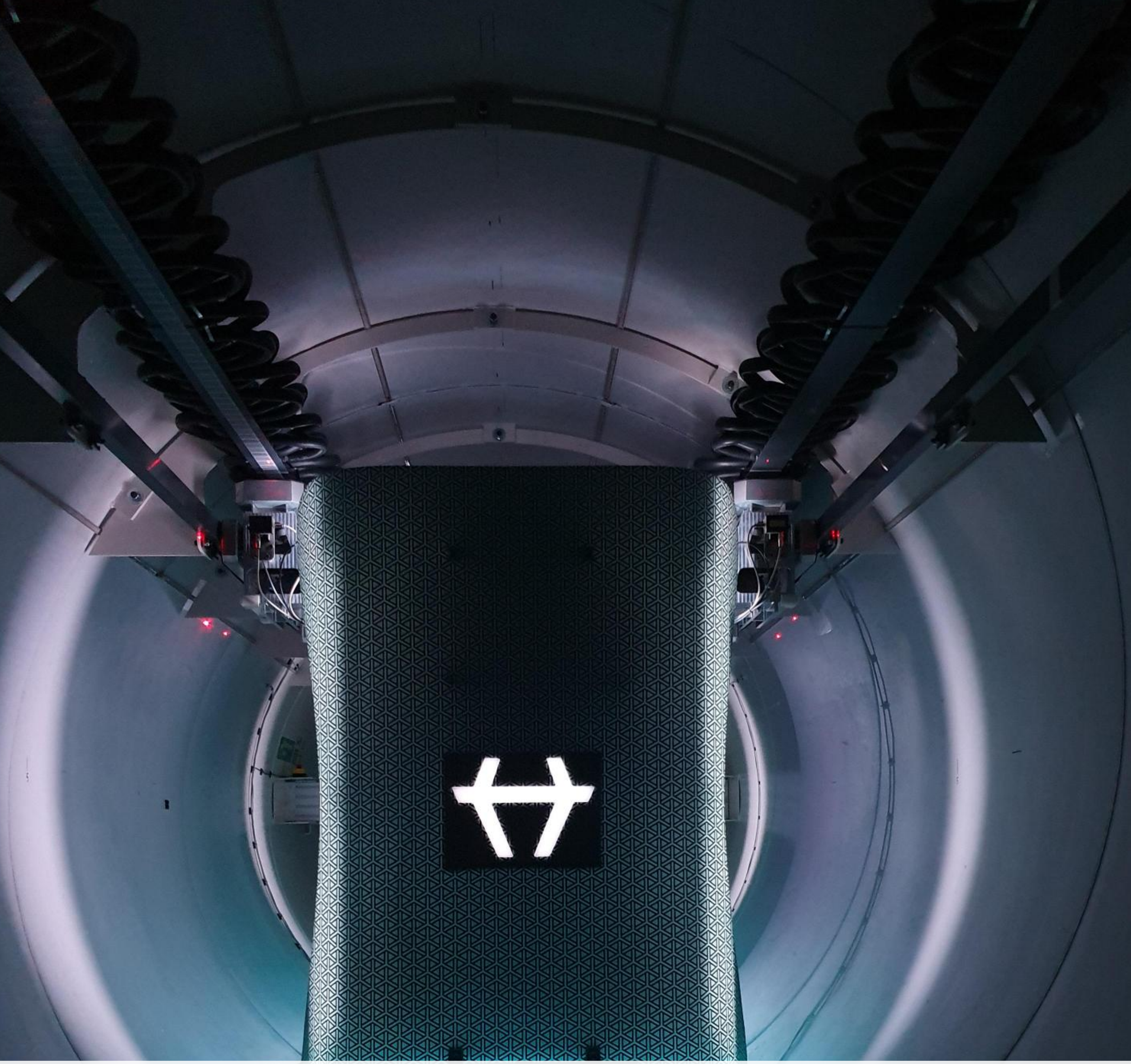

The Cargoloop: An economic feasibility study on a cargo application of the hyperloop in Europe.

Marcha Pijnenburg

TUDelft

HARDT HYPERLOOP

The Cargoloop: An economic feasibility study on a cargo application of the hyperloop in Europe

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The Cargoloop

An economic feasibility study of a cargo application of the hyperloop in Europe

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Preface

In the past six months I have experienced what it is like to shape the future of transport. A challenging, instructive but most of all an interesting and exciting period. I mean, let's be honest: working on this completely new form of transport is pretty cool. From day one, the subject has fascinated me, and it did so until the very last. I increasingly discovered how complex and challenging it is to implement a completely new form of transport but also how much pleasure it brings to me to work on such complex issues. It was truly a unique experience.

I want to thank the members of my graduation committee for their valuable input. My first supervisor, Jan Anne Annema, thank you for always making time available to discuss the progress of my research, being critical and for thinking along in solutions when needed. My second supervisor, Martijn Warnier, thank you for providing ideas on how the potential Cargoloop route could be determined, your input was very useful. Finally, my chairman, Bert van Wee, thank you for providing useful feedback from a fresh point of view and clear directions to go to next.

Next to my committee, I want to thank the team of Hardt Hyperloop. The team that is working with great motivation on this every day, made sure that I worked with a lot pleasure and enthusiasm on my thesis. In particular, I would like to thank Inge Beerlage, my external supervisor at Hardt Hyperloop. You were always incredibly involved in my research and you provided me in the right directions with critical and constructive feedback. I enjoyed working with you and learned a lot from you over the past six months.

I also want to thank all the people who are close to me for your endless support. I feel privileged to have so many nice people around me.

Finally, I hope that everyone who reads this thesis will read it with as much pleasure and enthusiasm as I have worked on it over the past six months.

Marcha Pijnenburg
Delft, September 2019

Summary

This study investigates the economic feasibility of a new form of cargo-transport: the Cargoloop, a cargo application of the hyperloop. In order to be able to do this, the Cargoloop must first be designed. This study therefore consists of a two-step approach: in the first step a potential design of the Cargoloop is established and an initial route is proposed, followed by the second step in which the economic feasibility of the Cargoloop is investigated by means of a cost-benefit analysis.

Situation

It is expected that the express delivery market will grow strongly in the coming years. This growth, however, is restricted by the shortage of express transportation capacity and is increasingly causing congestion. The transport sector is not only subject to this growing demand from a business perspective but also faces environmental challenges. The unsustainable nature of current transport combined with the limited capacity, have led to an interest for a new form of transport: the Cargoloop. The Cargoloop, is a cargo application of the hyperloop. The fundamental concept of this idea is that cargo will be transported through an autonomous ground-based system that consists of vehicles within a low-pressure tube, in which high speeds of around 1000 kilometres per hour can be achieved. By reducing the air resistance in the tube, little energy is necessary to put the pressurized vehicles in motion which in turn, results in an energy efficient form of transport. Moreover, it is hypothesized that the Cargoloop could act as a stepping stone towards transporting passengers via the hyperloop. However, so far, little research has been done into this topic.

In exploring the possibilities of this new form of transport, theoretical underpinning is necessary. It was found that the framework of Feitelson & Salomon (2004) is applicable for exploring the feasibility of the Cargoloop in its preliminary phase of development. Since so little research has been done into the Cargoloop, exploring any form of feasibility described in the framework of Feitelson & Salomon would contribute to today's body of knowledge. In practice, however, this would not be realistic due to the limited research time of this study. It was therefore decided to only focus on the economic feasibility since this form of feasibility has an impact on many factors while it is only influenced by one: the suggested innovation, which is already determined. Exploring the economic feasibility would therefore be a good 'starting point' for investigating the feasibility of the Cargoloop overall. This study therefore aims to answer the following research question:

Whether and to what extent is the Cargoloop economic viable on the trajectory between the airports of Cologne-Bonn and Paris-CDG?

Approach

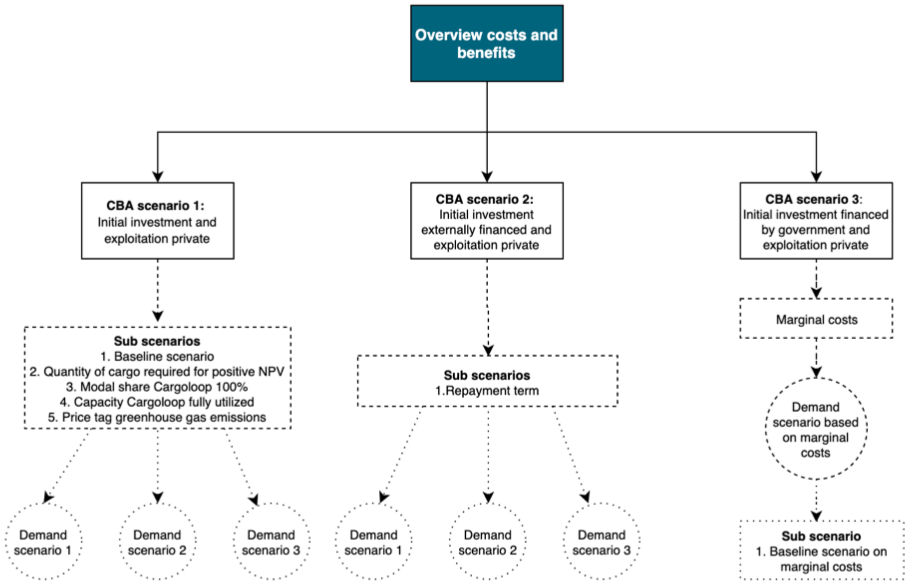
A widely used technique for estimating ex ante the viability of transport projects, which is also used in this study, is the cost-benefit analysis (CBA). The CBA provides an overview of the effects and risks in corresponding costs and benefits and helps in answering the question whether the costs of a project outweigh the benefits. In other words, to find out whether a project is economically viable. As aforementioned, before this CBA can be carried out, the Cargoloop must first be designed first. For the design of the Cargoloop, desk research, input from interviews with

transport scientists and in-house expertise were used. The current express freight market was investigated and on the basis of this analysis, transport scientists for the interviews were selected. In total, four scientists were interviewed. The experts shared their expertise and were introduced with the concept of the Cargoloop. In every interview, the scientists suggested how they would see the introduction of the Cargoloop in the current express freight market. Quotes from these interviews, combined with insights from analysis of the current express freight market, were used to establish the main lines of the design of the Cargoloop. In-house expertise was used to further elaborate the design technically. Ultimately, a potential route of the Cargoloop was estimated through an analysis of the Eurostat database in which the air cargo flows between airports were mapped.

In the second step, the CBA was conducted. In doing so, the potential route found during the development of the design of the Cargoloop was used. A step-by-step preparation approach for the CBA that was proposed in literature, has also been used as guide in this study. This approach consisted of the following steps: problem analysis, demand in reference scenario and policy alternative, determining the costs and the benefits, overview of the costs and benefits, analyse variants and risks and the results of the CBA.

The demand of the Cargoloop was calculated through a multinomial logit model. In doing so, three demand scenarios were created in which the tariffs of the Cargoloop differed: in the first demand scenario the tariff of the Cargoloop was similar to the tariff of road transport (0.11 €/tonne-km), in the second demand scenario the tariff of the Cargoloop was based on the average tariff of road and air transport (0.25 €/tonne-km) and in the third demand scenario was the tariff of the Cargoloop similar to the tariff of air transport (0.39 €/tonne-km).

The overview of the costs and the benefits was presented in three different CBA scenarios: 1) a first scenario in which the financing of the initial investment and exploitation of the project is private; 2) a second scenario in which the initial investment is financed externally but exploitation is private; 3) a third scenario in which the initial investment is financed by the government, but the exploitation is private. The earlier found demand scenarios were used to calculate the outcomes in the first two CBA scenarios. Moreover, within the first scenario, several sub scenarios were included to get an impression of the costs and the benefits under different circumstances. The approach of the latter scenario, however differed from the first two scenarios as not the previous estimated demand for the Cargoloop was used, but the modal share of the Cargoloop was estimated based on the marginal costs. An overview of the structure of the three CBA scenarios is shown below.



Results

Design Cargoloop

The process of designing the Cargoloop was divided into three steps: 1) main lines of the design; 2) technical specifications; 3) potential route of the Cargoloop. In the first step, it was found that the Cargoloop could serve as an alternative to the current aviation industry within Europe. In doing so, the Cargoloop would connect airports. It was found this route between two airports, however, is characterized by three important factors: 1) most of the air cargo is not flown between airports but is trucked within Europe; 2) in both modes the transport is mostly done via pallets and the most common used pallet is a EURO pallet; 3) both aviation and road transport deal with a consolidation constraint.

In the second step, the design of the Cargoloop was further elaborated technically. The determination of the tube diameter was crucial for the implementation costs, as the costs grow exponentially with the tube diameter. No information was available about the size of the air cargo transported and therefore the dimensions of the EURO pallet combined with the largest boxes offered by integrators were used as an input. Considering that, a Cargoloop with a 142 cm tube diameter was established. A diameter that is smaller than the required diameter for passenger transport and will therefore thus result in a cargo-only application. When further elaborating the design technically, the speed, frequency, payload, capacity and energy consumption were determined.

In the third step, the route between the airports of Cologne-Bonn and Paris-CDG was found as a potential route for the Cargoloop. The choice for this route was based on the requirement proposed by the experts to find the route that consists of the largest air cargo flow within Europe. When establishing the route from a geographical perspective, it was decided to choose the route that passes by Liège. This decision was made with respect to the possibility of including this airport into the future network of the Cargoloop, as the airport of Liège belongs to the top ten cargo airports of Europe. On the other hand, the challenge of choosing for this route is that it will almost completely pass through Belgium, while it is not certain whether Liège will be involved. In order to get an agreement to build this route through Belgium, the plausibility that Liège will be added to this route must be clearly mapped out. Otherwise, it will be likely that Belgium would not agree upon an infrastructure through their landscape, without being a part of it.

Economic feasibility
The different tariffs used in the three demand scenarios resulted in the following modal shares for the Cargoloop respectively: 77%, 20% and 2%. For the demand of the Cargoloop that was established on the marginal costs a modal share of 92% was found.

In neither of the three CBA scenarios the Cargoloop was found as economically viable. A fundamental factor for explaining why the Cargoloop is not economically viable is that when looking at the number of vehicles that would be annual operational on the route between the airports of Cologne-Bonn and Paris-CDG compared to the annual capacity of the Cargoloop, it could be found that only a small percentage of the capacity of the Cargoloop is utilized on this route. Substantial more cargo would need to be transported to make the Cargoloop economically feasible on this trajectory. This could be realized by obtaining a larger modal share or by expanding the network, so the overall cargo flow will become larger.

Regarding this first suggestion; a larger modal share for the Cargoloop, it was found in CBA scenario 1 that if the modal share of the Cargoloop would be 100% on the route between the airports of Cologne-Bonn and Paris-CDG, the Cargoloop would only be feasible from a tariff of 0.16 €/ton-km or higher. Meaning that the Cargoloop tariff would be higher than that of road transport, ensuring in turn that a 100% modal share of the Cargoloop would not be realistic in practice. When the modal share was calculated on the basis of marginal costs (CBA scenario 3), a modal share of 92% was found. A substantial increase compared to the previously estimated modal shares. This was expected as the marginal cost was substantially lower (0.049 €/tonne-km) than the tariffs used in this study for road and air transport. The marginal cost here was calculated at an annual capacity of 1%, which was the average capacity of the Cargoloop found in the earlier demand scenarios on the route between Cologne-Bonn and Paris-CDG. This low marginal cost with a relatively large modal share, however, also resulted in not being economically feasible. This was already expected as it was found that 0.16 €/tonne-km is necessary to obtain a positive net present value (NPV).

Regarding the second suggestion: increasing the overall cargo flow, an interesting finding was the quantity of cargo required to obtain a positive NPV in demand scenario 1 (modal share of 77%) of CBA scenario 1. It was found that approximately an overall additional amount 500,000 tonnes of cargo would be needed to make the Cargoloop economically viable between the airports of Cologne-Bonn and Paris-CDG. Considering the route between the airports of Cologne-Bonn and Paris-CDG, which passes by Liège because of the possibility of including this airport into the future network, obtaining a positive NPV in this scenario might be realistic when the airport of Liège would be included on this trajectory. In realizing this, the airport of Liège would need to meet the required additional amount of 500,000 tonnes. The latter could be considered as realistic as Liège belongs to the top ten largest cargo airports in Europe and knowing that approximately 900,000 tonnes of cargo are transported between the airports of Cologne-Bonn and Paris-CDG which also both belong to this top ten of largest cargo airports. However, no answer could be given on that question yet as more research is needed due to the lack of the available data regarding the transport of air cargo from and to the airport of Liège.

The above finding, in which it is described that adding Liège on the route between the airports of Cologne-Bonn and Paris-CDG could make the Cargooop economically viable, also stresses the importance of including Liège on this Cargoloop route. This would make it more likely that Belgium would agree upon a Cargoloop route through their country as it will be ensured that Liège will be included on the route.

Furthermore, when comparing CBA scenarios 1 and 2, it could be found that financing the initial investment externally, resulted in a higher NPV and benefit-cost ratio (BCR) compared to when the initial investment is privately financed. The longer the duration of the payback term for the external financing, the less negative NPV and BCR became.

Following on what is described above, it would be interesting to calculate the amount of cargo that is needed to obtain a positive NPV in demand scenario 1 of CBA scenario 2. As it was discussed in the previous paragraph, external financing of the initial investment resulted in a higher NPV and BCR compared to these values in CBA scenario 1.It would therefore be expected that the amount of cargo needed to obtain a positive NPV in demand scenario 1 of CBA scenario 2 would be lower than 500,000 tonnes resulting in an even higher probability that this scenario could be economic feasible when including Liège.

Recommendations for further research

The main recommendations for further research are the following: 1) Include Liège in the trajectory, obtain data about the cargo flows of Liège airport and investigate whether the amount of cargo that could be added would be enough to make the connection between the airports of Cologne-Bonn and Paris-CDG economically viable; 2) Verify the implementation and operational costs of the Cargoloop; 3) Investigate the vision of the industry on the design of the Cargoloop.

Contents

List of acronyms

ASC	Alternative specifc constant
BCR	Benefit cost ratio
CBA	Cost-benefit analysis
HSR	High-speed rail
IIA	Independence from Irrelevant Alternatives
IID	Independent and Identically Distributed
MNL	Multinomial logit
NEL	Northern European Natural Gas Line
NPV	Net present value
RMSE	Root Mean Squared Error
RUM	Random utility maximizaiton

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Introduction

1.1 Problem introduction

The world in which we live today is more connected than ever. Ordering a package online and having it delivered the next day is nowadays considered to be normal, while only five years ago, this was not so self-evident. This fast and on-time delivery of products is known as 'express delivery'. An increase in demand for this type of service delivery can be observed and it is expected that, combined with trends such a population growth, digitalization, globalization and demographic change, the express delivery market will grow strongly in the coming years (Vakulenko, Shams, Hellström, & Hjort, 2019).

This growth, however, is restricted by the shortage of express transportation capacity, which is mainly made possible via road and air (Bi, He, & Ato, 2019). A small selection of the bottlenecks, that are hampering the ability to accommodate the growing demand for express deliveries are: a) the limited capacity at airports which results in a decrease of cargo flights at large airports as passenger flights are often preferred (Liang, Tan, Whiteing, Nash, & Johnson, 2016); b) the congested roads which lead to unreliable delivery times (Kennisinstituut voor Mobiliteitsbeleid, 2018).

The transport sector, however, is not only subject to the increasing demand from a business perspective but also has to react to environmental challenges such as the need to reduce the greenhouse gases, noise pollution or congestion problems. This aspect is becoming an increasingly important topic, as environmental awareness grows on a global level (Meersman et al., 2016). Next to that, also quantitative targets are placed such as an initiative of the European Union to reduce the greenhouse gas emissions of the transport sector by 60% in 2050 compared to 1990. In overcoming these challenges, current transport modalities need to become more sustainable and new solutions for transport are needed. In the past years, several new transportation technologies have been developed with promising solutions for cargo transport. Examples of such technologies are cargo drones, the Cargo Sous Terrain concept or the hyperloop concept (Schodl et al., 2018).

This last concept, transporting cargo via the hyperloop, is explored in this study. The concept of the hyperloop was described in the Hyperloop Alpha paper by Space X in 2013. In this paper, this new transportation system was proposed as an alternative for the rail connection that was planned to be built between Los Angeles and San Francisco. The hyperloop is an autonomous ground-based system that consists of vehicles within a low-pressure tube, in which passengers and freight can be transported at high speeds of around 1000 kilometres per hour. By reducing the air resistance in the tube, a lot less energy is necessary to put the pressurized vehicles in motion. This in turn, results in speeds comparable to aviation while being more energy efficient than rail, making the hyperloop a sustainable mode of transport. If this new mode of transport could be realized, it would be a major innovative breakthrough for the transportation sector.

However, transitioning to a new and sustainable mode of transport is a challenge. Especially since transport innovations often have high infrastructure investment costs and the improvements in externalities in the long term are often not enough to outweigh the large short-term costs (Geels, 2012). But if the improvements in externalities are in line with the social, institutional and political rationale, these sectors could drive the investment of sustainable innovations (Saunila, Ukko, & Rantala, 2018).

1.1.1 Cargoloop as a solution for bottlenecks in express delivery market

A cargo application of the hyperloop, the Cargoloop, could theoretically offer a solution for the aforementioned bottlenecks in the express delivery market. As the main objective is that it will be a cargo solution, freight transport will have the priority over passenger transport. In addition, by moving freight transported via the road to the Cargoloop, the traffic density will decrease and with it also the congestion. Furthermore, when looking from an environmental perspective, the Cargoloop complies with the current wishes regarding the environmental awareness.

The introduction of a new mode of transport, however, offers many new possibilities. Everything can be rethought. From the size of the vehicles to the loading and unloading process of the cargo. In addition, the fact that it will be a cargo application and the transport of passengers need not be taken into account, also offers new insights such as for example the required diameter of the tube. However, if it wants to be a solution in practice, it will need to be explored how the Cargoloop can best tackle the current problems while being a competitive and interesting alternative to existing transport modes.

In this research, the concept of the Cargoloop is studied. The fact that it can be shaped from the very beginning, makes it even more interesting to investigate and design its possibilities and to find out whether this alternative could solve the current bottlenecks in the express delivery market.

1.2 Identification of knowledge gaps

The hyperloop technology is until today, in a preliminary phase of development. At first, the focus was mainly on the transport of passengers, as the benefits of this application are clear. However, when looking from a safety perspective and the procedures that will have to be passed to be able to prove that the hyperloop is a safe form of transport for passengers, it is a logical step to first prove the technology on cargo (Taylor et al. 2016). This shift of attention can also be observed through reports and news articles published by hyperloop companies. Based on public information, three hyperloop companies have already been started with searching the possibilities of the cargo application for the hyperloop. Interesting to note is that these companies all have a different vision of this application. A short summary of their ideas is given here:

Virgin Hyperloop One announced on 29 April 2018, the DP World Cargospeed: a global cargo transportation system operated by DP World and facilitated by Virgin Hyperloop One. Virgin Hyperloop One argues that the potential of the hyperloop for cargo can be found in the transport of palletized high-priority and on-demand goods in a mixed-used system, meaning that both passengers and cargo could be transported via this system. (Virgin Hyperloop One, 2018). Hyperloop Transportation Technologies on the other hand, focuses on the transport of sea containers. They established a joint venture with the port of Hamburg, in order to create a network in which cargo is quickly moved to ports further inland. In doing so, the amount of cargo that the port of Hamburg can handle could be increased (Venture Beat, 2018). Finally, also TransPod investigated the possibility of transporting cargo via the hyperloop. TransPod mentioned that a hyperloop route between Montreal, Ottawa and Toronto could led to travel time savings of 2,150, 000 hours every year. Besides that, TransPod argues that the benefit of a hyperloop cargo system lies in providing the connection between a regional hub and its local hub and offering the transport of both, containers and pallets.

This shift of attention, however, cannot yet be observed in the scientific literature. As a result, little research has been done into a cargo application of the hyperloop. Only two scientific studies were found in which the cargo application was explored. A brief summary of these studies is discussed here:

Recent research of Werner et al. (2016), explored the potential of shared value by transporting cargo via the hyperloop, using a 300 km network in Northern Germany as case study. Shared value is here defined as the value that is created for society by using the hyperloop. In doing so, they compared the transport of cargo via road to transport of cargo via the hyperloop. By replacing a large part of the cargo transported by truck to the hyperloop, individual and collective benefits are obtained. Monetizing these benefits resulted in the so-called shared value. According to Werner et al. transporting cargo via the hyperloop in Northern Germany would result in annual shared value of €660-€900 million.

A study of Taylor et al. (2016) explored the commercial feasibility of the hyperloop. In this research they examined various aspects of the hyperloop, such as the environmental impact, costs, safety issues and regulatory and policy issues. In doing so, they also paid attention to the commercial potential of cargo services. In their study Taylor et al. argued that air cargo would be the most interesting market for transporting cargo via the hyperloop. However, they also mentioned that it would be difficult to compete as aviation has several advantages such as its flexibility which enables this sector to switch between routes easily. The Hyperloop, on the other hand, is slightly less flexible as in that is less easy to stop operating routes or to add new routes.

In short, there is one paper that describes the potential shared value of transporting cargo via the hyperloop and one paper that describes the commercial potential of these cargo services. Furthermore, there are three ideas initiated by hyperloop companies regarding the possibilities of transporting cargo via the hyperloop. It can thus be concluded that so far, little research has been done into the transport of cargo via the hyperloop. What is currently lacking is therefore a lot of knowledge about this possible application. As for example, it is unknown how the design of the application should look like, how this technology could be integrated into the existing network of transport systems or what its effects on the existing market would be.

The aim of this study is to investigate the economic feasibility of the Cargoloop (the choice for this subject will be further explained in Chapter 2). However, before this can be done, this new form of transport has to be designed. The following knowledge gaps are therefore identified and selected in this study:

- Knowledge gap 1: Design of a Cargoloop
- Knowledge gap 2: Economic viability of the Cargoloop

As a result, this study consists of two parts: the first part investigates the design of the Cargoloop and proposes an initial route, the second part investigates the economic feasibility of the Cargoloop by means of a cost-benefit analysis.

1.3 Research objective and questions

The aim of this study is to fill the aforementioned identified knowledge gaps. Therefore, the knowledge gaps identified are translated in the following research questions:

1. *How should the design of a cargo-application of the Cargoloop look like considering the introduction of the Cargoloop in the current express freight market in Europe, and what could be an initial route?*
    - *1.1 How does the existing express freight transport market in Europe look like?*
    - *1.2 What type of market would be interesting for a cargo application of the hyperloop?*
    - *1.3 How should the design of a cargo application of the Cargoloop look?*
    - *1.4 What could be a potential route for the Cargoloop?*

2. *Whether and to what extent is the Cargoloop economic viable on the trajectory between the airports of Cologne-Bonn and Paris-CDG?*
    - *2.1 What are the effects of the Cargoloop on the current freight market?*

There are various approaches and indicators to assess the feasibility of an innovation. In order to determine the appropriate approach for the Cargoloop, theoretical underpinning is necessary. Therefore, it is first explored how the feasibility of a new transportation system can be examined. In doing so, it was found that the framework of Feitelson & Salomon will be used as theoretical framework within this study. Furthermore, it was determined that a cost-benefit analysis will be carried out to explore the economic feasibility. Therefore, a thorough understanding of both the supply and demand side of the current express freight sector in Europe is necessary. With this knowledge in mind and input from experts in the field, the potential design of the Cargoloop is determined. Followed by the impacts of the Cargoloop on the existing market. Finally, an insight can be obtained about the economically viability of the Cargoloop.

1.4 Report outline

The introduction and the problem have already been discussed and these have led to the main research question. In chapter 2, the theoretical framework which is used to explore the economic feasibility of the Cargoloop is described. As there are various approaches to do so, theoretical underpinning is necessary. Chapter 3 discusses the research approach and the research methods that are used within this study to answer the research questions. It is described how these methods are used for both, collecting and analyzing of the data. Chapter 4 provides background information of the hyperloop technology. This serves as a stepping stone for formulating the design of the Cargoloop later on. Chapter 5 describes the design of the Cargoloop. In chapter 6, the first steps as preparation for the CBA are carried out: determining the demand in the reference scenario and policy alternative. In chapter 7, the costs and the benefits of the project alternative are described. In chapter 8, an overview of the costs and the benefits in different scenarios is presented. In chapter 9, a sensitivity analysis and scenario analysis are carried out. Finally, in chapter 10 the results of the cost-benefit analysis are discussed. In chapter 11 the research questions proposed at the beginning of the study are answered and conclusions are drawn. Finally, chapter 12 ends the thesis by reflecting on the limitations of the study and providing recommendations for further research.

2

Theoretical framework

In exploring the possibilities of a new form of transport, theoretical underpinning is necessary. In this chapter, the choice for investigating the economic feasibility of the Cargoloop in this study is described. In doing so, it is first described that the Cargoloop could be identified as a sustainability transition. This is followed by a brief description of the four approaches that are considered being central in the theoretical framing of these type of transitions. These approaches are in turn linked to four frameworks to investigate their applicability for exploring sustainability transitions. From these frameworks, the political economy model of transport innovations by Feitelson and Salomon (2004) is chosen as theoretical framework. This framework is elaborated more in detail and from here, the choice was made to only focus on the economic feasibility of the Cargoloop.

2.1 Sustainability transitions

The implementation of an innovation does not only involve a technological change. Rather, it also ensures changes in elements such as regulation, infrastructure or user practices (Geels, 2002; Rip & Kemp, 1998). These interactions between actors, institutions and artifacts are conceptualized as 'socio-technical systems'. Sectors such as energy supply and transport can be seen as such socio-technical systems (Markard, Raven, & Truffer, 2012). These systems highlight that various elements are strongly interrelated and dependent on each other. This embeddedness, however, also results in difficulties for innovations to break through. Especially for more radical system transformations, since elements such as infrastructure are aligned to the existing technologies (Unruh, 2000; Freeman & Perez, 1988).

A socio-technical transition is a set of various processes leading to a fundamental shift in socio-technical systems. A transition consists of major changes along various elements such as: technological, institutional, economic, political, social and cultural. Therefore, also several actors are involved in a transition. During the process of a transition, new concepts of services, products and business models arise which may partly complement or substitute the existing ones. This in turn results in major changes in for example technological systems or political systems but also impacts the perception or user practice of a particular service. It takes typically 50 years or more for a transition to be unfolded (Markard et al., 2012).

A sustainability transition can be seen as a socio-technical transition towards a more sustainable system (Markard et al., 2012). A typical characteristic of such a transition compared to socio-technical transition, is that the government often plays an important role. This can be, for example, in the form of long-term goals, which steer the direction of the transition. In such a guided transition, it is expected that regulatory and institutional support from the government play an important role (Smith, Stirling, & Berkhout, 2005).

The implementation of the Cargoloop in the cargo transport market could be defined as a sustainability transition. The transition towards this new mode of transport would result in a fundamental sustainable shift in the existing transport system and will bring about significant changes in many areas. However, before it can be implemented, the impacts and changes that will occur due this transition should be investigated.

2.2 Approaches for theoretical framing of sustainability transitions

Socio-technical transitions and the development of sustainable technologies have received more and more attention over the past 10-15 years. This section describes the four approaches that are considered being central in studying the process of sustainability transitions: socio-technical regime, strategic niche management, transition management and technological innovations systems (Markard et al., 2012). The key concept of these approaches is briefly described in table 1 below.

Table 1 - Description of key concepts of central approaches for theoretical framing of sustainability transitions

	Key concept
Strategic niche management	Using niches, which are defined as protected spaces or specific markets, to develop (radical) innovations without being subject to the prevailing system.
Socio-technical regime	Technology is seamlessly intertwined with expectations and skills of technology users, institutions and other infrastructures.
Transition management	Combination of technological transition combined with complex systems theory and governance activities for (sustainable) development.
Technological innovations systems	Transitions in current innovation systems or the evolution of new innovation systems should co-evolve with technological change.

These approaches in turn, can be linked to frameworks, which will provide a more practical way of how these approaches can be applied to studying the process of sustainable transitions. In doing so, the following frameworks are linked at each approach and the purpose of each framework is described, shown in table 2.

	Framework	Author(s)	Product
Strategic niche management	Ten niche strategies	Ortt, Langley, & Pals (2013)	Ten niche strategies are proposed to commercialize new high-tech products
Socio-technical regime	Political economy model of transport innovations	Feitelson & Salomon (2004)	Framework is proposed to explore the feasibility of innovations by means of the interaction between various factors
Transition management	Transition management cycle	Loorbach (2010)	Provides a framework that can serve as the basis for management transitions in operational sense
Technological innovations systems	Functions of innovations systems	Hekkert, Suurs, Negro, Kuhlmann, & Smits (2007)	Proposes a framework that focuses on a number of processes that are important for well performing of innovation systems

Table 2 - Frameworks linked to the central approaches for theoretical framing of sustainability transitions

From table 2 it can be seen that the products of the frameworks are different. This also clearly shows that not every framework is applicable in every study but that it depends on the subject of the study. In the next section, it is discussed which framework is best applicable for exploring a new form of transport that is still in its preliminary development phase.

2.2.1 Applicability of frameworks to explore new form of transport

As aforementioned, the products of the frameworks differ. In determining which framework is suitable for exploring this new form of transport within this study, the framework must be in line with the phase in which the Cargoloop finds itself. The hyperloop technology is until today still in a preliminary phase of development. As far as the choice of the framework is concerned, this means that the framework should be focused on the feasibility of innovation itself and not, for example, already on the commercialisation of the technology, as the technology is not proven to be feasible yet.

With this in mind, it can be concluded that the frameworks of Ortt et al. (2013) and Loorbach (2010) are not suitable for this research. Both frameworks are focused on steps that take place further in the development phase of an innovation: the commercialization and implementation of an innovation.

When a more in-depth look is taken at the frameworks of Feitelson & Salomon (2004) and Hekkert et al. (2007), it can be found that both frameworks could be applicable for exploring the Cargoloop in this preliminary phase of development. The major distinction between both frameworks can be found in describing the key activities that are needed for well performing innovations (Hekkert et al.) and exploring the feasibility of the Cargoloop by means of the interaction between various factors (Feitelson & Salomon). The latter approach is chosen in this study because so little research has been done into the Cargoloop and it is therefore interesting, to obtain a first insight into whether the Cargoloop could be feasible at all. The framework of Feitelson & Salomon is more elaborated in the next section.

2.3 Political economy model for Cargoloop

The framework of Feitelson and Salomon (2004) is shown in figure 1. The political economy model of transport innovations shows that the adoption of innovations is related to the technical, economic, social and political feasibility of the innovation. It is thus insufficient if the innovation is only technical feasible, only supported from a political perspective or solely has a positive benefit-to-cost ratio. Rather, it is the combination of the several forms of feasibility that at least need to be met to ensure the adoption and diffusion of a transport innovation.

What also can be seen from figure 1, is that various factors influence different forms of feasibility and some forms of feasibility are influenced by the same factors. The political feasibility is even influenced by the social feasibility itself. This clearly shows the interaction of the different elements in the socio-technical systems and the strong interrelation and dependence of the different elements on each other.

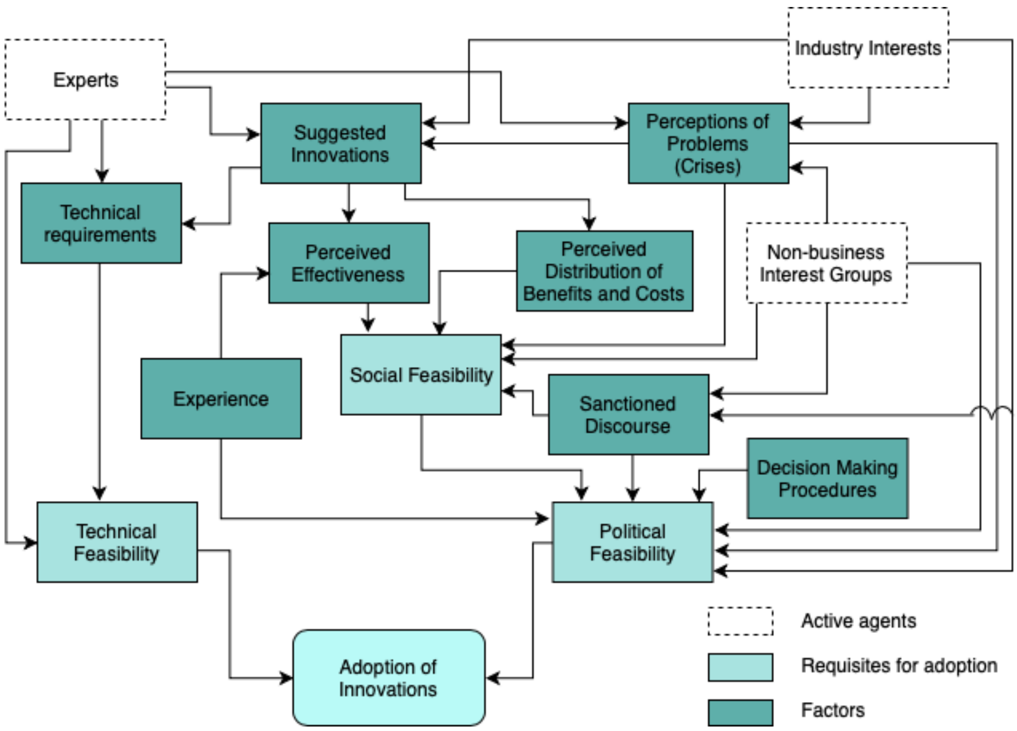


Figure 1 - A political economy model for explaining the adoption of transport innovations. Source: Feitelson & Salomon (2004).

2.3.1 Economic feasibility of the Cargoloop

As aforementioned, little research has been done into the Cargoloop. Exploring any form of feasibility described in the framework of Feitelson & Salomon would therefore contribute to today's body of knowledge. However, in practice, it would not be possible to explore them all within this study due to the limited amount of time. It was therefore decided to only focus on one of the feasibility forms. In doing so, the economic feasibility is chosen as topic of interest within this study because, as can be seen in figure 1, the economic feasibility (which is presented in this model as the 'perceived distribution of benefits and costs') has an impact on many factors but is only influenced by one: the suggested innovation. The suggested innovation is already determined and exploring the economic feasibility would therefore be a good 'starting point' to start from when investigating the feasibility of the Cargoloop.

As mentioned above, the economic feasibility in this model is explained by the 'perceived distribution of benefits and costs'. However, perceiving this distribution can only take place when the costs and the benefits have been determined in the first place. As this is not done yet, the area of interest of this research lies a step before this perceived distribution. When looking at the model, it can be seen that the 'perceived distribution of benefits and costs' is only affected by the suggested innovation. In order to place the area of interest of this study in the model of Feitelson & Salomon, an additional factor between the 'suggested innovation' and the 'perceived distribution of benefits and costs' is placed: the economic (impact) analysis. This results in the adjusted political economy model, shown in figure 2 below.

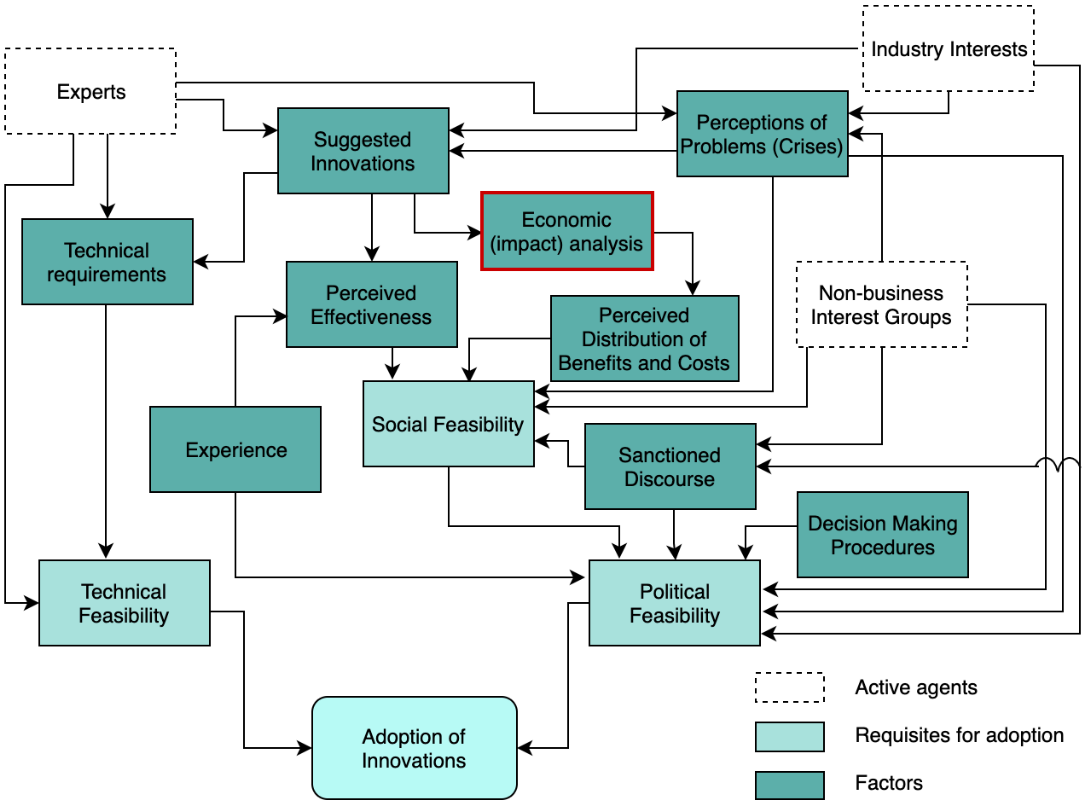


Figure 2 - Adjusted political economy model of Feitelson & Salomon (2004)

The added factor and area of interest within this study, economic (impact) analysis, is shown by the red outline in figure 2 above. The new factor combines two types of economic analysis: 1) the economic analysis of the innovation itself such as what investment is needed, what are the fixed and variables costs of the innovation; 2) the economic impact analysis in which the effect of the new innovation on the existing socio-technical systems is explored and translated into monetary values. By combing these two types of analysis, an overview of the costs and the benefits of the Cargoloop can be obtained.

3

Methodology

In this chapter, the research approach and methods that are used within this study to answer the research questions are discussed. First, the research approach is described. Followed by how the economic (impact) analysis of the Cargoloop will be explored; by means of a cost-benefit analysis (CBA). However, before this CBA can be carried out, the Cargoloop should be designed first. This study therefore consists of a two-step approach: the first step investigates the design of the Cargoloop and proposes an initial route, the second step investigates the economic feasibility by means of the CBA. A general overview of the structure of the report combined with the appropriate methodologies used per step and products of the methods in this study are shown in figure 3.

3.1 Research approach

The research approach used in this study is an exploratory research. This research approach is often used in areas where little or no previous research is been conducted. The intention of such a research approach is to explore the research topic and to provide insights, not conclusive answers, to the research questions (Saunders, Lewis, & Thornhill, 2009). In other words, exploratory research is an initial research, which will help in better understanding the research topic and will often provide the basis of more in-depth and conclusive research (Singh, 2007).

Exploratory research thus explores the research topic further. In doing so, use is made of desk research, in which available literature and/or data is analyzed. Additionally, exploratory research also relies on qualitative research approaches such as informal discussions and more formal approaches, such as interviews or case studies, with experts (Saunders, Lewis, & Thornhill, 2009; Singh, 2007). The use of qualitative information, however, ensures that the interpretation of this type of information is subject to bias. Therefore, the results from an exploratory research cannot be generalized and should be interpreted with discretion, as the results may or may not be representative for the topic studied (Singh, 2007).

The above-mentioned characteristics of the exploratory research approach suits this study, as little previous research has been done into economic feasibility of a cargo application of the hyperloop. By exploring the research topic, a first insight of the economic feasibility can be obtained, and knowledge is contributed to the existing literature.

3.2 Cost-benefit analysis

As described in Section 2.3.1, the focus within this study lies on the economic (impact) analysis of the Cargoloop. A widely used technique for carrying out an economic (impact) analysis, is the CBA (Hayashi & Morisugi, 2000). The CBA has become a standard tool for estimating ex ante the viability of transport projects. In doing so, it provides an overview of the effects and risks in corresponding costs and benefits. These costs and the benefits are quantified and valuated (in euros) as accurate as possible.

The CBA provides an insight into the social-welfare effects of the proposed new measure or alternative by deducting the costs from the benefits. This balance also includes the costs and benefits of those elements for which no direct 'market price' exist, such as nature, noise annoyance and landscape. By expressing these factors as well as possible in monetary terms, it is possible to compare the pros against the cons in an easily understandable manner. This helps in answering the question whether the costs of a measure outweigh the benefits and to find out whether a project is economically viable. Therefore, a CBA is often used as a supportive tool to support the decision-making process of the government in their decision whether to proceed or not with a new policy alternative. It should be noted however, that a CBA does not provide any quantitative insight into the degree to which various groups experience the costs or benefits of a measure but it can describe the distributed effects (CPB & PBL, 2013).

Sometimes there can be doubts about whether it is useful or even possible to carry out a CBA. These doubts about the usefulness for example, may arise if the economic feasibility is of little or no importance, such as with projects in which moral values or human dignity are central. In such projects, a CBA is not considered as an appropriated tool. In addition, the extent to which it is possible to determine and value (in monetary terms) the costs and benefits can also vary between CBAs. This depends on the availability of earlier impact studies. A possible lack of data, however, should not be seen as a shortcoming of the CBA but as a result of the fact that further research is needed before the CBA can be completed. The CBA can thus also serve as useful purpose in determining in a structured manner what is known and what is unknown about the proposed measure (CPB & PBL, 2013).

The guidance document 'Overview of the Effects of Infrastructure (OEI)' (Eijgenraam et al., 2000) is a widely used guideline as a preparation of a CBA carried out for transport infrastructure projects in the Netherlands. Since its publication in 2000, it has been further developed in many ways. The number of industries in which the guidelines can be applied to, has also been increased and is still expanding. To capture these changes in a new guidance as preparation for CBAs, the 'General Guidance for Cost-Benefit Analysis' is written in 2013 by CPB Netherlands Bureau for Economic Policy Analysis and PBL Netherlands Environmental Assessment Agency. The expertise and experience gained in the past years have been incorporated in this guideline and it is applicable for a wide range of fields. This general guidance has been used as a guideline for the CBA carried out in this study.

3.2.1 Preparation of a CBA

The preparation of a cost-benefit analysis can generally be broken down into a number of steps, from problem analysis and the establishment of the baseline alternative to the presentation of the results. This step-by-step approach is described in the 'General Guidance for Cost-Benefit Analysis' (CPB & PBL, 2013). In the figure below this step-by-step approach is shown, a more detailed version with explanation of the different steps is described in Appendix A:

1. Problem analysis
2. Establishment of reference scenario
3. Define policy alternatives
4. Determine effects and benefits
5. Determine costs
6. Analyse variants and risks
7. Overview of costs and benefits
8. Presentation of results

The order of the aforementioned steps is logical however, this order does not always have to be followed. It sometimes is necessary to go back and to review an earlier step, if conditions have changed or new insights have been obtained. But also the other way around can be possible, to first look ahead and then carry out a previous step (CPB & PBL, 2013).

3.2.2 Type of CBA

Although the technique is widely used for ex-ante evaluation, the type of parameters and the weighting of the parameters varies from country to country and from project to project (Hayashi & Morisugi, 2000). This is related to the type of CBA that is performed. In practice, a distinction is made between a comprehensive CBA and a indices CBA. In a full CBA, each research step is executed in detail and all effects are identified, determined and monetized as precise as possible. It therefore provides a detailed insight into the pros and cons of a measure. However, such a comprehensive CBA is not always needed, useful or possible in the stage of the decision-making process. In an indices CBA on the other hand, the identification and measurement of the effects is less precise as less information is available about the measure and its effects (CPB & PBL, 2013). This also means that more assumptions need to be made and the CBA consists of more uncertainties. This is the case within this study, as it is an explorative study and no CBA has been carried out on this subject before. The CBA carried out in this study can therefore be seen as an indices CBA.

3.2.3 Research methods per step

As aforementioned in Section 3.2.1, this study can be broken down into two parts: 1) the design of the Cargoloop and proposal of an initial route; 2) the economic feasibility of the Cargoloop by means of a CBA. This CBA can in turn be broken down into a number of steps. This step-by-step approach is also followed in this study. For the design of the Cargoloop and this step-by-step approach of the CBA, different research methods are used. In figure 3 below, the research methods used per step, the products that results from these methods and the place of the steps in this study are shown.

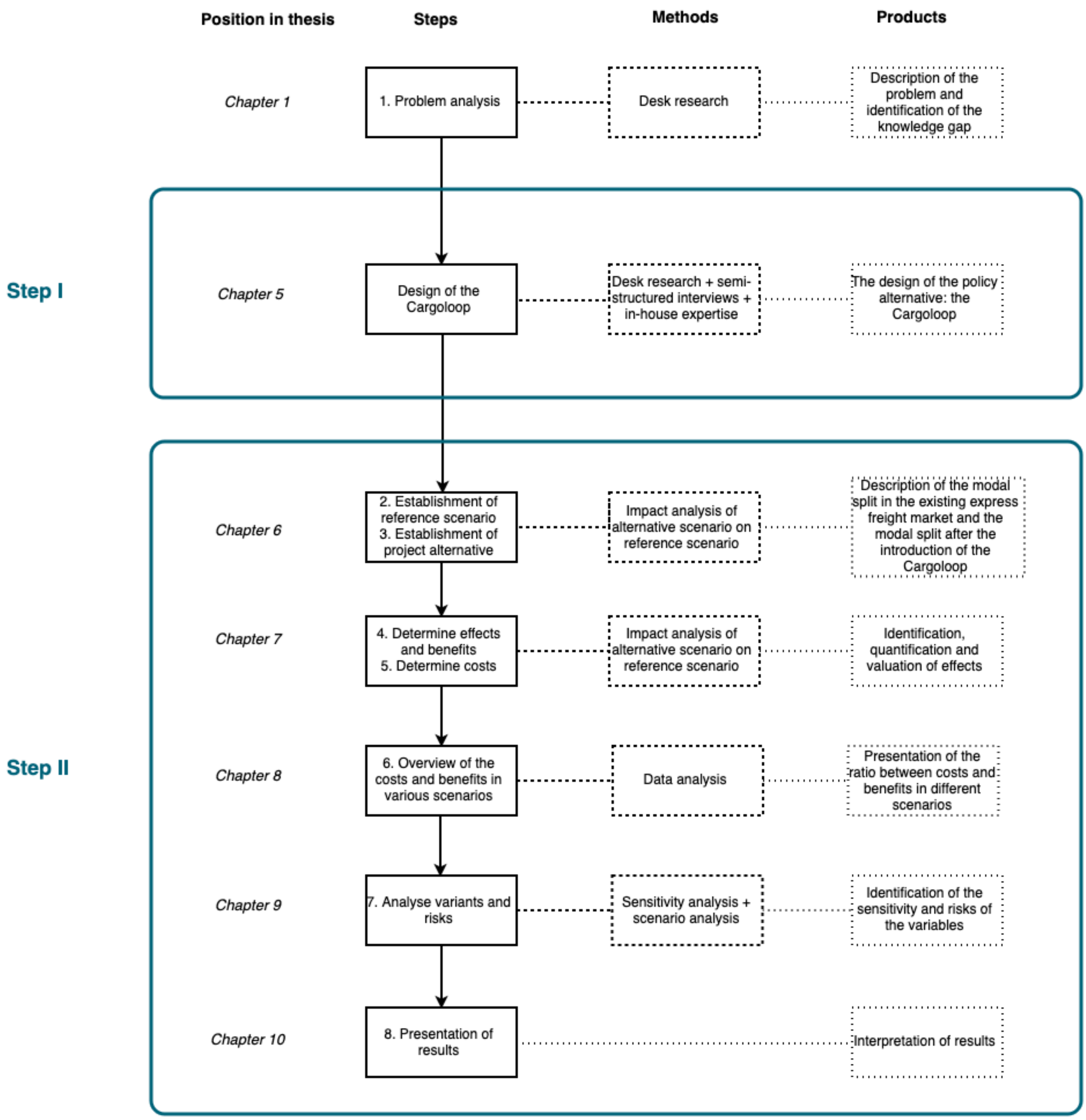


Figure 3 - Overview of the research methods used per step in the CBA approach, the products that result from these methods and the place of the steps in this study

In figure 3, it can be seen that step 6 and 7 from the step-by-step approach of the CBA have been reversed. The reason for this is that there is not one CBA scenario, but there are various. So first, an overview of the various CBA scenarios is shown, followed by a sensitivity analysis on one of these scenarios.

The following sections elaborate on each of the research methods mentioned in figure 3.

3.2.3.1 Desk research

The first method used to collect data is desk research. Desk research consists of the analysis and documentation of existing material produced by others (Singh, 2007). This existing material can consist of among others, scientific papers, studies or data.

Desk research is carried out to answer partly the first sub question. In answering this, it is necessary to know what type of transport modes execute express deliveries in Europe and what the characteristics of these transport modes are. Therefore, a general analysis of this industry in Europe is conducted to identify these transport modes and their characteristics. In doing so, the desk research focuses on transportation via road, via air and via high-speed rail. In this analysis, the topics as products, loading units, network, trends and drawbacks are discussed. Subsequently, all these topics are addresses for the three transport modes. This will result in a general overview of the current express freight transport in Europe, which is presented in appendix D.

3.2.3.2 Semi-structured interviews

There is a lack of publicly available data on freight transport, which is due to the commercial nature of this type of data (Tavaszzy & de Jong, 2014). Therefore, to verify but above all to complement the information found during desk research, semi-structured interviews were conducted. By choosing for semi-structured interviews, that are known for their informal approach, the interviewer does not follow a strict planned sequence of questions to be asked but room is created for input of the respondent. Semi-structured interviews are characterized by a set of pre-determined open questions to address the central topics of the research. The interviewee can determine which variables will be discussed more in-depth or to introduce new variables (Sekaran & Bougie, 2003).

The objectives of the interviews were: (1) to review, validate and complement the desk research, (2) to find arguments as a foundation for the market and design of the Cargoloop. The outcomes of the interviews are thus used to (partly) answer sub question 1 and 2. The pre-determined open questions and topics of the semi-structured interviews in this study were based on the information found and gathered through desk research. After the questions and topics were defined, interviewees were selected based on their expertise and experience in the topics under consideration. The type of questions asked, and topics discussed during the semi-structured interviews were varying according to the expertise of the experts.

Data collection semi-structured interview

In total four interviews were executed with experts in the fields of transporting express cargo. An overview of the profession of the experts is shown in table 3 below:

Table 3 - Profession of the interviewed transport experts

Transport expert	Profession
Transport expert A	Former director of knowlegde institute for mobility
Transport expert B	Researcher at an economic research institute
Transport expert C	Director at a research industry for air cargo
Transport expert D	Researcher at knowledge institute for mobility

These four interviews were sufficient to fill in the previously identified knowledge gaps during the analysis of the current express freight market. In addition, the transport experts initiated similar ideas for the implementation of the Cargoloop (this is discussed further in chapter 5) which provided enough information for the design of the Cargoloop.

It is important to mention that the experts spoken do not have an industrial background as this could have an influence on the design of the Cargoloop. The approach for these semi-structured interviews is discussed elaborately in appendix B, including an example of an introductory document that was used as preparation for the interviews, but a brief summary will be given here. As the interviewees had approved of sharing their knowledge on behalf of the study of the Cargoloop and a date for the interview was set, they received an introductory document. This introductory document consisted of a description of the goal of this study, background information regarding the concept of the hyperloop and open questions that give an indication of the direction of the interview. That this was only meant as an indication and that they were free to come up with their own input was also explicitly mentioned in the mail conversations on beforehand. When the interview had taken place, a point-by-point summary consisting of quotes used in the interviews was made. This was then sent back to the interviewee to confirm the correct interpretation of his/her words. After conformation of the right interpretation, often combined with any adjustments, the findings were used in this study.

Data analysis of semi-structured interviews

The data obtained in the semi-structured interviews is analyzed based on the point-by-point summaries consisting of quotes used by the transport experts. In doing so, first only the relevant quotes for this study were selected out of the summaries. These quotes were then sorted in Excel per mode of transport. So quotes that concerned air cargo were assigned to air transport and the same case goes for HSR and road transport. In addition, also a selection of general quotes regarding express freight was made and a selection of quotes concerning their vision for the application of the Cargoloop. This resulted in a list of relevant quotes in five different categories: air transport, high-speed rail, road transport, general express freight and the Cargoloop. The results of the selected quotes can be found in appendix C. Finally, the quotes are used within this study by referring to transport expert A, B, C and D.

Validity and reliability of the data analysis

To ensure the reliability and validity of the data that is collected and analysed from the semi-structured interviews, verification of the data is necessary. Verification is a process that consist of checking, confirming, making sure and being certain of the data. In qualitative research this refers to the procedures used during the research. In following this mechanism, data will be systematically checked, and errors can be identified and corrected before they are used in the research. Improving thus the reliability and validity of the data (Morse et al., 2002).

Verifications strategies can help to ensure both the reliability and validity of the data. In this study, using such a strategy is useful since the data obtained from the semi-structured interviews are undermined onto the interpretation of the answers. In verifying this data, the strategy of 'collecting and analysing data concurrently' is approached. In this verification strategy, there is an iterative interaction between the data and the analysis (Morse et al., 2002). By sending a summary with quotes back to the interviewee before using them in an analysis, there is an extra check to make sure that the findings are interpreted in the right manner. Which in turn, ensures the reliability and validity of the data.

3.2.3.3 In-house expertise: Hardt Hyperloop

To determine the design and characteristics of the Cargoloop, in-house expertise is obtained from Hardt Hyperloop. In doing so, they have supported with their knowledge to the design of the Cargoloop. In addition, Hardt also provided essential data regarding the performance characteristics of the Hyperloop which are essential for the identification and quantification of the cost and the benefits in the CBA. This support is necessary to answer sub question 3 and to partly answer sub question 4.

3.2.3.4 Impact analysis

The impact of the Cargoloop on the reference scenario is determined by a discrete choice model. The most important elements of this model are discussed here.

Discrete choice model

For analyzing the impact of the Cargoloop on the reference scenario, a discrete choice model is used. Discrete choice models can be used to analyze the choice behavior. In doing so, the models can explore to what extent variables influence the choice of a decision maker. Furthermore, these models also allow to predict the future choices of a person (Koppelman & Bhat, 2006). This is necessary in this study in order to be able to determine the impact (modal shift) of the Cargoloop on the existing express freight industry in Europe and thus to answer research question 4.

In this study, the assumption is made that the shipper of the goods is the decision-maker. This means that the shipper, often a firm that need to send goods to a receiving client and therefore has a demand for a transport service, makes the decision for the mode choice of the shipments that need to be transported. A key characteristic of the alternatives (transportation modes) used in this study is that these are all discrete alternatives. The model is therefore called a discrete choice model.

The utility function

The theoretical foundation of the discrete choice model is that of Random Utility Maximization (RUM). This means that the model assumes utility maximization as the decision rule (Train, 2009). The decision maker will thus choose the alternative for which his or her utility is maximized. Utility is defined as a 'constructed measure of well-being and has no natural level or scale' (Train, 2009, p11). In other words, only the difference in utility matters. The total utility of an alternative consists of the systematic utility and an error term. The systematic utility concerns everything that can be observed. The error term, on the other hand, consists of everything else such as unobserved factors.

This discrete choice model was originally developed to model passenger transport as utility maximization belongs to the economics of consumer behavior. The foundation of firms, on the other hand, is standard profit maximization. A basic equation of this RUM model is shown in the following equation:

$$U_{ik} = V_{ik} + \varepsilon_{ik}$$

In which:

U_{ik}: utility that decision-maker k obtains from choice alternative i
V_{ik}: observed utility component
ε_{ik}: unobserved utility component

However, the RUM model can also be applied to freight transport choices by making the total generalized costs, which is here the observed component of utility, negative and introduce one or more random costs components. The generalized transport costs are the direct monetary costs of transporting goods plus possible other characteristics of the transport modes expressed in monetary terms, such as reliability. Defining these generalized costs can thus vary from general to more detailed.

$$U_{ik} = -G_{ik} + e_{ik}$$

In which:

G_{ik}: observed component of generalized transport costs
e_{ik}: unobserved cost component

An increase in costs will thus lead to a decrease in utility. In these study also so-called, alternative-specific constants (ASC) are included in the model to improve the fit of the model. These ASCs shows the average effect on the utility of the factors that are not included in the model. Important to note is that there can only be N-1 ASCs in a model, with N defined as the number of available alternatives, which means that the ASC of one of the available modes is fixed to 1. This has to do with the fact that ultimately in comparing the different alternatives, only the differences in the observed utility matter (Koppelman & Bhat, 2006).

Choice probabilities

The utility of the alternatives is used to calculate the choice probabilities: the chance that the decision maker will choose an option from the set. In this study, the interest lies in the probability that the Cargoloop will be chosen over the other available transport modes. To be able to calculate these probabilities, an assumption has to be made about the probability distribution of the error terms. Different choice models assume different assumptions about the error term.

Estimated choice model

The estimated choice model that is used here is a Multinomial Logit Model (MNL). This leads to the following choice probabilities:

$$P_{ik} = \frac{e^{G_{ik}}}{\sum_i e^{G_{ik}}}$$

In which:

P_{ik}: probability that choice alternative *i* is chosen

This model is widely used due to its simplicity. The model is thus a probability model, it does not generate one choice, but it shows the probabilities for choosing each of the available transport modes. In order to deal with the error components, which represent variables that are not observed but do affect the utility, an assumption about the errors has to be made. By choosing for an MNL model as presented here, it is assumed that the error term is independently and identically distributed (i.i.d.) (Train, 2009). This assumption results also in the IIA-property (Independence from Irrelevant Alternatives), meaning that the relative popularity of A and B does not depend on C. However, this might not be the case in practice, as one mode of transport will compete more with another since they 'belong' to the same category for example public transport. This in turn, would mean that the errors terms are correlated and the applied MNL incorrectly exhibits the IIA property due to the incorrect assumption of the i.i.d. error components.

3.2.3.4 Sensitivity & scenario analysis

The future is uncertain which means that the ex-ante estimation of costs and benefits of a new alternative are subject to a certain degree of uncertainty. This in turn also causes that the outcome of the CBA is uncertain. Regarding this uncertainty, there can three types of uncertainty can be distinguished: 1) prediction uncertainty; 2) estimation uncertainty; 3) structural uncertainty (CPB & PBL, 2013). The first two types of uncertainty can be assessed by a sensitivity analysis and the latter by using scenarios of possible future trends.

3.2.3.5. Data analysis

The last method used is data analysis. This part consists of the presentation of the results of the cost-benefit analysis and the interpretation of the results. This is necessary to answer the last sub question. In doing so, there are different types of methods of analysis to determine the economic efficiency of a project. In this thesis use will be made of the Net Present Value (NPV) and the Benefit to Cost Ratio (BCR).

The NPV is used to compare the difference between the costs and the benefits of a project. It subtracts the total discounted costs of a project over its time span from the total discounted benefits of a project.

$$NPV = (B_i/(1+d)^r) - (C_i/(1+d)^r)$$

In which

B_i = Project benefits in years i, with i = 0 to n years

C_i = Project costs in years i, with i = 0 to n years

d = The discount rate

The outcome of NPV can be interpreted as follows, if the NPV is negative the project is not considered viable. If the NPV of a project is positive, the project is considered viable. The higher the NPV, the greater the benefits are of the project.

The BCR shows the ratio of the benefits versus the costs of a project. It sums the total discounted benefits of a project over its time horizon and divides it over the total discounted costs of the project. The BCR can be calculated as follows:

$$BCR = \frac{(B_i/(1+d)^r)}{(C_i/(1+d)^r)}$$

In which

B_i	= Project benefits in years i, with i = 0 to n years
C_i	= Project costs in years i, with i = 0 to n years
d	= The discount rate

The outcome of the BCR can be interpreted as follows:

- If the BCR < 1.0, the costs exceed the benefits. Based on this criterion, the project should not be proceeded and will not be viable.
- If the BCR = 1.0, the costs are equal to the benefits. Based on this criterion, the project could proceed but with little viability.
- If the BCR > 1.0, the benefits exceed the costs. Based on this criterion, the project should be proceeded and will be viable.

4

Hyperloop technology

The problem analysis has already been performed but before the next step in the step-by-step preparation approach for the CBA is carried out, the technology of the hyperloop is explained in this chapter. This serves as a stepping stone for formulating the project alternative later on. In describing this technology, first background information is provided on how the hyperloop came to the attention of the public. Followed by a description of the technology used for the hyperloop. Here the technical components of both, the vehicle and the infrastructure are described. Finally, the specifications of the Cargoloop regarding the technology used for this application are outlined.

4.1 The hyperloop

In 2013, SpaceX published the Hyperloop Alpha paper in which a fast and sustainable alternative for long distance travel was proposed: the hyperloop (SpaceX, 2013). In this paper, this new transportation system was proposed as an alternative for the high-speed rail connection that was planned to be built between Los Angeles and San Francisco. They argued that the hyperloop would make it possible to travel this distance in 35 minutes, more than two hours faster than the proposed high-speed rail. In addition, the intent of this paper was to create a new open source platform to further refine the hyperloop technology. Since then, several hyperloop initiatives have emerged and the concept of hyperloop is until today, still in its developing phase.

As already introduced in the first chapter, the hyperloop is a new form of transport for large volumes of passengers and cargo. It is a ground-based, high-speed (i.e. theoretical speed is 1000 km/h), sustainable transportation system. In this system, vehicles travel within a low-pressure tube. This means that the air resistance inside the tube is reduced. Without this air resistance, a lot less energy is necessary to keep the vehicles in motion. As a result, it is possible to travel quickly without using a lot of energy.

The tube acts a guideway and in doing so the vehicles are protected from the environment. In other words, the transport is not influenced by external factors such as weather conditions. On the other hand, the combination using tubes, having a low-pressure environment and using magnetic levitation ensures that there is no noise nuisance for the environment.

4.2 The technology

In figure 4 the breakdown of the hyperloop system is shown. The hyperloop system can basically be separated into two parts: the vehicle itself and the infrastructure. In this section, both parts will be discussed more in detail.

Starting with the vehicles which are equipped with both electric and permanent magnets. These magnets make sure that the vehicle is lifted and stabilized inside the tube. By means of a linear electric engine, the lifted vehicles are able to move through the tube. This electric engine, however is unlike with an electric car, embedded in the track. This electric engine in combination with the magnetic levitation system equipped in the vehicles, allows the vehicle to move through the tube by a magnetic wave. In doing so, the vehicles travel independently and autonomously through the tube. This can either be separately or in short trains.

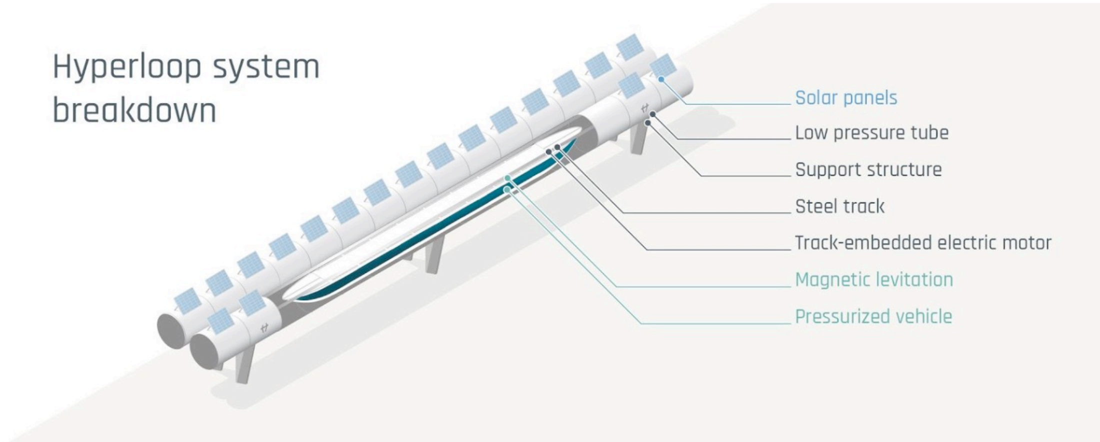


Figure 4 - Hyperloop system breakdown

When looking at the infrastructure inside the tube, the infrastructure consists of tracks that are made of steel. As a result, this reduces the energy needed for levitating even more. As aforementioned the electric motor is embedded in these tracks by means of cables in the track. When looking at the outside of the infrastructure, it can be seen in figure 4, that there are two tubes next to each other. This will always be the case when transport in both directions is offered, as each tube only provides the transport in one direction. The tubes can be built either above ground or underground, depending on the characteristics of the terrain on which the route is build. In building this system, mainly the existing infrastructure of existing transport modes such as road and rail will be followed.

The use of high-speed lane switches allows vehicles to travel directly to their destination, so no transfers or intermediate stops in between are required. This also means, however, that vehicles travelling to different locations make use of the same infrastructure. The concept is just like a high-way, vehicles can enter and exit the hyperloop network at any point along the route, as shown in figure 5. When arriving at the stations, the (un)boarding takes places through a sealed door (airlock), which maintains the low-pressure environment in the tube.

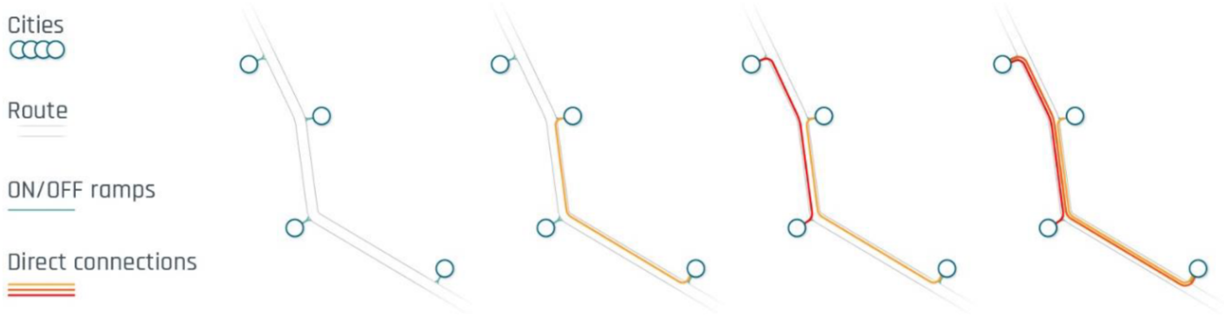


Figure 5 - Schematic overview showing how a hyperloop can offer direct connections without intermediate stops.

4.3 Cargoloop: the cargo-only application of hyperloop technologies

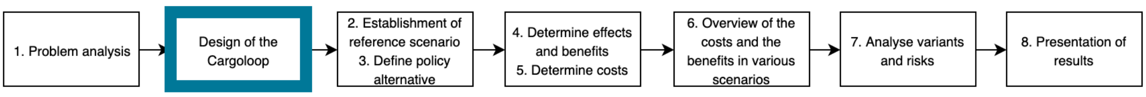
When talking about a cargo-only application of the hyperloop, an infrastructure is meant that is dedicated to the transport of cargo via the hyperloop. In other words, no passengers will be transported through this tube and cargo operators will thus not have to compete with passenger demand. The technology used in this application is, however, the same as described for the Hyperloop, only the application is different.

The fact that the infrastructure is dedicated to cargo also means that certain characteristics of the hyperloop could be filled in differently, such as the diameter of the tube or the design of the vehicles. The diameter of the tube could be for example tailored on the type of the cargo transported and the design of the vehicle could be adapted to the load devices used to transport the cargo.

5

Design of the Cargoloop

As already mentioned in the introduction, little research has been done into the Cargoloop. Before the CBA can be carried out, this new form of transport has to be designed. In this chapter, the process towards establishing the design of the Cargoloop is described. Input from experts in the fields and the insights obtained from the analysis of the express freight transport market in Europe (described in Appendix D) are used to design the main lines of the Cargoloop. In addition, in-house expertise is used to further elaborate the design technically. Ultimately, an initial route of the Cargoloop is estimated through an analysis of the Eurostat database in which the air cargo flows between airports were mapped.



5.1 Main lines of design Cargoloop

To obtain the main lines of the design of the Cargoloop, input form experts in the fields and insights obtained from the analysis of the express freight transport market are used. In this section first, the input from the transport experts is discussed (Section 5.1.1). Followed by the insights from the analysis (Section 5.1.2). Finally, the main lines of the design of the Cargoloop are described (Section 5.1.3).

5.1.1 Input from transport experts

During the interviews with the transport experts, the concept of the Cargoloop was discussed and they shared their vision about the integration of this mode in the existing transportation system. In doing so, it was said that in order to create a competitive form of transport, the Cargoloop has to perform well on all the following aspects: costs, capacity, reliability, offer a more reliable mode of transport to their customers and solving the negative effects of the aviation by for example closing the airports (Transport expert C).

The striking thing that emerged from these conversations was that it was according to transport expert D not the speed that would be the most interesting selling point of the Cargoloop, but rather the costs, reliability and predictability would be (Transport expert D). From these characteristics, reliability would be the most important as that goods need to be there on time, not too early and not too late. However, transport expert C argued that it is precisely the time savings that should be significant to ensure that the current transport market would get out of their fixed pattern. When it was discussed where the Cargoloop would fit best in today's transport market or where it would be of highest added value, it was mainly suggested that the Cargoloop could serve as a good alternative to the current aviation industry within Europe (Transport expert A, B, C and D). In doing so, several network positions of the Cargoloop were initiated which will be discussed briefly per transport expert here.

According to transport expert A the Cargoloop network should at least be connected to an airport. Moreover, the expert said that there should be looked at a connection between natural consolidation nodes when implementing the Cargoloop. In doing so, a consolidation point in the North of Europe and another one in the South of Europe were discussed as possibilities due to the amount of congestion that is on this route. Also, a connection between the hubs of the integrators DHL, UPS and FedEx was considered interesting. In addition, also the connection between München and Frankfurt was mentioned. As these are both hubs of Lufthansa, a large cargo carrier, and will therefor result in a consolidated flow.

Transport expert B indicated that it would just be interesting to connect the integrators hubs to the other airports. In doing so, routes as Amsterdam-Frankfurt-Paris, Amsterdam-Paris-Madrid and Amsterdam–Luxembourg–Milan were mentioned as interesting. Besides these initiatives, also the Eurotunnel, the tunnel between France and England was mentioned as a good option because of the large amount of cargo that is transported back and forth through this tunnel which results in turn into a lot of congestion in both ways.

According to transport expert C, the most important thing to ensure when building the Cargoloop was that a neutral infrastructure would be needed. In view of the high investment, it was best to offer a neutral infrastructure such as airports, road and rail. In being more concrete, the expert argued that the Cargoloop would be interesting on the 'big' routes, routes that feed the cargo hubs. This led to the following suggestion, a connection between the four main airports in Europe: Amsterdam-Paris-London-Frankfurt and the integrator hubs: Brussels-Cologne-Liège-Leipzig.

Transport expert D argued that it might be interesting to follow the structure of the distribution centres in the Netherlands. As there are several logistics hotspots, which are quite good distributed in the Netherlands, this might be an interesting case. The expert also mentioned that for example, as the idea proposed by Hyperloop Transportation Technologies, to transport maritime containers would not be an interesting option for the port of Rotterdam. Since there is still a lot of transport capacity left that can be used in a more efficient way.

5.1.2 Insights from analysis of reference scenario

In appendix D, a general analysis of the existing express freight transport in Europe is described. In doing so, the characteristics of aviation, HSR and road transport were described on the basis of different topics such as type of products, loading units and the type of network. In doing so, several differences have been observed between the modalities that offer express transport.

Input from the experts revealed that the Cargoloop would be most interesting between two airports. The general reference scenario showed that most of the air cargo is not flown between airports but is trucked within Europe. It was found that trucking mainly takes place on a distance between 200 and 600 kilometres from an airport. A potential link between airports concerns thus not only the transport of cargo by air but also by road.

Therefore, in this section, insights obtained from this analysis regarding the transport of via road and via air are described. In describing this, the structure of the analysis of the general reference scenario has been retained. In other words, the insight will be discussed based on the earlier topics: products, transportation modes, network, loading units, trends and drawbacks.

Products

From the analysis of the products transported it appeared that the type of products transported via air and via road have a lot of similarities. Both, the air and road industry, transport products such as food, agricultural products, chemicals and mail/parcels. However, road transport on the other hand also transports bulk, while air transport is really only focused on high-quality goods.

Type of transport modes

The type of air cargo that is transport determines what kind of an aircraft is used for the transport. 5-15% of the global air cargo has to be shipped by all-cargo aircraft exclusively, due to their dimensions or hazardous characteristics. Within Europe, transport in the belly of aircraft does not occur, as the bellies are too small for the amount of cargo transported and it causes delays on the passenger flights. In road transport the truck can be adjusted to the amount and size of the cargo transported, however, for express freight most of the time standard trailers are used.

Network

The network of the transports modes differs. The airports on which airlines fly, depend on the type of airline. It appeared that most of the air cargo is not flown but trucked between airports in Europe. Large intercontinental hubs are frequently supplied by freight transport via trucking in order to get the aircraft full. An interesting contrast with integrators, who do fly within Europe. Road transport on the other hand, is characterized through is flexibility. Trucks are able to drive anywhere and are not dependent on specific infrastructure such as airports or railway stations. This also enables trucks to deliver door-to-door service.

Loading units

When looking at the loading units used to transport the goods, it was found that both air and road transport make use of EURO pallets. This was shown in an analysis of a dataset of a European airline in 2014. Moreover, the standard trucks used for express freight are in such a way designed that they can carry precisely 33 EURO pallets. The goods transported in these trucks can either be loose or palletized.

Trends

The trends found during the analysis regarding aviation mainly showed that due to the growth, which pattern is not the same for all airlines, some routes have to deal with strong imbalance between inbound and outbound flows. This results in capacity issues, especially for cargo-only airlines. Besides that, due the to the increasing shortage of capacity at large international hubs, the freight operations are transferred to regional airports which is possible due to the footloose character of freight. Finally, also a consolidation trend was found. To achieve the benefits of scale, freight forwarders strive to consolidate as much of the air cargo as possible into a single hub. Finally, several trends were found in road transport that al resulted in an increasing demand for truck transport. However, also a counter-movement is observed in which the trucks are prevented in the cities and are replaced by smaller, more sustainable vehicles.

Drawbacks

The drawbacks found in the transport of the transport modes are different. For example, both air and road transport have a negative impact on the environment and have to deal both with the limited capacity of the infrastructure. In doing so, aviation carries out night flights and road transport has to deal with congestion. Another drawback of aviation is the consolidation trend mentioned earlier which results in long standing still of trucks and the reservation time of twelve months in advance for air cargo transport. Due to this long reservation time, there is often more space booked for air cargo than there are actually which results in capacity problems.

5.1.3 Main lines of design Cargoloop

Based on the input of the transport experts, it was found that a connection between two airports would fit best in today's transport market. However, to the question between what type of airports this connection should be or what first connection would be the most interesting, different initiatives were suggested. What did emerge from these initiatives was that it is most relevant to look for the largest air cargo flows due to the high investment costs of the Cargoloop. However, in order to determine this, data is necessary. In chapter 7, based on data, an initial route will be determined for the Cargoloop where the cargo flows are the largest. For now, it is just assumed that the Cargoloop will fit best in connecting airports.

When looking at how a link between two airports is typified, three important characteristics on this flow between airports in Europe were found. First of all, it appeared that most of the air cargo is not flown between airports but is trucked within Europe. Airports are frequently supplied by freight transported via road. It was found that trucking mainly takes place on a distance between 200 and 600 kilometres from an airport. A potential link between airports concerns thus not only the transport of cargo by air but also by road.

Second, the cargo transported by aviation and road transport is characterized by their use of loading unit. First of all, both, aviation and road transport use the EURO pallet as loading unit. If the Cargoloop would be integrated on this route it should be able to handle the pallets, to not current adversely affect the logistics process. However, one could also assume that a new modality will also result in a new design of unit load devices, similar as for example within the aviation industry. However, designing such a new load unit, would be a completely new study on its own. Besides that, if by using the Cargoloop, the goods would have to be transferred to another loading unit, it would now result in extra time and costs and would make the Cargoloop less attractive as transport mode. Therefore, the current loading units used now are used as an input parameter for the Cargoloop.

Third, when looking at the trends and drawbacks found regarding the transport via air and road and those that are relevant for the specification of the Cargoloop, the consolidation trend/problem should be taking into account for the design of the Cargoloop. Due to the consolidation trend, trucks are long standing still at airports. If the Cargoloop vehicles would become smaller, it would earlier be profitable to transport the goods resulting in less waiting time of the trucks. It is therefore interesting to take trend/problem into account.

5.2 Technical design of Cargoloop

In the previous chapter, the main lines of the design of the Cargoloop are defined. In defining this, it was found that the Cargoloop would fit best in a connection between airports. This route between two airports is characterized by three important factors: 1) most of the air cargo is not flown between airports but is trucked within Europe; 2) in both modes the transport is mostly done via pallets and the most common used pallet is a EURO pallet; 3) both modes have to deal with a consolidation constraint. In this section, in-house expertise is used to further elaborate the design technically. In doing so, the following key performance indicators are used to describe the technical specifications of the Cargoloop. These key performance indicators are based on the indicators found in the study of Werner et al. (2016). In doing so, also the diameter and the capacity of the Cargoloop are added since these are important explanatory variables in the CBA. The technical specifications of the Cargoloop will therefore be described based on the following factors:

- Diameter
- Speed
- Frequency
- Payload
- Capacity
- Energy consumption

The factors will be described more in detail in the coming sections. First, the diameter of the Cargoloop is discussed (Section 5.2.2) and as last, the energy consumption of the vehicle (Section 5.2.7)

5.2.1 Diameter

In the section before, the niche of the Cargoloop is defined. The choice is made to transport goods by making use of pallets as loading units. The type of pallets considered for this transport are the EPAL EURO pallets. This is the standard type of pallet within Europe and the most widely used pallet in the world. These dimensions and specifications of this EURO pallet are specified by the European Pallet Associations and are defined in ISO standards. Below in table 4, an overview of these specifications can be found:

Table 4 - Specifications of EPAL EURO pallets as defined by EPAL

Specifications EPAL EURO pallet	
Length:	1200 mm
Width:	800 mm
Height:	144 mm
Weight:	25 kg
Safe working load:	1500 kg

The diameter of the tube must thus be matched to the dimensions of the EPAL EURO pallet in such a way that the EPAL EURO pallet fits in the tube. For determining the diameter of the tube, it does not matter how long the pallet is, as this is only interesting for the vehicle design. In defining the diameter, the width and the height are important. This means that the diameter of the Cargoloop should at least be larger than 800 mm.

Determining the size of the tube, however, is a trade-off between, among others, the height of the goods that can be transported on the pallets and the implementation costs that are related to the diameter. If the height of the goods transported on the pallets becomes higher, the diameter also increases. In other words, it is also a trade-off between the part of the market that you can serve with your vehicle by offering a transport to a certain height and the higher investment costs associated with a larger diameter as the costs of the tube increase almost exponentially with the diameter.

In making this trade-off between the market you can serve with a larger vehicle and the increasing investment costs, the dimensions of the largest boxes offered by integrators and dimensions of pallets transport via air and road are used as an input. This led to the following preliminary design, a Cargoloop with a 142 cm tube diameter. This 142 cm tube diameter allows the transport of half-height Europallets, which have a dimension of 120x80x80 cm. See the Figure 6 below, for a schematic overview of the 142 cm Cargoloop.

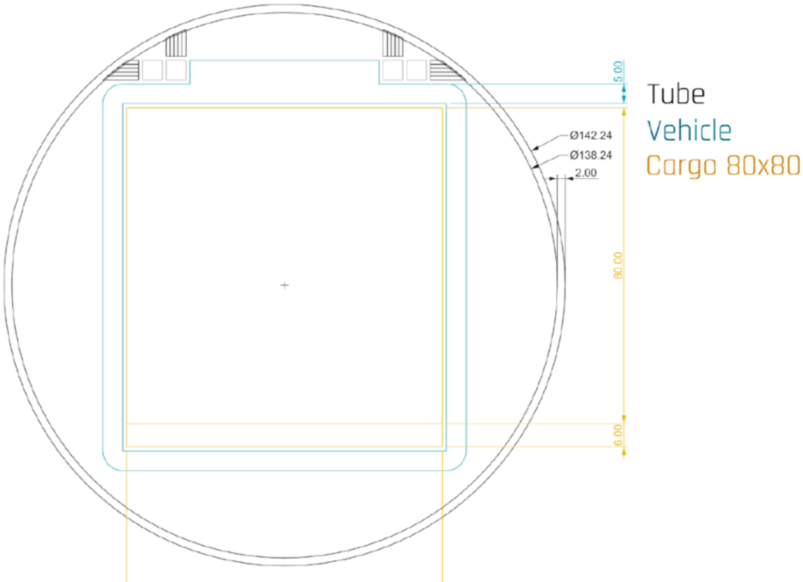


Figure 6- Design of the 142 cm Cargoloop

5.2.2 Speed

As already mentioned in chapter 4, the theoretical speed of the Cargoloop can be approximately 1000 km/h. However, in practice, the infrastructure will not be completely straight ahead but will also contain bends. These bends will not be sharp and will contain a very large radius, but due to this it is likely that the theoretical speed will not be the cruise speed in practice. Therefore, the assumption is made by Hardt that the average cruise speed of the Cargoloop will be approximately 700 km/h.

5.2.3 Frequency

The Alpha Paper indicated that during peak hours in each lane every 30 seconds a vehicle could depart. On average, however, every 2 minutes a vehicle per lane would depart. Hardt Hyperloop, on the other hand, assumes that every 10 seconds a vehicle can depart from a lane in a station. This results in 6 departures per minute. This assumption is also used for the technical specifications of the Cargoloop. In other words, is assumed that a Cargoloop vehicle can depart in each lane every 10 seconds.

5.2.4 Payload

In determining the payload of the vehicle, the first assumption that is made is that the payload of the Cargoloop vehicle will not be restricted by the capacity of the magnets. In other words, the magnets are able to lift extremely large weights. In practice, however, this may not be the case.

In exploring the payload of the vehicle, the length of the vehicle will also be determined. Moreover, this is also a trade-off between the costs per vehicle-km and choosing the most efficient size so that as many 'full' vehicles as possible will be transported. It is therefore also likely that there will be different vehicles sizes. However, no detailed investigation has yet been carried out into this and an assumption has to be made to able to determine the effects in the CBA.

The study of Werner et al. (2016) assumed an average payload of 12 tons per vehicle. The vehicle could then transport 8 pallets, which would result in a vehicle length of almost 10 meters. Based on this reasoning combined with some first insights from Hardt about the energy usage compared to different vehicle lengths and the consolidation problem discussed earlier in aviation and road transport, the choice is made to go for a vehicle that will be slightly longer than 7.2 meters. The vehicle would then thus be able to transport 6 EPAL Euro Pallets, which would result of a payload of the Cargoloop vehicle of 6 x 1,500 kg = 9,000 kg or 9 tons.

5.2.5 Capacity

The capacity of the Cargoloop is determined based on the frequency, operational hours and operational days in a year. The frequency was already determined in the section before, which is about 6 departure per minute. For determining the operational hours and operational days in a year, assumptions have been made.

First, it assumed that the Cargoloop will operate 365 days a year, as it is an autonomous vehicle. Therefore, the operational days are not restricted to public holidays. In making this assumption, the assumption is also made that the other procedures such as for example loading and unloading of the vehicle will also be autonomous in the future.

The second assumption made is the number of operational hours a day. It is assumed that the vehicle will be operational 20 hours per day. In other words, 4 hours per day are calculated for the maintenance of the vehicle. This in turn, is also based on the assumption that the maintenance of the vehicles will be limited due to the closed environment in which they are operational.

Combining the frequency, operating hours and operational days would result in the following annual capacity of the Cargoloop, as shown in table 5:

Table 5 - Annual capacity of the Cargoloop

Capacity of the Cargoloop	
Departures per minute	6
Operational days in a year	365
Operating hours	20
Annual capacity in vehicles	2.628.000
Payload per vehicle	9
Annual capacity in tons	23.652.000

Based on the assumptions made earlier, an annual capacity of 2.628.000 vehicles could be achieved on one route. This is equivalent to an annual capacity of 23.562.000 tons. In making this comparison, it is assumed that the load factor of the Cargoloop will be 100%. In practice, however, this will likely not be the case.

The load factor for air cargo transport is estimated to be 49.3% and that for road transport is 45%. As the Cargoloop vehicles are smaller compared to the trucks and the cargo aircraft, is expected that it will be easier to have enough consolidated cargo which allows for more full vehicles to be transported and for empty trips to be avoided as much as possible. In doing so, the assumption is made that the load factor of the Cargoloop will be 80%.

5.2.6 Energy consumption

The main energy components that use energy during the operation are the motors for the propulsion of the vehicle and the pumps to maintain the low-pressure environment. The energy usage is influenced by parameters such as frontal area and vehicle weight. Hardt Hyperloop estimated that the energy usage for a vehicle and the pump in a 142cm tube is 454Wh/vehicle-km.

No other research was found in which the energy usage of 142 cm diameter tube was calculated. The value estimated by Hardt Hyperloop could therefore not be verified. The use of this value by estimating the operational cost must be interpreted carefully.

5.3 Potential route of Cargoloop: Cologne and Paris

In the previous chapter, the main lines and the technical design of the Cargoloop are defined. In defining this, it was found that the Cargoloop would fit best in a connection between airports. However, to the question between what type of airports this connection should be or what first connection would be the most interesting, different initiatives were suggested by the experts in the field. It did emerge from these initiatives that it is most relevant to look for the largest air cargo flows. In this section, first the initial route is determined (Section 5.3.1), followed by the geography of this route (Section 5.3.2).

5.3.1 Route of project alternative

So far, it appeared that connecting airports would be the most interesting for a cargo application of the hyperloop. Furthermore, it emerged from conversations with experts in the field that it is most relevant to look for the largest air cargo flows due to the high investment costs of the Cargoloop. Therefore, the choice of the route of the project alternative is based on a demand analysis of the air cargo transport market in Europe. For this analysis, data from Eurostat was used. The detailed approach of this analysis is written down in appendix E, however a brief summary will be given here:

First, the ten largest cargo airports in Europe were identified using the database of Eurostat. These airports have been used as origins and destinations for finding data about the cargo flows transported between them. To obtain the amount of cargo transported between the airports, the database of Eurostat was used again. This data about the specific flows was then translated into an origin-destination matrix. This origin-destination matrix is shown in table 6. From this table, it can be seen that most of the air cargo is transported between Cologne-Bonn and Paris-Charles de Gaulle (CDG) in 2017. Important to note is that 2017 is taken as a reference year, as the dataset of 2018 was less complete compared to the dataset of 2017.

In rationale with the substantiation of the experts in the fields - that the Cargoloop would be most interesting on the largest air cargo flows – the connection between the airports of Cologne-Bonn and Paris-CDG is chosen to explore the economic feasibility of the Cargoloop on in this CBA.

Table 6 - Origin-destination matrix with amount of tonnes air cargo loaded and unloaded within Europe in 2017. Zeroes mean that no data was available. Source: Eurostat

Origin/Destination	Frankfurt	Paris-CDG	London-Heathrow	Amsterdam-Schiphol	Leipzig-Halle	Luxembourg	Cologne-Bonn	Liège	Milano-Malpensa	Brussels
Frankfurt	-	13.676	9.828	0	13.778	0	0	0	2.124	0
Paris–CDG	3.829,5	-	3.594,5	3.665	15.487,5	0	34.899	3.441	21.234	2.942
London-Heathrow	4.999	3.814	-	3.270,5	9.848,5	0	0	0	1.628	5.230
Amsterdam-Schiphol	0	6.666,5	4.411	-	15.335	0	0	0	5.678,5	0
Leipzig-Halle	16.085	16.834	2.793	11.151	-	0	10.946	0	7.181	27.802
Luxembourg	0	0	0	0	0	-	0	0	14.138	0
Cologne-Bonn	0	46.550	0	0	9.495,5	0	-	0	0	0
Liège	0	704	0	0	0	0	0	-	0	0
Milano-Malpensa	2.598,5	24.059	8.440	209	10.250,5	21350	0	0	-	0
Brussels	0	375,5	3.305	0	22.823,5	0	0	0	0	-

The table, however, also shows that a lot of data is missing. This means that it could be the case that there are even larger transport flows between airports in Europe.

5.3.2 Geography of route of policy alternative

The Cargoloop route between the airports of Cologne-Bonn and Paris-CDG will mainly follow the existing road's infrastructure as described in section 4.2. There are several ways which can be followed between the airports of Cologne-Bonn and Paris-CDG. However, the route for the Cargoloop chosen in this study is as follows, shown in figure 7 below.

The distance of the route showed in figure 7 is 475 km. This route is chosen because as it can be seen in the above figure, the Cargoloop route will lead traffic right by several cities including Liège, which also belongs to the top ten cargo airports in Europe. With respect to the potential future of the Cargoloop, this makes sense, as Liège could then be potentially included in the Cargoloop network.

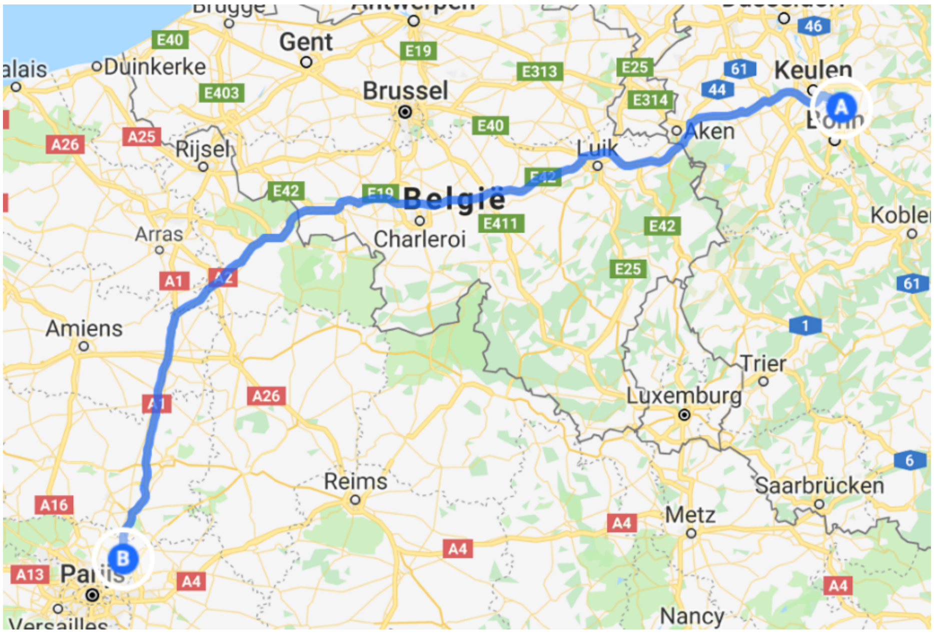


Figure 7 - Potential first Cargoloop route between the airport of Cologne and Paris - Charles de Gaulle

On the other hand, the challenge of choosing for this route is that it will almost completely pass through Belgium, while it is not certain whether Liège will be involved. It is expected that in order to get an agreement to build this route through Belgium, the plausibility that Liège will be added to this route must be clearly mapped out. Otherwise, it will be likely that Belgium would not agree upon an infrastructure through their landscape, without being a part of it.

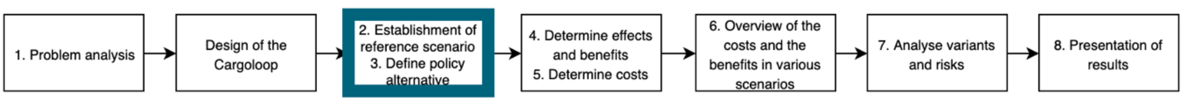
The project alternative can thus ben summarized as follows on the route between the airports of Cologne-Bonn and Paris-CDG as follows:

Components	Description
Cargoloop infrastructure	2 tubes
Cargoloop route	475 km
Diameter of the tube	142 cm
Cargoloop stations	2

6

Demand in reference scenario and policy alternative

In the previous chapter, the Cargoloop is designed. In this chapter, the first steps as preparation for the CBA are carried out. In doing so, first the demand in the reference scenario is determined (Section 6.1) and second, the demand in the policy alternative (Section 6.2). The latter is determined by means of a RUM MNL model. The approach for this model is divided in four subsections: first, the data collection for the demand in the policy alternative is described (Section 6.2.1), followed by a short discussion about the representativeness of the data used in this model and the implication of this (Section 6.2.2). Then it is described how the choice between the Cargoloop and the alternative existing transportation modes are modelled (Section 6.2.3) and finally, the results of these scenarios are presented (Section 6.2.4).



6.1 Demand in reference scenario

The literature and semi-structured interviews revealed that most of the air cargo is actually trucked between airports in Europe instead of flown. These 'additional' flows should therefore also be considered when exploring the amount of cargo transported between airports. Therefore first, it is discussed how the data for the scenario is collected (Section 6.1.1). Followed by the expected growth of the market (Section 6.1.2). Finally, the reference scenario is established (Section 6.13).

6.1.1 Data collection and preparation

The dataset for air cargo shown in table 6 is used in the choice model. This data was extracted on the 20th of July 2019 from the Eurostat database and the last update of the dataset had found place on the 15th of July 2019. The dataset is from 2017, as the dataset of 2018 was not complete yet. The detailed approach of the extraction of this dataset from Eurostat is explained in Appendix E.

Below the establishment of the air cargo trucked data discussed by describing how the dataset for the trucking is determined based on the research of Visser & Gordijn (2014).

Establishment of air cargo trucked data

To estimate the choice model, the dataset for trucking has to be made first as no data is available about the amount of air cargo that is trucked between airports. To estimate this, the study of Visser & Gordijn (2014) is used as a reference case. As aforementioned, Visser & Gordijn explored the share of road transport (in transporting air cargo) per distance from and to Schiphol.

Table 7 gives an overview of the modal share of air cargo trucking that is used to establish the data set for trucking. This table shows the average road share per distance range derived from the research of Visser & Gordijn (2014). It is averaged and rounded up for simplicity reasons as in their research the modal share is split into traffic to and from Schiphol. The original tables from the research of Visser & Gordijn are presented in appendix F.

Table 7 - Share of road transport to distance based on the research of Visser & Gordijn (2014).

Distance	Share of road transport via trucking
0-200 km	100%
200-400 km	100%
400-600 km	92%
600-800 km	94%
800-1000 km	85%
1000-1200 km	53%
1200-1400 km	79%
1400–1600 km	85%
1600-1800 km	49%
1800-2000 km	46%

To obtain the amount of trucked air cargo, the trucking distance between the airports mentioned in table 6 needed to be determined. When the distance between each airport was determined, combined with the share of road transport per distance class described in table 9, the amount of cargo trucked was obtained. In other words, if in the distance class 600-800 km the share of road transport is 94%, then the share of earlier found cargo transported via air is 6%. The demand matrix for air cargo trucked is shown in Appendix G and the distances used between the airports is shown in appendix H.

In the distance range in which Cologne-Bonn and Paris-CDG are located, Visser & Gordijn found that on average 92% of the air cargo is trucked. To obtain the amount of trucked air cargo on this route, the modal share of 8% transported via air and 92% transported via road is used. This resulted in the following origin-destination demand matrix, shown in table 8:

Table 8 - Total amount of cargo transported in x1000 tonnes between Cologne-Bonn and Paris-CDG in 2017. Source: Eurostat combined with research of Visser & Gordijn (2014)

x1000 tonnes	**From Paris-CDG to Cologne-Bonn**	**From Cologne-Bonn to Paris-CDG**	**Total amount of cargo on route**
Air transport	34.9	46.5	81.5
Road transport	401.2	535.3	936.5

6.1.2 Growth of market

The amount of cargo transported on the route between the airports of Cologne-Bonn and Paris-CDG in 2017 is now defined. However, by establishing the reference scenario, also the expected growth of the market should be considered. In doing so, it was found that according to the 'world air-cargo forecast 2018-2037' of Boeing (2018) the annual average growth rate of intra-Europe air cargo between 2018 and 2037 is forecasted at 2.3%.

No other research was found with a specific demand prediction for air cargo flown within Europe over a long period of time. The value found in the study of Boeing could therefore not be verified. The use of this value by Boeing for predicting the future demand must be applied with great caution.

6.1.3 Reference scenario

The amount of cargo transported between the airport of Cologne-Bonn and Paris-CDG via air and road, is derived. Moreover, also the growth rate of the air cargo market is known. Combining these data ensures that the reference scenario can be calculated for the coming years.

The calculation of the demand of cargo transported in the reference scenario is based on the time horizon chosen for the CBA. The period of the CBA is 30 years as this as common time period for new infrastructure projects. The growing rate defined by Boeing however, is only calculated for the coming 20 years. Due to simplicity reasons this growth rate defined by Boeing has been adopted as growth rate for the total 30 years considered in the CBA.

The growing demand over the coming years is calculated by the following formula, in which the growth rate is set at 2.3%.

$$Demand\ in\ year\ n = current\ demand\ (1 + growth\ rate)^n$$

In which:

n is the amount of years

This results in the following reference scenario for the coming 30 years as can be seen in table 9.

Table 9 - Reference scenario for coming 30 years

Total amount of cargo on route Cologne-Bonn – Paris-CDG	**Year 0** (2017)	**Year 10** (2027)	**Year 20** (2037)	**Year 30** (2047)
Air transport *(in x1000 tonnes)*	81.5	102.2	128.3	161.1
Road transport *(in x1000 tonnes)*	936.5	1,175.7	1,475.8	1,852.7
Total *(in 1000x tonnes)*	**1,018.0**	**1,277.9**	**1,604.2**	**2,013.8**

6.2 Demand in policy alternative

The demand for the Cargoloop is determined by means of a RUM MNL model. The theory of the RUM MNL model used in this study was already described in section 3.2.3. In this section, it is described how this model is applied within this study. First, the preparation and collection of the data is explained (Section 6.2.1). Followed by a short discussion about the representativeness of the data used and the possible implications for the model (Section 6.2.2). Then it is explained how the choice is modelled between the Cargoloop and the existing alternative modes of transportation (Section 6.2.3). Finally, the results of the RUM MNL are presented and discussed. (Section 6.2.4)

6.2.1 Data collection and preparation

The dataset for air cargo shown in table 6 and the dataset for the demand of air cargo trucked in Appendix G are used in the choice model. Before this dataset can be applied for determining the demand of the Cargoloop, adjustments have to be made. These adjustments are discussed below.

Adjusting the data for the Cargoloop

The current traffic volumes of air cargo between the airports of Cologne-Bonn and Paris-CDG have been identified in section 5.1.3. However, no information was found about the size of the cargo that is transported on this route. Based on logical reasoning, it can be assumed that not all cargo will fit in the Cargoloop due to its small diameter.

During the general analysis of the express freight market in Europe, it was found that 5-15% of the global air cargo has to be shipped by all-cargo aircraft exclusively, due to their dimensions or hazardous characteristics (Transport experts B & C; Kupfer, et al., 2017). It is likely that the cargo that can only be shipped in all-cargo aircraft exclusively, will also not be able to be shipped via trucks as the content of a cargo plane is larger than that of a truck. As the height of the Cargoloop is smaller compared to the height of a cargo airplane, it is considered that 15% cannot be transported via the Cargoloop. In other words, 15% of the earlier founded air cargo flows has to be subtracted, based on the assumption that this percentage cannot be transported by the Cargoloop due to its dimensions.

6.2.2 Representativeness of the sample and implications for the estimated choice model

The sample that is used in this study consist of a dataset concerning air cargo flows in Europe from Eurostat combined with the share of road transport per distance regarding air cargo trucked which were found in a research of Visser & Gordijn (2014). The geographical position of Schiphol in Europe, however, is different compared to the airports at which the findings are applied. In the case of the connection between the airports of Cologne-Bonn and Paris-CDG, it could be said that Schiphol is slightly less centrally located in Europe compared to the airports of Cologne-Bonn and Paris-CDG. This difference in position, could also affect the share of road transport between Cologne-Bonn and Paris-CDG. It would be expected that the modal share via road would be higher, due to shorter distances to other airports because of its centralized position in Europe.

Moreover, when looking at the characteristics of the airports of Cologne-Bonn and Paris-CDG compared to Schiphol, it was found during the general analysis of the express freight market in Europe (Appendix D) that Paris-CDG and Schiphol can be considered as the same type of airports: they are both airports in which the amount of freight and number of passenger transported is balanced. Cologne-Bonn on the other hand can be seen as a cargo-oriented hub, a hub that handles large volumes of cargo and only few passengers. However, what makes a significant difference between the hubs is that both, Paris-CDG and Cologne-Bonn are hubs of integrators. Schiphol, on the other hand, is not a hub of an integrator. During the interviews, it was found that integrators most of the time do fly within Europe (Transport expert B). It could therefore be expected that the modal share via air would be higher on this route.

As already can be observed from the two paragraphs above, the representativeness of the sample can be affected by for example the centralized position of an airport or by the presence of integrators at the airports. It depends on the size of these effects; how large their impact is on the modal share. Regarding this study, this means that the estimation of the amount of air cargo trucked can deviate from the numbers that are assumed.

Implications for estimated choice model
The collected data will be used to estimate the logit choice model. The above-mentioned expectations already show a contradiction between the expectation described in the first paragraph and the expectation described in the second paragraph. This indicates that the modal share that is used now, could be not representative for the modal share between the airports of Cologne-Bonn and Paris-CDG. However, whether it is representative cannot be checked as no information is available about the modal share on this route. The substantial chance that it will not be representative, however, will have implications on the estimated choice model. Namely, the parameters used to determine the modal share of the Cargoloop are based on the current modal split (this will be explained in Section 6.3). The uncertainty in the current modal split thus also results in an uncertainty in the estimated modal split for the Cargoloop. The modal share estimated in the choice model must therefore be interpreted very carefully.

6.2.3 Modelling the choice between the Cargoloop and the existing available modes
In order to estimate the demand for the Cargoloop, a framework for a simplified RUM MNL model to explore the demand of a new form of transport proposed by Tavasszy in his course 'Freight Transport Systems: Analysis and Modelling', is used. This RUM MNL model can generally be divided into three steps. An overview of these steps is shown in figure 8.

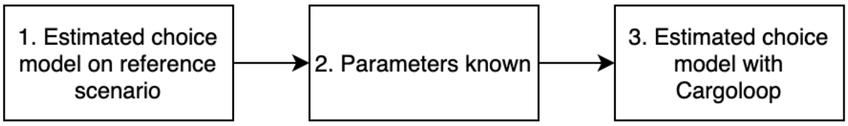


Figure 8 - Three steps for choice modelling Cargoloop

First, the estimated choice model will be carried out on the reference scenario (the transport of air cargo via road and air) to calculate the unknown parameters such as value of time (VOT), ASC and Mu (these dependent variables will be explained below). As the parameters are known, these variables can be used to calculate the demand of the Cargoloop.

In the following, it will be explained for each step, how the step is carried out and how the results of that step are obtained.

Step 1: Estimated choice model on reference scenario

In the first step, a RUM MNL model is used to determine the unknown parameters: VOT (a_g), ASC and Mu (μ). These parameters are determined through Solver, an application in Excel. This application finds the values of the unknown parameters in this case by trial and error and minimizing the squared errors in this case. A conceptual overview of how the RUM MNL model is applied, is shown in figure 9.

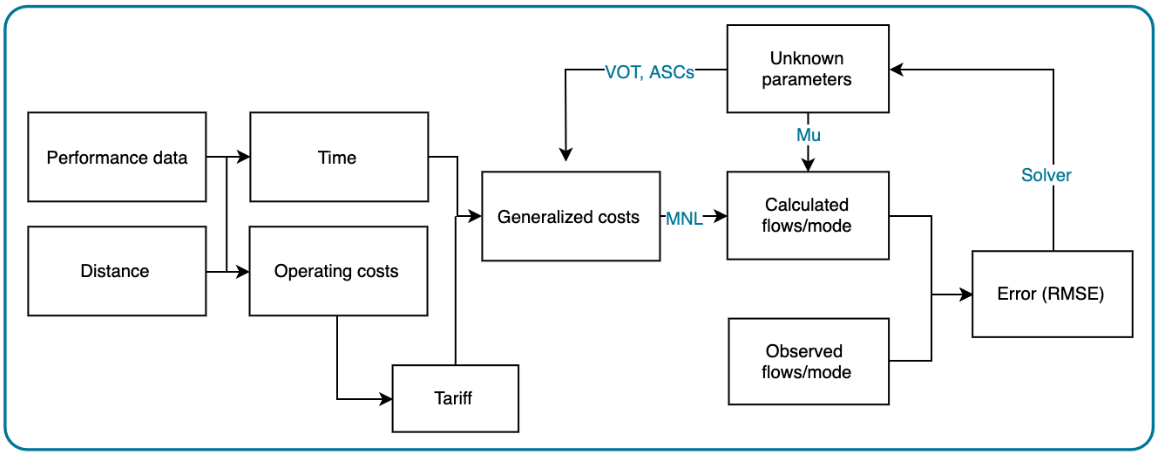


Figure 9 - Conceptual overview of the approach used to model the RUM MNL model in this study

The different blocks as shown in the conceptual model are now explained more in detail.

Performance data, distance and travel time

The distance and the travel time between the airports per transport mode (road and air) are shown in appendix H. In calculating the travel time per connection, a speed of 80 km/h was applied for road transport and a speed of 800 km/h for aviation. Important to note, is that the travel time does not include the loading and unloading time or other factors that could influence the travel time but only concerns the travel time over the route.

Operational costs

The operating costs of the available transport modes are determined based on desk research. According to Werner et al. (2016) the average operating cost of transporting cargo by truck is €0,10 per tons per kilometers. The operating costs of aviation on the other hand, are €0,30 per tons per kilometer (European Organisation for the Safety of Air Navigation, 2018).

Tariff

The tariff is determined based on the operational costs supplemented with a profit margin per sector. These profit margins however, were difficult to obtain from the literature due to the commercial nature of such a data (Tavasszy & de Jong, 2014). Therefore, margins found per industry sector found in the database found from professor Damodaran New York University are used. For the aviation sector the margin was 29.79% and for the truck industry this was 11.45%. Multiplying these margins with the earlier found operating costs results in the following transport tariffs as shown in table 7:

Table 7 - Transport tariffs of the available transport modes

Available transport modes	Operating costs *(in €/tonne-km)*	Profit margins *(in %)*	Transport tariff *(in €/tonne-km)*
Road	0.10	11.45	0.11
Air	0.30	29.79	0.39

Generalized costs

The probability that mode m is chosen depends on the differences in utility of the available transport modes. The utility is determined by the generalized costs. If the generalized costs become larger, the utility becomes smaller and the probability that mode m will be chosen will also become smaller. These generalized costs in turn, are determined by the following equations:

Road transport

$$G_{m,g} = C_m + a_g T_m$$

Air transport

$$G_{m,g} = C_{air} + a_g T_m + ASC_{air}$$

In which:

G_{mg} = generalized costs (in €/ton)
C_m = transport tariff (in €/ton)
a_g = value of time (€/ton*hour)
T_m = travel time (hour)
ASC_m = alternative specific constant
m = mode
g = express freight

The generalized costs depend thus on the transport tariff, distance, value of time, travel time and the alternative specific constant. The transport tariffs are determined in the section above and the travel time is also known. In doing so, the ASC of road transport is fixed to 1 (why the ASC of road transport is fixed to 1 and not the ASC of air transport, is described in step 3). The fact that the ASC of one of the two modes is fixed to 1 is because when determining the utility per transport mode per trajectory, only the difference in the observed utility matter. The ASC of air transport thus shows the average effect on the utility of the factors that are not included in the model.

MNL model
The utility is determined by the following equation in this model:

$$U_{m,g} = \mu G_{m,g} + \varepsilon$$

$$U_{m,g} = \mu G_{m,g} + \varepsilon$$

In which

U_{mg}	= observed utility
μ	= constant to map G into utility
G_{mg}	= generalized costs (in €/ton)
ε	= error term that is independently and identically distributed

Important to note here, is that an increase in the generalized costs will lead to a decrease in utility. In order to ensure this condition, the parameter μ is forced to be smaller than zero in the model.

The probability that a mode will be chosen as transport mode is calculated with the following equation:

$$P_{mg} = \frac{e^{\mu G_{mg}}}{\sum_m e^{\mu G_{mg}}}$$

Root mean square error (RMSE)
The model is estimated by minimizing the root mean square error (RMSE). In doing so, the model tries to give the Cargoloop a 'fair' share, which is in line with the current behavioral preferences of customers. By minimizing the RMSE, the current behavioral preferences of the customers are approached as well as possible by approaching the current modal split.

Step 2: Value of parameters

The RUM MNL model resulted in the following values for the unknown variables as shown in table 8 for the VOT and Mu and table 9 for the ASCs per connection. The constraints to which the variables were subjected are presented in Appendix I.

Table 8 - Results of dependent variables a_g and μ

Variable	Value
a_g	16.48
μ	-0.04

Table 9 - Results of dependent variable ASC per connection

ASC	Frankfurt	Paris-CDG	London-Heathrow	Amsterdam-Schiphol	Leipzig-Halle	Luxembourg	Cologne-Bonn	Liège	Milano-Malpensa	Brussels
Frankfurt		30.6	52.4		46.5				37.1	
Paris-CDG	36.9		44.7	22.3	38.8		39.8	89.5	29.4	89.5
London-Heathrow	73.9	59.9		59.3	75.8				66.4	126.5
Amsterdam-Schiphol		26.6	48.4		42.5				33.1	
Leipzig-Halle	40.6	26.5	48.3	25.9			43.5		33.0	93.1
Luxembourg									56.1	
Cologne-Bonn		27.9			43.8					
Liège		83.3								
Milano-Malpensa	42.9	28.9	50.7	28.3	44.8	56.1				
Brussels		83.0	104.8		99.0					

From table 8, it can be seen that the VOT is 16.48 €/ton-hour. A value as this was expected when looking at the VOTs of air and road transport combined with the fact that the fundamental larger share of road transport on most of the connections. It was found in research of de Jong et al. (2014) that the VOT of air cargo is approximately around the €133/ton-hour. In research of De Jong, Bakker, & Pieters, (2004), the VOT of high-value goods that are trucked was found to be 6.75 €/ton-hour. The VOT found in the model could thus be representative for the sample.

Regarding the ASCs, the ASCs are only calculated for the connections for which data was available and show the average effect on utility of the factors that are not included in the model. It can be seen that all ASCs are positive which means that the ASCs contributes negatively to the utility (the constraints of the ASC variable allowed it to be negative as well), as the generalized costs are made negative in the utility function by μ. In other words, this means that there is a certain 'dislike' in the unobserved factors for the transport via air. The ASCs that are relevant for this research are the ASC from Cologne-Bonn to Paris-CDG: 27.9 and the ASC from Paris-CDG to Cologne-Bonn: 39.8.

Step 3: Estimated choice model with Cargoloop

As the VOT, Mu and ASC for the connection between Cologne-Bonn and Paris-CDG are known now, the modal share of the Cargoloop can be calculated. In doing so, three different tariff scenarios for the Cargoloop are created:

Demand scenario 1: Cargoloop has similar tariff as in road transport
Demand scenario 2: Cargoloop has average tariff of road and air transport
Demand scenario 3: Cargoloop has similar tariff as in air transport

Before, the results will be presented, first the performance characteristics of the Cargoloop on the route between the airports of Cologne-Bonn and Paris-CDG needs to be discussed. The aforementioned blocks in figure 9 that concern information that is relevant for calculating the utility of the Cargoloop are discussed here. These blocks are: the performance data, distance and travel time, tariff and the generalized costs.

Performance data, distance and travel time

The performance characteristics of the Cargoloop on the trajectory between the airports of Cologne-Bonn and Paris-CDG are defined in the below. The speed for the Cargoloop used is 700 km/h.

Cologne-Bonn – Paris-CDG	Cargoloop	Air transport	Road transport
Travel time *(in minutes)*	41	28	285
Route *(in km)*	475	404	475

Tariff

As the tariff of the Cargoloop is not yet determined and depends on various factors, it recommended to develop various scenarios (European Commission, 2014). The underlying principle in creating those scenarios is that the Cargoloop should be competitive on the price. The three different scenarios consist of low, medium and high tariffs. As already aforementioned, in the first (low) scenario the tariff of the Cargoloop is the same as that of road transport: 0.11 €/ton-km. In the third (high) scenario the tariff of the Cargoloop is the same as that of air transport: 0.39 €/ton-km. The tariff of the Cargoloop in the second (medium) scenario is the average of the tariffs of road and air transport: 0.25 €/ton-km

Table 10 - Transport tariffs per available transport mode used in the different scenarios for demand modelling

Scenario	Cargoloop *(in €/ton-km)*
Demand scenario 1	0.11
Demand scenario 2	0.25
Demand scenario 3	0.39

Generalized costs

As aforementioned, the generalized costs depend on the transport tariff, value of time, travel time and the ASC. These variables are described above. The value of time and the ASC for air transport on the trajectory between the airports of Cologne-Bonn and Paris-CDG were calculated in step 2.

As the ASC for a transport mode can only be calculated for modalities from which the modal shares are known, one of the fundamental questions with new technologies is which ASC could be used to forecast the demand. Depending on the interpretation of the ASC, one can choose to take the same value as transportation mode that has the most similarities, except for similarities in costs and time because these components are already included in the model. In the case of the Cargoloop, it is assumed that the ASC of the Cargoloop will be the same as that air because of the flexible character of road transport and requirement for stations, just like airports, for the Cargoloop as destinations. This resulted in the following formula for the generalized costs of the Cargoloop:

Cargoloop

$$G_{m,g} = C_m + a_g T_m + ASC_{air}$$

In which:

G_{mg} = generalized costs (in €/ton)
C_m = transport tariff (in €/ton)
a_g = value of time (€/ton*hour)
T_m = travel time (hour)
ASC_m = alternative specific constant
m = mode
g = express freight

MNL model

The utility of the transport via air and road was already described, the utility Cargoloop however, is determined by the following equation in this model:

$$U_{m,g} = \mu G_{m,g} + \varepsilon$$

In which

U_{mg} = observed utility
μ = constant to map G into utility
G_{mg} = generalized costs (in €/ton)
ε = error term that is independently and identically distributed

The probability that a mode has the lowest generalized costs and will thus be chosen as transport mode is calculated with the following equation:

$$P_{mg} = \frac{e^{\mu G_{mg}}}{\sum_m e^{\mu G_{mg}}}$$

6.2.4 Results

The results of the RUM MNL Model used to model the demand of the Cargoloop are described in this section. First, the parameters found are discussed and then the results are presented, finally results are discussed

Parameters found

The following parameters were found on the estimated choice model. These parameters were in turn used to determine the demand of the Cargoloop:

Variable	Value
a_g	16.48
μ	-0.04
ASC_{air} Cologne-Paris	27.9
ASC_{air} Paris-Cologne	39.8

Presentation of results

The different tariffs in the three scenarios resulted in the following modal share of the Cargoloop per scenario, as shown in table 11. Due to the specific ASC per transport direction, the modal share was at first also determined per transport direction. However, due to simplicity reasons the average of both values are combined into one overall modal share per transportation mode on the route overall, regardless of the direction of the transport.

Table 11 - Outcome of MNL model showing the probabilities in each scenario

Scenario	Air transport *(in %)*	Road transport *(in %)*	Cargoloop *(in %)*
Demand scenario 1	2	21	77
Demand scenario 2	6	74	20
Demand Scenario 3	7	91	2

These probabilities can be used to get the market shares of the alternatives (Tavaszzy & de Jong, 2014). In doing so, the predicted demand of the Cargoloop in the three different scenarios can be calculated. This resulted in the following amount of cargo transported by the hyperloop in the three scenarios, shown in table 12.

Table 12 - Amount of cargo transported per scenario per transport mode

Scenario *x1000 tonnes*	Air transport	Road transport	Cargoloop
Demand Scenario 1	17.3	181.9	667.1
Demand Scenario 2	51.9	641.1	173.3
Demand Scenario 3	60.6	788.4	17.3

Discussion of results

In the first scenario, where the transport tariff of the Cargoloop is the same as that of road transport, the largest share of the cargo is transported via the Cargoloop. This was an expected outcome, as the travel time of the Cargoloop is much faster compared to road transport. This in turn, will result in a higher utility and thus a larger probability for the Cargoloop.

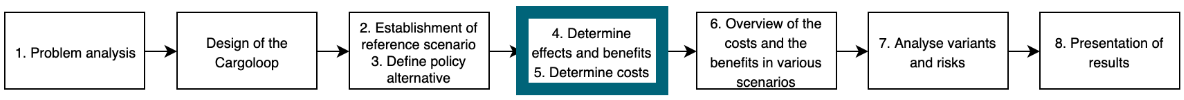
In the second scenario, the modal share of the Cargoloop is reduced substantial to only 20%. Based on logical reasoning, it was expected that the share would be higher, as the Cargoloop is faster than road transport but cheaper than air transport, this provided the intuition that by opting for a mid-range tariff, it could still obtain a relatively large modal share. That this is not the case, however, can be explained by the VOT. If the earlier found VOT would be higher, the modal share of the Cargoloop in this scenario would also become larger. In other words, this also means that the VOT of the goods transported on this route may not be of such a high standard that the shipper would be willing this mid-range tariff for the transport with the Cargoloop.

Finally, in the third scenario, only 2% of the cargo will be transported via the Cargoloop. This scenario, however, was expected as based on a comparison between distance and travel time of air transport and the Cargoloop, air transport has a shorter distance and a faster travel time, resulting in a higher utility. Whether this is realistic in practice, is another question as it will be likely that the transport via the Cargoloop will be faster due to the smaller size of the vehicle and a more efficient handling procedure. These aspects, however, are not taken into account.

7

Cost and benefits

The demand for the reference scenario and the project alternative is defined now. The next step in the preparation for the CBA is determining the effects of the project alternative in costs and benefits. In this chapter, first the effects of the are identified (Section 7.1), followed by the description of the costs (Section 7.2) and finally, the effects of the modal split (the benefits) are discussed (Section 7.3)



7.1 Identification of effects

The Cargoloop route will reduce the air and road traffic between the airports of Cologne-Bonn and Paris-CDG. The current way of transport has to deal with factors such as capacity limitation, noise nuisance, congestion and pollution. The current infrastructure will be put under pressure even more as an increase is expected in the amount of cargo. The objectives of the project alternative are to: 1) provide fast and reliable transport for the long distance; 2) reduce congestion; 3) improve capacity; 4) reduce environmental impact; 5) increase safety.

Based these project objectives, the following costs and benefits are identified in this study as shown in figure 10:

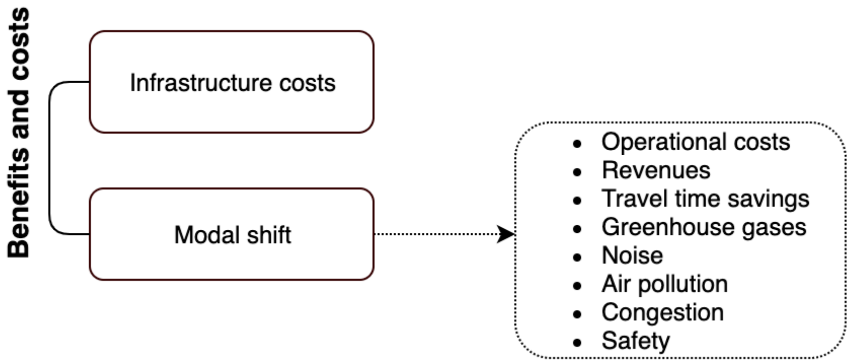


Figure 10 - Identification of costs and benefits of the Cargoloop

As can be seen in figure 10, the costs and the benefits of the Cargoloop can be divided into two categories: 1) infrastructure costs; 2) modal shift. Starting with the infrastructure costs, these are the investment costs of the infrastructure of the Cargoloop. These costs will be one-off, during the implementation of the Cargoloop. Second is the modal shift, the implementation of the Cargoloop will affect the modal split on this route, this in turn will also determine the demand of the Cargoloop. A consequence of this modal split is that there will be operational costs, revenues will be earned but moreover, it also has an effect on variables that do not have directly a market price such as travel time savings, greenhouse gases or noise.

The structure presented in figure 10 will also be used in this chapter to describe the costs of the benefits of the Cargoloop. So first, the costs will be discussed. Followed by the modal shift, this in turn results to the benefits which will be discussed last.

7.2 Costs

In this section the costs that arise due to the proposed measure are calculated. In doing so, the costs of the Cargoloop are quantified and monetized.

7.2.1. Infrastructure costs

When looking at the implementation costs of the infrastructure of the Cargoloop, similarities can be found within the industry of natural gas transport. This industry transports gasses through a system of pipes that usually vary in size from 2 to 60 inches (5.1 to 152.4 cm) in diameter, constructed form carbon steel. Moreover, these pipelines are implemented below ground.

In determining the costs of a pipeline project, the costs components can be divided into four areas according to McAllister (2014): right of way, material, labor and miscellaneous. When looking at the material costs, it is important to mention that the size of the diameter has a large impact on the costs. The implementation costs of a pipeline increase almost exponentially by increasing the tube diameter (Ogden, Johnson, Yang, & Lin, 2005).

As a reference project for determining the costs of the implementation of the Cargoloop, the Nordeuropäische Erdgasleitung/Northern European Natural Gas Line (NEL) is used. This is a 440 km onshore natural gas pipeline in Germany, consisted of steel pipelines with a diameter of 142 cm. It is expected that the implementation of this project did cost approximately €1 billion. It took approximately 15 months to construct the pipeline. These characteristics of the project are summarized in Table 13. When dividing the implementation costs by the length of the pipeline, this results in a cost of €2,3 million per km.

Table 13 - Project characteristics of the Northern European Natural Gas Line

Project	**Construction time** ***(in months)***	**Diameter** ***(in cm)***	**Implementation costs** ***(in million)***	**Length** ***(in km)***	**Costs per km** ***(in million)***
NEL pipeline	15	142	€1,000	440	€2.3

When comparing this project, to the proposed initial route of the Cargoloop several similarities can be found. The most important one is the similar diameter used of the tube. Besides that, both projects are implemented onshore. Finally, also the length of both routes is about the same which means that this project could give an indication of the economies of scale.

Based on the four cost components mentioned by McAllister (2014), several assumptions have to be made in order to be able to make an estimation of the implementation costs of the Cargoloop. For simplicity reasons, it assumed that the costs of the labor, material and right of way are the same as for the Cargoloop. However, when looking at the miscellaneous costs, it is expected that these costs are higher due to the internal structures that are needed within the Cargoloop, which are not included in these natural gas pipelines.

These internal structures consist of the tracks, the attachments, motor, drives, magnets, pumps, stations and power & distribution. An estimation provided by Hardt shows combining these internal structures would result in cost of €1,16 million per kilometer. In this price, the costs of the internal structures are included as well as the costs of the construction of these internal structures.

On top of these costs, there will also be unforeseen costs. These types of costs are always included in projects. For a gas distribution network, these costs are between the 10% an 20% of the total infrastructure costs (European Commission, 2010). Taken into account that it will be the first time that internal structure be secured in the tube, the maximum percentage is taken. So, 20% of the total infrastructure costs will be unforeseen costs.

An overview of all the costs made for the infrastructure of the Cargoloop are shown in table 14 It should be taken into account that the both pipeline costs, as well as the costs of the internal structures are doubled since the track between Cologne-Bonn and Paris- Charles de Gaulle will exist of two tubes, each going one-way.

Table 14 - Infrastructures costs of the Cargoloop

Infrastructure elements	Costs *(in million €/km)*
Pipeline costs:	2.3
Internal structures:	1.16
Unforeseen:	0.692
Total:	4,152

Construction time period

As aforementioned, the construction time of the NEL gas pipeline was approximately 15 months. Taken into account that also the internal structure has to be secured in the tube and there will need to be built two tubes instead of one, it is assumed that the construction time of the Cargoloop will approximately take double as long as the NEL gas pipeline. Therefore, a construction time of 3 year is calculated for constructing the Cargoloop route between the airports of Cologne-Bonn and Paris-CDG.

The distribution of the costs over the first three years is based on a research of The Van Horn Institute (2004) in which the construction of a HSR connection between Calgary and Edmonton was investigated. Their distribution of the costs was calculated on a construction time of 5 years, in which the first two years were devoted to the final design, engineering, securing approvals, land acquisition and preparation of the contractor tenders and the last three years to the construction. To use this as a reference for the distribution of the construction costs over the years, these costs are reckoned with the construction period of the Cargoloop. This resulted in the following distribution of the infrastructure costs per year, shown in table 15:

Table 15 - Deviation of infrastructure costs per year

Deviation of infrastructure costs per year	*In %*
Year 1	6
Year 2	43
Year 3	51

7.3 Effects of modal split

For the quantification and valuation of all of the effects and benefits except the operational costs and travel time savings, the 'Handbook on External Costs of Transport' provided by CE Delft for the European Commission in 2019, is used. In this handbook, however, the costs of air cargo are not included due to the lack of data. Therefore, an older research published in 2008 of E. Pels for the OECD is used to determine the external costs (besides again the operational costs and the travel time savings) regarding the transport of air cargo. The external effects published in this research however, dated from 2000. In assessing the results of the CBA, these difference in the external costs used for road transport and air transport must therefore be taken into account.

7.3.1 Operational costs

The operational costs of the Cargoloop can be divided in two types of costs: 1) the maintenance costs and 2) the energy usage costs. These costs will be described more in detail in this section.

7.3.1.1 Maintenance costs

The main factors that influence the maintenance of vehicles and infrastructure are the traffic load, the weather conditions and the interaction between these two factors (Liao, Kumar, Dojutrek, Labi, & Asce, 2018). When looking at these with respect to the Cargoloop, it can be found that the maintenance costs of the Cargoloop will be probably be low.

The Cargoloop is in a closed environment, which means that it will not be affected by weather conditions or other external factors that could influence the performance of the operations. This will result in lower maintenance costs. In addition, as the Cargoloop makes use of magnetic levitation, no direct contact is made between the vehicle and the infrastructure. This results in practically no friction between the vehicle and the infrastructure, which in turn will also result in lower maintenance costs.

As a reference project for determining the maintenance costs of the Cargoloop, the maintenance costs of a MagLev technology are used, as the same principle levitation principle is used within the Cargoloop. However, two major differences are that current MagLev technologies do not operate in near vacuum tubes and the diameter of the MagLev vehicle is significantly larger than the Cargoloop, as the existing MagLev systems transport passengers. This could lead to a susbstantial reduction of the costs and will have to be taken into account when estimating the maintenance costs of the Cargoloop. The maintenance costs that have been estimated by (Rocky Mountain Rail Authority, 2010) for MagLev are shown in the table below:

Table 16 - Maintenance costs of MagLev systems. Estimations converted to €/km from $/mile at a rate of 0,561

Maintenance costs Maglev	
Costs per track km *(in €/km):*	€ 36,493.29
Costs per vehicle-km *(in €/vehicle-km):*	€ 4.05

Taking into consideration the above-mentioned differences with respect to the diameter and the environment in which the systems operate, Hardt believes that the maintenance costs of the Cargoloop would only be 25% of these costs. Furthermore, when recalculating the maintenance costs per vehicle size from a Maglev (153 meter) to that of the Cargoloop (7.2 meter). This results in the following maintenance costs for the Cargoloop, shown in table 17:

Table 17 – Maintenance costs of the Cargoloop based on 25% of the MagLev maintenance costs

Maintenance costs Cargoloop	
Costs per track km *(in €/km):*	€ 9,123.32
Costs per vehicle-km *(in €/vehicle-km):*	€ 0.05

7.3.1.2 Energy costs

As discussed earlier in section 4.2, the main energy components during the operation are the motors for the propulsion of the vehicle and the pumps to maintain the low-pressure environment. Hardt estimated that the energy usage per vehicle-km in a 142cm tube is 454 Wh/vehicle-km. In this estimation the energy of the motors and the pumps is included.

The average industrial electricity price in Europe in 2017 was €0.11 per kilowatt hour (Eurostat, 2017). Using this electricity price, this would result in in the following energy costs of the vehicle per vehicle-km, as shown in table 18:

Table 18 - Energy costs of the Cargoloop

Energy costs of vehicle	
Industrial electricity price *(in €/kWh)*	€ 0.11
Energy usage of vehicle *(in Wh/vehicle-km)*	454
Energy costs of vehicle *(in €/vehicle-km)*	€ 0.049

7.3.2 Revenues

As already mentioned earlier, for determining the demand of the Cargoloop, three different tariff scenarios were created. The revenues used in determining the demand in these scenarios, are also used as revenue in that specific CBA scenario. The tariff on which the Cargoloop demand is calculated in scenario 1, which was €0,11/ton-km, is also the used revenue in the CBA that is calculated based on the demand scenario 1. In doing so, there are thus three different CBA in which three different revenue prices are used. The revenue prices used for these different scenarios are shown in table 19:

Table 19 - Revenues used for the Cargoloop in the different scenarios

Scenario	Cargoloop *(in €/tonne-km)*
Scenario 1	0.11
Scenario 2	0.25
Scenario 3	0.39

7.3.3 Travel Time Savings

Travel time saving is the most significant benefit when introducing a new or improvement of existing transport infrastructures. A reduction in travel time will benefit the freight transport in the following ways: it will reduce the driver wage costs per trip, it will reduce the vehicle operating costs per trip and finally, it will improve the time reliability of the transported goods (European Commission, 2014).

However, as can be seen from the description of the performance data in chapter 6, the speed and travel distance of aviation are both, faster and shorter, compared to the Cargoloop. In other words, an aircraft would travel on the route between the airports of Cologne-Bonn and Paris-CDG faster than the Cargoloop, which in turn would mean negative travel time savings when transport would be carried out with the Cargoloop. This will be in practice, however, very unlikely as the Cargoloop will probably have a much faster loading and unloading process due to the smaller size of the vehicles. Therefore, the choice was made to look only look at the travel time savings of trucking.

When looking at the value of time of transporting freight via road, several values can be found depending on the type of goods that are transported. In research of De Jong, Bakker, & Pieters,

(2004) it was found that the travel time valuation of goods transported via the road lie between the €3.49 per ton per hour and €6.75 ton per hour. This first value concerns the transport of low-value goods and the latter one, the transport of high-value good. As the goods transported on this route are goods that will also be transported via air and thus can be considered as high-value goods, the value of €6.75 ton per hour will be used to determine the travel time savings of trucking.

7.3.4 Greenhouse gases

Transport results in emissions of greenhouse gases such as CO_2, N_2O and CH_4. These gases are contributing to global warming and climate change. Identifying these effects is therefore important. However, as the effects of climate change are global and have risk patterns which are complicated to estimate, it is a complex process to determine these external costs.

Air transport

The external costs of climate change of air freight transport are based on the greenhouse gases emissions emitted by air freight. In doing so, the costs of CO_2 emissions are calculated by multiplying the CO_2 emitted per vehicle times a cost factor. Moreover, also the costs of nature and landscape are taken into account. This resulted finally in an average external cost of €0.2357/tonne-kilometer (OECD, 2008).

Road transport

The climate change effects that are taken into account when determining the external costs of climate change by road transport are for example: sea level rise, crop failures and biodiversity loss. In doing so, the greenhouse gas emission per vehicle type, the GWP of greenhouse gas emissions (manner to compare the different type of emissions) and the climate change costs per tonne of CO_2 are used. In doing so, the following average external cost was found: €0.0053/tonne-kilometer (CE Delft, 2019).

Cargoloop

The Cargoloop has no direct emissions, however, it makes use of electricity to maintain the low-pressure environment and for the propulsion of the vehicles. The use of electricity also results in the emission of CO_2. However, the emissions only occur during the electricity generation. As this part, the emission of the production of the 'fuel' is also not included in the other modes of transport, it also not included here. This results in that the external costs of the Cargoloop are: €0.00/tonne-km.

Transport mode	Average costs greenhouse gases *(in €/tonne-km)*
Aviation freight	0.2357
Heavy good vehicles	0.0053

7.3.5 Noise

In general noise can be defined as unwanted sounds that vary in their intensity or duration. Noise from traffic is mostly experienced as disutility and can cause physical or psychological harm to people. However, the thresholds for which noise is considered as annoyance is arbitrary, which makes it more complex to estimate the external costs of noise annoyance. However, as the noise annoyance has such a negative impact, it is important to valuate these effects and include them in a CBA when calculating the effects of a new project.

Air transport
For determining the external costs of noise annoyance caused by air transport, a willingness to pay procedure is used. In doing so, a database from OECD is used. The costs included in the external costs of noise annoyance are medical costs and monetary valuation of increased health risk. This resulted in the following external costs of noise annoyance by aviation freight: €0.0089 /tonne-kilometer (OECD, 2008).

Road transport
The external costs of noise caused by road transport are calculated on the base of costs for noise annoyance and the health costs of noise. In doing so data about the people exposed to noise annoyance, environmental prices and weighting factors for different vehicles are used. This resulted in the following external costs of noise annoyance by road transport: €0.008/tonne-kilometer (CE Delft, 2019).

Cargoloop
As the Cargoloop moves through a tube, which is a protected environment that is sealed off from the environment, it is assumed that the environment is not burdened by noise nuisance. The external costs of noise nuisance of the Cargoloop are therefore: €0.00/tonne-km

Transport mode	Average costs noise *(in €/tonne-km)*
Aviation freight	0.0089
Heavy good vehicles	0.008
Cargoloop	0.00

7.3.6 Air pollution
The emission of air pollutions can lead to various types of damages. Most pertinent and also best explored type of damages are the health effects due to air pollution. However, other effects are also relevant such a loss in biodiversity or material damages. It is therefore important to valuate these effects and include them in a CBA when calculating the effects of a new project.

Air transport
The external costs of air pollution by air transport are based on surveys in which the willingness to pay is explored. In doing so, the following average external cost for air pollution caused by aviation freight is found: €0.0156/tonne-kilometer (OECD, 2008).

Road transport
The air pollution costs used for road transport in this CBA are calculated on the following four types of impacts which are caused by the emission of transport related activities:

- Health effects: The inhalation of air polluting particle such as PM_{10}, $PM_{2.5}$ and NO_x increases the risk of various diseases. These negative health impacts can lead to for example, medical treatment costs or illness, which in turn can have further consequences for work or private life.

- Crop losses: Agricultural crops can be damaged by the emissions such as SO_2 or NO_x and VOC, which affects the ozone layer. As a result, the yield of the crops can become lower.
- Material and building damage: Air pollution mainly causes two types of damage to material and buildings: 1) pollution of the surfaces of buildings through particles and dusts; 2) damage of materials and buildings due to corrosion processes, as a result of acidic matters.
- Biodiversity loss: Air pollution can cause damages to the ecosystems. This in turn, can lead to decrease in the biodiversity.

In calculating the costs of air pollution, the emissions of air pollution for different transport modes was used and the cost factor for these air pollution costs. This resulted in the following external costs for air pollution for heavy good vehicles: €0.0076/tonne-kilometer (CE Delft, 2019).

Cargoloop
The Cargoloop does not emit air pollutants as it only uses electricity to be operational. In other words, the Cargoloop thus does not pollute the air. Therefore, the external costs for air pollution of the Cargoloop is €0.00/tonne-kilometer.

Transport mode	Average costs air pollution *(in €/tonne - km)*
Aviation freight	0.0156
Heavy good vehicles	0.0076
Cargoloop	0.00

7.3.7 Congestion

Congestion is defined as condition in which vehicles are delayed when they travel a particular route. Costs for congestion arise when the travel time of the journey is increased by a decreased speed of the vehicles through congestion.

Air transport
Pricing the congestion in aviation is a relevant topic as many airports have to deal with capacity problems and less than half of the flights are not delayed. However, it is often discussed whether the congestion of aviation can be seen as an external cost. On the macro-economic level, if an aircraft is delayed, the aviation sector has to pay the costs of its own delays. The same as with congestion in road transport. However, on micro-economic level, the decision of one airline when to fly also impacts the travel time of other airlines.

The conclusion from literature is therefore that the congestion costs from airports that are only served by one airline, are internal. However, most of the airports are served by several airlines. In this case, the congestion that is imposed on the airline’s self is internalized, the rest of the costs is externalized.

There is however, a lack in data concerning the external congestion costs of freight aircraft. As aircraft transport freight already during the night due to the lack of capacity during the day, the amount of delays they face differs with respect to the passenger aircraft. There is however, no data available upon this topic and it will therefore also not be included.

Road transport
There are two approaches to estimate the congestion costs via road, the delay costs and the deadweight loss costs. The delay cost occurs as the flow increases, the speed reduces, the travel time increases and the travel costs as well. The deadweight loss costs are based on the demand in excess. For calculating these costs, a distinction was made between congestion costs in urban areas of inter urban areas. The inter urban value is taken for this study as the airports do not lie within the city. The input for the congestion costs in inter-urban regions consisted of the speed-flow functions, demand curve, value of time, load factor, localization of the congested areas in the European intra-urban road network, characteristics of road network and the profile files of daily traffic. This resulted in the following external costs of congestion 0.005 €/tonne-km(CE Delft, 2019).

Cargoloop
As the Cargoloop will operate autonomously it is expected that no congestion will occur. The congestion costs of the Cargoloop are therefore established at 0.0 €/tonne-km.

Transport mode	Average costs congestion *(in €/tonne-km)*
Aviation freight	0.00
Heavy good vehicles	0.0050
Cargoloop	0.00

7.3.8 Safety
Accidents occur in every type of traffic, with every mode of transport and results in substantial costs. These costs consist of two types of elements: material costs such as damage to the vehicle; and immaterial costs such as pain or suffering. For determining the material costs, market prices can be used. However, for immaterial costs this is not the case. It is therefore important to include also these costs when determining the external costs of safety.

Air transport
For the accidents costs of air freight transport a value of a statistical life approach is used (1.5 million euro) and the database of ICAO for determining the fatalities. This resulted in an external cost of €0.0/tonne-kilometer. The reason why this is probably so low is that air travel is one of the safest modes of transport, so almost no accidents happen and when an accident happens with a cargo plane there are not a lot of people involved as compared to passenger transport (OECD, 2008).

Road transport
In determining the accidents costs of road transport, the following five main components are included: human costs, medical costs, administrative costs, production losses and material damages. It is important to note that costs related to the prevention of accidents are not included

in these costs. In calculating these costs use was made of accident statistics and costs per casualty. This resulted in an external costs of €0.013/tonne-kilometer (CE Delft, 2019).

Cargoloop

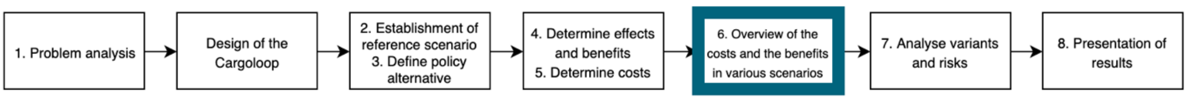
As the Cargoloop will operate autonomously it is expected that no accidents will happen. The safety costs of the Cargoloop are therefore established at 0.0 €/tonne-km.

Transport mode	Average costs safety (in €/tonne-km)
Aviation freight	0.00
Heavy good vehicles	0.013
Cargoloop	0.00

8

Overview costs and benefits in various CBA scenarios

In order to obtain an idea of the economic feasibility of the Cargoloop, three scenarios are created. These scenarios can be divided into the way the initial investment is financed: 1) in the first CBA scenario, the initial investment and the exploitation of the project is private; 2) in the second CBA scenario, the initial investment is financed externally, but the exploitation is private; 3) in the third CBA scenario, the initial investment is financed by the government, but the exploitation is private again. In addition, within these three CBA scenarios, different sub scenarios are created to explore the scenarios under different conditions. such as what the effect is of a 100% modal share of the Cargoloop is on the NPV or what the effect is when the full capacity of the Cargoloop is used. In order to keep an overview of the different scenarios, figure 11 provides the structure of this chapter.



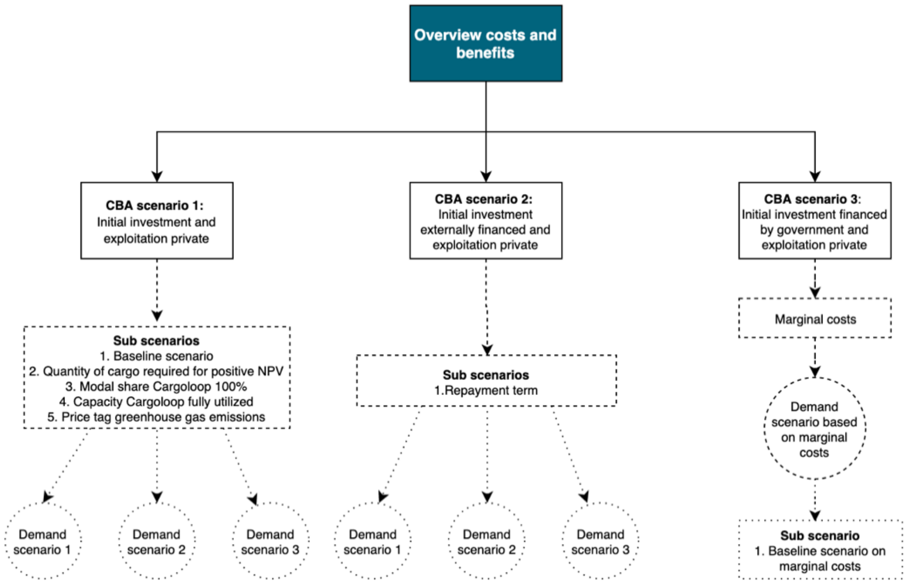


Figure 11 - Overview of structure of chapter 10

8.1 CBA Scenario 1: Initial investment and exploitation of the project is private

In this first CBA scenario, the initial investment and the exploitation of the project is private. To investigate the economic viability of the Cargoloop in this scenario under different conditions, several sub scenarios are created. However, first, an overview is given of the costs and the benefits without making any adjustments to the current parameters. This scenario will be called the 'baseline' scenario. In order to examine this baseline scenario under different conditions, the following sub scenarios are created:

Sub scenario 1: Quantity of cargo required for positive NPV
Sub scenario 2: Modal share Cargoloop 100%
Sub scenario 3: Capacity Cargoloop fully utilized
Sub scenario 4: Price tag for greenhouse gas emissions

In all these scenarios the wider economic benefits are included. The structure of this section is as follows, first the base scenario is described (Section 8.1.1), followed by a description of the sub scenarios 1 to 4 successively in the following sections (Section 8.1.2 till 8.1.5)

8.1.1 Baseline scenario

The demand in this baseline scenario of the Cargoloop is derived from the earlier found modal shares in the three different demand scenarios in chapter 6. This means that the modal share of the Cargoloop in the successive scenarios 1, 2 and 3 is equal to 77%, 20% and 2%. Moreover, the tariffs used for the Cargoloop in the successive scenarios 1, 2, and 3 are equal to 0.11€/ton-km, 0.25 €/ton-km, 0.39 €/ton-km. A detailed overview of the cost and the benefits in this baseline scenario is shown in table 20.

The first aspect that stands out when looking at table 20 is that there is no scenario in which the Cargoloop is economically feasible. Referring to the earlier discussed interpretation of the outcome of the NPV and BCR, it can be found that no scenario has a positive NPV and none of the

scenarios has a higher BCR than 1. This means that the costs do not exceed the benefits and the project cannot be considered as viable.
When looking at an explanation for this negative outcome, the main reason that can be found is that the capacity in each scenario is far from fully utilized. Looking at the ratio between the annual operational vehicles in the scenarios and the annual capacity of the Cargoloop, it can be found that in scenario 1, only 3.5% of the capacity is utilized. Furthermore, in scenario 2 this is respectively 0.73% and in scenario 3 only 0.09%.

Table 20 - Overview of costs and the benefits in million euros in the baseline scenario

	Demand scenario 1	**Demand scenario 2**	**Demand scenario 3**
Discount factor: 5%[1]			
Investment cost	-€ 3,677	-€ 3,677	-€ 3,677
Operating costs – maintenance track	-€ 115	-€ 115	-€ 115
Operating costs – maintenance vehicle	-€ 81	-€ 21	-€ 2
Operating costs – energy	-€ 80	-€ 20	-€ 2
Revenue	€ 1,295	€ 764	€ 119
Travel time savings	€ 366	€ 93	€ 5
Greenhouse gas	€ 457	€ 147	€ 67
Air pollution	€ 109	€ 30	€ 6
Noise	€ 102	€ 27	€ 4
Congestion	€ 141	€ 36	€ 2
Traffic safety	€ 54	€ 14	€ 0.77
Total NPV	**-€ 1,429**	**-€ 2,722**	**-€ 3,592**
Benefit-cost ratio	**0,64**	**0,29**	**0,05**

An explanation for this low capacity utilization can be found in the estimated modal shares or in the amount of cargo transported. Meaning that estimated modal share is too low in the scenarios to make a positive business case or there is not enough cargo carried on this route overall.

[1] The discount rate proposed by the European Commission (2014)

This however, raises the next questions such as what the NPV would be if the modal share of the Cargoloop would be 100% on this route and whether the amount of cargo transported on the route between the airports of Cologne-Bonn and Paris-CDG would be enough to obtain a positive NPV overall. These questions, among others, will be answered in the following section (Section 8.2) in which different sub-scenarios will be established.

8.1.2 Sub scenario 1: Quantity of cargo required for positive NPV

In the baseline scenario, described earlier in Section 8.1, it was found that in none of the scenarios the NPV of the Cargoloop is positive. It was discussed that this could be a consequence of the amount of the cargo that is transported on the route. In this sub scenario it is investigated what amount of cargo is needed to cover the costs in each scenario. In doing so, the modal share in each scenario is stayed the same, so it is determined what the overall amount of additional cargo should be to cover the costs (resulting in also an increase in the amount of cargo transported via road and air).

Table 21 – Additional amount of cargo that is needed to obtain a positive NPV in each tariff scenario

Scenarios	Current amount of cargo *(in tonnes)* transported between Cologne-Bonn and Paris-CDG	Overall additional amount of cargo *(in tonnes)* needed for positive NPV	Overall amount of cargo *(in tonnes)* needed for positive NPV
Demand scenario 1	900,000	500,000	1,400,000
Demand scenario 2		2,200,000	3,100,000
Demand scenario 3		8,000,000	17,000,000

From table 21 it can be seen that to make demand scenario 1 feasible, 500,000 tonnes of cargo are needed. It was expected that the least amount of cargo was needed in this scenario as the modal share of the Cargoloop is the highest in this scenario. Taking into account the route between the airports of Cologne-Bonn and Paris-CDG, that was defined in Section 5.3, in which it was decided to go pass by Liège because of the possibility of including this airport into the future network, this scenario might be feasible when the airport of Liège would meet the required additional amount of 500,000 tonnes. Whether this is realistic, will be discussed further in chapter 10.

The overall additional amount of cargo needed to obtain a positive NPV in demand scenario 2 and 3, however, looks not realistic by only including Liège. In order to obtain the overall amount of cargo needed for a positive NPV, the route should be extended by including more airports. This, however, will also lead to an increase of the investment costs. It should therefore then be examined whether the benefits of the added amount of cargo will be enough to outweigh the costs of the extra investment costs.

8.1.3 Sub scenario 2: Modal share Cargoloop 100%

In the second sub scenario, it is investigated what the effect of a 100% modal share of the Cargoloop on the route between the airports of Cologne-Bonn and Paris-CDG would be on the NPV in each demand scenario. These demand scenarios are now not different anymore regarding their demand but in their tariffs. Referring back to Section 6.2, in which these different tariffs were primarily used to determine the demand. Summarizing in this sub scenario, the demand is the same in the scenarios, however, the tariffs used not. Meaning that the tariffs that are used for the Cargoloop are respectively 0.11€/ton-km, 0.25 €/ton-km and €0.39 €/ton-km. The results of this sub scenario are shown in figure 10 (to avoid the confusion as much as possible are instead of the previous distinction in demand scenarios, now tariff scenarios used in figure 12).

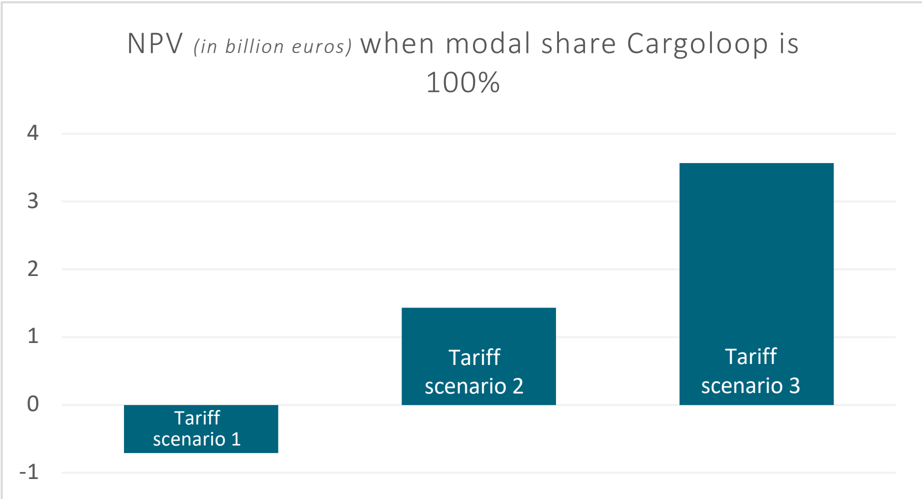


Figure 12 - NPV in billion euros in each scenario in which the modal share of the Cargoloop is 100% on the trajectory between Cologne-Bonn and Paris-CDG.

The first aspect that stands out when looking at the overview of the costs and the benefits in this sub scenario, is that the NPV of tariff scenario 1 is negative (EUR - 0,71 billion) but the NPVs of tariff scenarios 2 and 3 are positive (respectively EUR 1,43 billion and EUR 3,57 billion). This first finding, was already expected based on the results of the first sub scenario described in Section 8.1.2. It was found there, that approximately an additional 500,000 tonnes would be required to make the Cargoloop positive. This amount is fundamental larger than what can be achieved by shifting from the calculated modal share to a 100% modal share in scenario 1. That the NPV of the tariff scenarios 2 and 3 is positive, shows that the tariff used (respectively 0.25 €/ton-km and 0.39€/ton-km would be enough to cover the costs.

It is thus clear, that the break-even tariff in this sub scenario lies between the €0.11/ton-km and €0.25/ ton-km. When elaborating on this further, it was found that a tariff of €0.16/ton-km would make the Cargoloop economic viable when the modal share of the Cargoloop is 100% on the route between the airports of Cologne-Bonn and Paris-CDG.

8.1.4 Sub scenario 3: Capacity Cargoloop fully utilized

In the third sub scenario, it is investigated what the effect of a fully utilized capacity of the Cargoloop is on the NPV. In doing so, the same applies as in sub scenario 2: as the demand is fixed, the earlier mentioned demand scenarios now only differ in tariffs used. To avoid the confusion as much as possible, tariff scenarios is used again here instead of previous distinction made by using different demand scenarios.

The full utilization of capacity of the Cargoloop would mean that 2.628.000 Cargoloop vehicles, which is equivalent to the transport of 23.652.000 tons of air cargo, are used on the route between the airports of Cologne-Bonn and Paris-CDG. The results of this sub scenario are shown in figure 13.

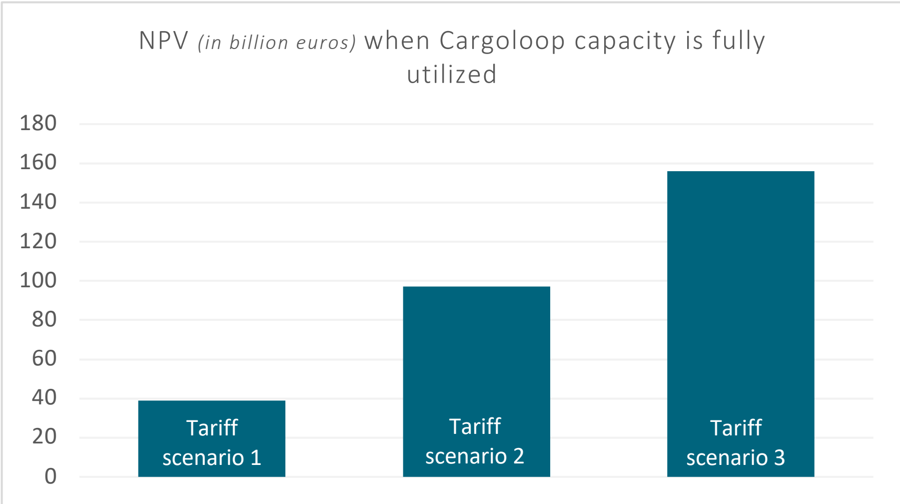


Figure 13 - NPV in billion euros in each scenario in which capacity of the Cargoloop is fully utilized on the trajectory between Cologne-Bonn and Paris-CDG.

It was earlier found in Section 8.1.1 that in demand scenario 1 was only 3.5% of the capacity is utilized, in demand scenario 2 this was respectively 0.73% and in demand scenario 3 only 0.09%. Capacity utilization rates that are quite low. Shifting to a 100% utilization rate, results in all three tariff scenarios that the NPV of the Cargoloop is positive, as can be seen in figure 13. The NPVs are respectively: EUR 39 billion, EUR 97 billion and EUR 156 billion. This was expected, as figure 12 already showed that for two of the three scenarios the total amount of cargo transported on the route between Cologne-Bonn and Paris-CDG would be enough to make the Cargoloop economic viable if the modal share is 100%.

8.2.5 Sub scenario 4: Price tag for greenhouse gas emissions

In this sub scenario it is explored what the price tag of greenhouse gas emissions should be to cover the costs of the Cargoloop in each demand scenario. In other words, it is investigated with which value for the external costs of greenhouse gas emissions emissions, the demand scenarios will have a positive NPV. In doing so, the following values for the external costs of greenhouse gas emissions were found in the appropriate scenarios as shown in table 22.

Table 22 - Price tag for CO2 to obtain a positive NPV

Scenarios	Current external costs *(in €/ton-km)*	Increasing with factor	New value of external costs *(in €/ton-km)*
Demand scenario 1	Air: 0,2357 Road: 0,0053	5	Air: 1.18 Road: 0.03
Demand scenario 2		20	Air: 4.71 Road: 0.11
Demand scenario 3		60	Air: 14.14 Road: 0.32

To obtain a positive NPV in demand scenario 1, the current external costs for the air transport should increase with a factor of 5. In demand scenario 2, this factor should be 20 and in demand scenario 3, an increase with a factor of 60 is required. Based on logical reasoning, it could be said that increasing the factors that are required for demand scenarios 2 and 3 will not occur practice because of their fundamental increase in price. The increasing factor required to make demand scenario 1 positive, is somewhat more likely. However, it is difficult to assess whether this increase could be possible in practice.

8.2 CBA Scenario 2: Investment externally financed, exploitation of the project is private

In this second CBA scenario, the initial investment is externally financed, and the exploitation of the project is private. To investigate the economic viability of the Cargoloop in this CBA scenario under different conditions, a sub scenario is created. In calculating the annual financing costs, assumptions have to be made about the repayment terms and interest rate. In doing so, it is assumed that the interest rate is fixed at 5%, however, one sub scenario is created to examine what the effect is of different repayment terms on the NPV:

Sub scenario 1: Various repayment terms

This sub scenario will be discussed below.

8.2.1 Sub scenario 1: Various repayment terms

As aforementioned it is assumed that the interest rate is fixed at 5%, the repayment term in this scenario however is considered as variable. Meaning that there is looked at how a different duration of the repayment terms affects the NPV of the project. In doing so, a range from 30 to 50 years is chosen as the maximum life duration of the Cargoloop is estimated at 50 years. The results of this sub scenario are presented in the table 23.

Table 23 - NPV and BCR in millions euros of demand scenario 1, 2 and 3 for various repayment terms

Demand scenario 1	30 years	40 years	50 years
NPV	-€1,915	-€805	-€621
BCR	0.69	0.76	0.80

Demand scenario 2	30 years	40 years	50 years
NPV	-€2,454	-€2,099	-€1,915
BCR	0.31	0.35	0.37

Demand scenario 3	30 years	40 years	50 years
NPV	-€3,366	-€3,012	-€2,828
BCR	0.05	0.05	0.06

From table 23, it can be seen that how longer the duration of the repayment term is, the higher the NPV and BCR become. In doing so, the positive increase has the most fundamental effect on scenario 1, in which the modal share of the Cargoloop is the highest. What also can be seen is that the Cargoloop is still not economically feasible. The, NPV and BCR, however improved, compared to the values found in Section 8.1.1 (this will be discussed more in detail in chapter 10) but still no positive NPV or a BCR higher than 1 is obtained. Meaning that the project cannot be considered as viable.

8.3 CBA Scenario 3: Initial investment financed by government, exploitation of the project is private

In the third CBA scenario, the initial investment is financed by the government and the exploitation of the project is private, a financial construction which resembles the financial construction of the Betuwe route. For this Dutch freight railway line, the government paid for the investment costs itself after the absence of investments from commercial parties. The exploitation costs, however, are operated in a cost-effective manner (Algemene Rekenkamer, 2016).

In this scenario, the above-mentioned construction of the Betuwe route is applied to the financing of the Cargoloop. In doing so, the exploitation of the project is not allowed to make any profit. The exploitation costs are thus calculated based on only covering the costs and no economic benefits are included.

The approach of this scenario therefore differs from the earlier described approaches. Whereas in the previous scenario the tariff of the Cargoloop was based on the prices of road and air transport, the price of the Cargoloop will now be calculated on the basis of the marginal costs. This in turn will also affect the modal share.

8.3.1 Marginal costs

The marginal costs depend om the number of vehicles used. The costs of the energy usage and the maintenance of the vehicles are calculated per vehicle-km. These costs are shown below. The costs of the maintenance of the track, however, depend on the capacity used.

	Costs in €/vehicle-km
Energy costs vehicle	€0.049
Maintenance costs vehicle	€0.05

It should be noted that the above values are presented in €/vehicle-km. To translate these values to €/tonne-km (in which also the tariffs of road and air transport are defined), it is dived by 9 as this was the previously defined payload of a Cargoloop vehicle described in Section 5.2.5.

To provide an insight into the marginal costs, different scenarios have been created for the capacity used of the Cargoloop: 100%, 75%, 50%, 25%, 5%, 1% and, 0,1%. The latter low values are relevant for the previously found capacity use in Section 8.1.1 of the Cargoloop on the route between the airports of Cologne-Bonn and Paris-CDG. An overview of the marginal costs per capacity usage percentage is shown in table 24.

Table 24 - Marginal costs per capacity usage percentage

Capacity used *(in %)*	**Marginal costs** *(in €/ton-km)*
100	0.011
75	0.012
50	0.012
25	0.013
5	0.019
1	0.049
0.1%	0.4

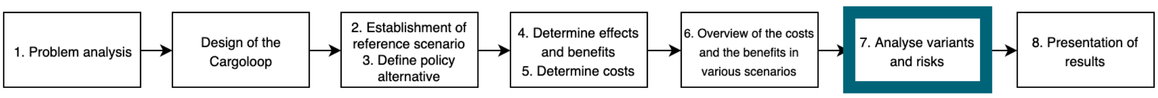
As it can be seen from table 24, the marginal costs increase when the capacity used decreases. An interesting finding is that when this financial construction would be applied for financing of the Cargoloop, the marginal costs of the Cargoloop would only exceed the current operating costs of aviation (0.39 €/ton-km) by a capacity usage of 0.1%. Furthermore, when looking at table 24, it can be seen that when the capacity is used for only 1%, the Cargoloop would also be lower compared to current operating costs of road transport (0.11 €/ton-km). This in turn, would also influence the modal share of the Cargoloop, as transport via the Cargoloop will become more attractive due to its lower price. It was earlier in Section 8.1.1 that in demand scenario 1, only 3.5% of the capacity is utilized. Furthermore, in demand scenario 2 this is respectively 0.73% and in demand scenario 3 only 0.09%. Capacity utilization rates that are quite low. It would therefore be interesting to find out what the effect of the marginal costs of 1% capacity usage would be on the modal share.

Using the same approach and parameters found for determining the demand of the Cargoloop in chapter 6, it was found that the marginal costs of a capacity utilization of 1% which is 0.049 €/tonne-km, would result in a modal share of 92%. A substantial increase compared to the previously found modal shares of the Cargoloop in the demand scenarios 1, 2 and 3 which were respectively 7%, 20% and 2%. When in turn, calculating whether this modal share and the marginal cost price would result in a positive NPV, it can be found that is not the case. This was, however, already expected as in Section 8.1.3 it was found that a tariff of 0.16 €/tonne-km would be necessary to obtain a positive NPV in case of a 100% modal share.

9

Analyse variants and risks

An overview of the costs and the benefits in several scenarios are presented in the previous chapter. The next step in the preparation for the CBA is an analysis of variants and risks. The future is uncertain which means that the ex-ante estimation of the costs and the benefits of a new alternative are subjected to a certain degree of uncertainty. This uncertainty also reflects in the outcome of the CBA. Regarding this uncertainty, there can three types be distinguished: 1) prediction uncertainty; 2) estimation uncertainty; 3) structural uncertainty (CPB & PBL, 2013). The first two types of uncertainty can be assessed by a sensitivity analysis and the latter by using scenarios of possible future trends. First the sensitivity analysis is carried out (Section 9.1), followed by the scenarios of possible future trends (Section 9.2)



9.1 Prediction and estimation uncertainty

Prediction and estimation uncertainty arise from the limitations of our knowledge about the effects and the measure of how to value them. In this section, the uncertainty of the independent parameters in the baseline scenario (discussed in Section 8.1.1) is investigated by means of a sensitivity analysis. These tested variables should be deterministically independent and as disaggregated as possible to make sure that no double-counting takes place. In the sensitivity analysis, one variable is changed at the time and the effect of that change on the NPV is listed. A guiding criterion in this analysis is that if a change of 1 %-point in a variable leads to more than, either positive or negative, 1 %-point change of the NPV, such a variable is considered as 'critical' (European Commission, 2014). The rationale behinds these critical variables is that a change in these critical variables affects the outcome substantial and it shows where additional analysis may be beneficial before accepting the project.

The sensitivity analysis is carried out on the baseline scenario described earlier in Section 8.1.1. The result of the sensitivity analysis of the CBA are presented below in table 25.

Table 25 - Sensitivity analysis of CBA

Change in NPV *(in %-point)*	**Demand scenario 1**		**Demand scenario 2**		**Demand scenario 3**	
Change *(in %-point)*	**-1**	**+1**	**-1**	**+1**	**-1**	**+1**
Discount rate	+15.69%	-12.51%	+2.68%	-1.92%	-1.32%	+1.32%
Expected growth of cargo	-23.6%	+28.38%	-5.56%	+6.67%	-0.8%	+0.98%
Investment costs	+2.57%	-2.57%	+1.35%	-1.35%	+1.02%	-1.02%
Maintenance costs - track	+0.08%	-0.08%	+0.04%	-0.04%	+0.03%	-0.03%
Maintenance costs - vehicle	+0.06%	-0.06%	+0.007%	-0.007%	+0.0005	-0.005%
Operational costs	+0.06%	-0.06%	+0.007%	-0,007%	+0.0006%	-0.0006%
Travel time savings	-0.26%	+0.26%	-0.03%	+0.03%	-0.0014%	+0.0014%
Emissions	-0.32%	+0.32%	-0.05%	+0.05%	-0.02%	+0.02%
Pollution	-0.07%	+0.07%	-0.01%	+0.01%	-0.002%	+0.002%
Noise	-0.07%	+0.07%	-0.01%	+0.01%	-0.001%	+0.001%
Traffic safety	-0.09%	+0.09%	-0.01%	+0.01%	-0.0005%	+0.0005%
Congestion	-0.04%	+0.04%	-0.005%	+0.005%	-0.0002%	+0.0002%

From table 25, it can be seen that a change of 1%-point in the investment costs, the expected growth of the cargo and the discount rate results in more than 1%-point change of the NPV. In other words, these variables are considered as the critical variables of the project. Additional research on these variables may be beneficial before accepting the project.

What also can be seen is that the as the modal share of the Cargoloop (which decreases from demand scenario 1 to demand scenario 3), the impact of the variables on the NPV decreases. As for example, a 1%-point change in the operational costs in demand scenario 1 has less impact on the outcome of the NPV compared to a 1%-point change in demand scenario 3. This was expected because as the modal share of the Cargoloop becomes lower, also the operational costs become lower and the share of these costs compared to investment costs becomes also lower.

What an interesting finding is, however, the effect of a 1%-point change in the discount rate in each of the scenarios. In table 25, it can be seen that in scenario 1 and 2, an increase in the discount rate will lead to an increase in the NPV. This was expected as by decreasing the discount rate, the money obtains more of its 'value' in the longer term. In scenario 3, however, the opposite can be observed. An explanation for this could be that if the discount rate is lower, the value of both the costs and the benefits is higher over the longer term, however as in scenario 3, these benefits are relatively low (as the Cargoloop has a low modal share on this route, only 2%) the impact of the costs increases more in proportion to the benefits.

9.2 Structural uncertainty

Structural uncertainty can be for example, uncertainty about the future. Future developments can influence variables, which in turn can have an impact on the outcome of the CBA. To deal with this type of uncertainty, scenarios can be created.

In Section 6.1.2 it was already described that the value of the air cargo growth within Europe found by Boeing (2017) could not be verified as no other research was found with a specific demand prediction of air cargo flown within Europe over a long period of time. Furthermore, the found growth rate of Boeing was for the next 20 years instead of 30 years for which it is used in this CBA. The probability that the growth rate will deviate from the growth rate used in this study is therefore large.

In this study, the uncertainty about the growth in the future demand is a structural uncertainty and is therefore assessed in this section. In doing so, the effect on the CBR for a change in various percentages on the growth factor is tested. This led to the following outcomes shown in table 26.

Table 26 - Results of demand scenario analyze

Change in growth *(in %-point)*	**-2**	**-1**	**0**	**1**	**2**
Cost to benefit ratio – demand scenario 1	0.48	0.55	0.64	0.74	0.86
Cost to benefit ratio – demand scenario 2	0.22	0.25	0.29	0.34	0.40
Cost to benefit ratio – demand scenario 3	0.04	0.05	0.05	0.06	0.07

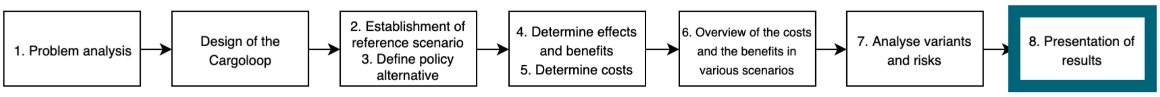
From this scenario analysis it can be seen that a positive change in the growth rate, result in a more positive BCR. Moreover, it was found that the higher the modal share in the demand scenarios, the faster the increase of the BCR. This was expected as the increase of cargo would result in more revenue and positive benefits.

It can be seen in table 26, that the BCR in demand scenario 1 increases quickly with an increase in the growth rate. Based on the above growth, it could be expected that by an increase of 3%-point of the growth rate, the Cargoloop might be economically feasible in demand scenario 1. In other words, if it was found that the growth rate deviates more than 3%-point of the current growth rate, the Cargoloop might be considered as economically feasible in demand scenario 1.

10

Results of CBA

All steps as of the preparation for the CBA have been carried out. In this chapter, the results of the various CBA scenarios described in chapter 8 (Section 10.1) are discussed, followed by a discussion of the analyse variants and risks (Section 10.2).



10.1 Discussion results CBA scenarios

In neither of the three CBA scenarios the Cargoloop was found as economically viable. A fundamental factor for explaining why the Cargoloop is not economically viable is that when looking at the number of vehicles that would be annual operational on the route between the airports of Cologne-Bonn and Paris-CDG compared to the annual capacity of the Cargoloop, it could be found that only a small percentage of the capacity of the Cargoloop is utilized on this route. Substantial more cargo would need to be transported to make the Cargoloop economically feasible on this trajectory. This could be realized by obtaining a larger modal share or by expanding the network, so the overall cargo flow will become larger.

A first remarkable finding that was found, was that by financing the initial investment externally, a higher NPV and BCR can be obtained compared to when the initial investment is privately financed. As for example, in CBA scenario 1, in which the initial investment and exploitation were both private, the NPV and BCR of demand scenario 1 were respectively: €1,429,000 and 0.64. While in CBA scenario 2, in which the initial investment was financed externally and exploitation was private, the NPV and BCR of demand scenario 1 were respectively: €1,915,000 and 0.69 (30 years payback terms). When the payback term increased, this even led to an NPV and BCR of respectively: €621,000 million euros and 0.80. A fundamental positive increase could thus be observed when the initial investment is externally financed. The increase was substantial but not crucial in the way that it did not cause the difference between being economically viable or not. In both CBA scenarios, the Cargoloop was with a negative NPV and a BCR lower than 1, still not economically viable.

An interesting finding, which was already shortly mentioned in chapter 9, was the amount of cargo that was needed to make demand scenario 1 in Section 8.1.2 economically viable. It was found that approximately an overall additional amount 500,000 tonnes of cargo would be needed on the trajectory between the airports of Cologne-Bonn and Paris-CDG to make the Cargoloop, with the estimated modal share (77%) in demand scenario 1, economically viable. Considering the route between the airports of Cologne-Bonn and Paris-CDG, that was defined in section 5.3 in which it was decided to go pass by Liège because of the possibility of including this airport into the future network, obtaining a positive NPV in this scenario might be realistic when the airport of Liège would be included on this trajectory. In realizing this, the airport of Liège would need to meet the required additional amount of 500,000 tonnes. The latter could be realistic as Liège belongs to the top ten largest cargo airports in Europe and knowing that approximately 900,000 tonnes of cargo are transported between the airports of Cologne-Bonn and Paris-CDG which also both belong to this top ten of largest cargo airports. However, no answer can be given on that question yet as more research is needed due to the lack of the available data regarding the transport of air cargo from and to the airport of Liège. Moreover, it would be interesting to calculate the amount of cargo that is needed to obtain a positive NPV in CBA scenario 2 (initial investment is externally financed). As it was discussed in the previous paragraph, external financing of the initial investment resulted in a higher NPV and BCR compared to these values in CBA scenario 1. Due to this effect, it would be expected that the amount of cargo needed to obtain a positive NPV in CBA scenario 2 would be lower than 500,000 tonnes resulting in an even higher probability that this scenario could be economic feasible when including Liège. The above-mentioned recommendations: 1) obtain data about cargo flows of Liège airport and; 2) calculate the amount of tonnes necessary to obtain a positive NPV in demand scenario 1 of CBA scenario 2; will be described as recommendations for further research in chapter 12. Important to note, however, is that this further research of including Liège in the trajectory, is not relevant in the demand scenarios 2 and 3 of CBA scenario 1. The overall additional amount of cargo needed to obtain a positive NPV in these scenarios, looks not feasible by only including Liège. In order to achieve a positive NPV, the route should be extended by including more airports. This, however, will also lead to an adjustment of the trajectory and an increase of the investment costs.

A final interesting finding were the marginal costs calculated in Section 8.3.1, which were based on the scenario in which the government would finance the initial investment and the exploitation costs would be private but only cost covering. It was earlier in Section 8.1.1 that in demand scenario 1, only 3.5% of the capacity is utilized, in demand scenario 2 respectively 0.73% and in demand scenario 3 only 0.09%. Capacity utilization rates that are quite low. It would therefore be interesting to find out what the effect of the marginal costs of 1% capacity usage would be on the modal share. It was found that if at least 1% of the Cargoloop's annual capacity is used, the rate of the Cargoloop that would be based on the marginal cost (0.049 €/ton-km) in this scenario, would be substantial lower than the tariffs used in this study for road and air transport (respectively 0.11 €/ton-km and 0.39 €/ton-km. This in turn, would also affect and result in a different modal share than the estimated one in chapter 6. As for example, the marginal costs of a 1% capacity usage of the Cargoloop (average capacity usage that was found in Section 8.1.1 of the

Cargoloop on the route Cologne-Bonn and Paris-CDG), which is 0.049€/ton-km, would result in a modal share of 92% for the Cargoloop and 8% for road transport (using the parameters found before in chapter 6). A substantial increase compared to the previously found modal shares of the Cargoloop in the demand scenarios 1, 2 and 3 which were respectively 7%, 20% and 2%. It was found that the marginal costs of a capacity utilization of 1% which is 0.049 €/tonne-km, would result in a modal share of 92%. When in turn, calculating whether this modal share and the marginal cost price would result in a positive NPV, it can be found that is not the case. This was, however, already expected as in Section 8.1.3 it was found that a tariff of 0.16 €/tonne-km would be necessary to obtain a positive NPV in case of a 100% modal share.

10.2 Discussion results analyse variants and risks

In the sensitivity analysis it was found that a change of 1%-point in the investment costs, the expected growth of the cargo and the discount rate resulted in more than 1%-point change of the NPV. In other words, these variables can be considered as the critical variables of the project and additional research on these variables may be beneficial before accepting the project. Finding these variables as critical variables and referring back to the way in which these variables are substantiated in this study and considering their crucial effect on the economic feasibility of the Cargoloop, highlights the importance of doing more research on these variables.

As mentioned before, the growth factor of the air cargo is only calculated on the basis of a study of Boeing (2017). The growth factor could not be verified as no other research was found with a specific demand prediction of air cargo flown within Europe over a long period of time. Furthermore, the found growth rate of Boeing was for the next 20 years instead of 30 years for which it is used in this CBA. The probability that the growth rate will deviate from the growth rate used in this study is therefore large. There is thus already a lot of uncertainty about the representativeness of the growth factor, this combined with the fact that it is a critical variable in the CBA, ensures even more that more research into the growth factors is necessary in order to obtain a more reliable outcome of the CBA in which this variable is clearly substantiated.

The investment costs of the Cargoloop are based on the implementation costs of the NEL pipeline. In doing so, it assumed that the implementation costs of the NEL pipeline have been doubled to calculate the costs of the Cargoloop (the implementation of the NEL pipeline only consisted of one tube). However, this does not have to be the case in practice, as for example, it could be expected that placing two tubes at the same time underground would be less than double the costs. It can thus be noted that also in this variable, there is a lot of uncertainty about the representativeness for the Cargoloop. This combined with the fact that it is a critical variable in the CBA, again ensures that more research is required in order to obtain a more reliable outcome of the CBA in which this variable is clearly substantiated.

11

Discussion and conclusion

This chapter answers and discusses the research questions that were asked at the beginning of the study. In Section 11.1 the first research question is answered, followed by the second research question in Section 11.2. Finally, there is a discussion of the results with respect to the theoretical framework in Section 11.3.

11.1 Answer to research question 1: Design of the Cargoloop

The starting point of this research was the expectation that the Cargoloop, could theoretically offer a solution for the bottlenecks found in the express delivery market. It is expected from this market that it will grow strongly in the coming years. Besides that, the Cargoloop was considered as a solution for the unsustainable nature of the current transport. Furthermore, the Cargoloop could also act as a stepping stone towards transporting passengers via the hyperloop. However, little research had been done into this cargo application of the hyperloop. The aim of this study was therefore to fill in some of the identified knowledge gaps. In doing so, the political economy model of transport innovations of Feitelson and Salomon was used as theoretical underpinning. In using this modal as theoretical framework, it was found that investigating the economic feasibility would be relevant as one of the first steps in exploring the feasibility overall as the economic feasibility impacts on many other factors and even other feasibility forms.

However, before the economic feasibility of the Cargoloop could be explored, the Cargoloop needed to be designed first. This process of designing the Cargoloop was divided into three steps: 1) main lines of the design; 2) technical specifications; 3) initial route of the Cargoloop. During the first step, it was found that the Cargoloop could serve as an alternative to the current aviation industry within Europe. In other words, the Cargoloop would connect airports. This connection between airports is characterized by three important factors: 1) most of the air cargo is not flown between airports but is trucked within Europe; 2) in both modes the transport is mostly done via pallets and the most common used pallet is a EURO pallet; 3) both, aviation and road transport deal with a consolidation constraint.

In the second step, the design of the Cargoloop was further elaborated technically. A Cargoloop with a 142 cm tube diameter was established. A diameter is smaller than the required diameter for passenger transport and will therefore thus result in a cargo-only application. When further elaborating the design technically, a speed of 700 km/h, frequency of 6 departures per minute, payload of 9-ton, annual capacity of 2,628,000 vehicles and energy consumption of 454 Wh/vehicle-km were determined.

Regarding the third step, the route between the airports of Cologne-Bonn and Paris-CDG was found as an initial route for the Cargoloop. The choice for this route was based on the condition mentioned by the transport experts to find the route that consist of the largest air cargo flow within Europe. When the route was defined geographically, it was decided to choose the route that goes through Belgium and passes by Liège. This decision was made regarding the possibility of including the airport of Liège into the future network of the Cargoloop, as this airport belongs to the top ten cargo airports of Europe. On the other hand, the challenge of choosing for this route is that it will almost completely pass through Belgium, while it is not certain whether Liège will be involved. In order to get an agreement to build this route through Belgium, the plausibility that Liège will be added to this route must be clearly mapped out.

It is however, important to note that the Cargoloop is new and no research into the design of the Cargoloop had been carried out before. This study made clear what a possible design of the Cargoloop could be when the identified type of market for the Cargoloop is the transport of air cargo. However, when the focus on the type of market changes, it is likely that the design of the Cargoloop will also be different. As for example, when the focus would be on the maritime sector, it is likely to assume that the Cargoloop would be able to transport maritime containers instead of EURO pallets, which in turn would affect the diameter of the tube.

11.1.1 Discussion of results research question 1

Defining the main lines of Cargoloop design

The main lines of the design of Cargoloop have been established based on the input of the transport experts. Their input was crucial for the design of the Cargoloop. In total four interviews were held as these interviews were sufficient to fill in the previously identified knowledge gaps during the analysis of the current express freight market. Besides that, the transport experts initiated similar ideas for the implementation of the Cargoloop and no new insights regarding the type of market for the Cargoloop were obtained anymore. As the design of the Cargoloop has never been investigated before, it was not possible to compare the suggestions found in this study to designs of possible similar studies. There is therefore a certain chance that if other experts were interviewed, this could possibly lead - in the worst-case scenario - to another design. This is however based on logical reasoning, is not expected, as the interviewed transport experts came up with similar ideas independently from each other. In addition, those who have been interviewed mainly had a scientific background. This means that the design of the Cargoloop comes not from an industrial perspective. It could therefore be possible that the design does not have the specifications that would have been desired in practice.

Technical specifications of the Cargoloop

The technical specifications of the Cargoloop are based on in-house expertise and logical reasoning. These specifications however, could not be verified, because as mentioned earlier, the design of the Cargoloop was never investigated before. These specifications, however, are crucial later in the study when the CBA is carried out. For example, the choice for the diameter has a tremendous impact on the initial investment and thereby also on the economic feasibility of the Cargoloop. The same also goes for the payload and the energy use of the vehicle. It should be considered therefore, that these specifications are subject to a certain uncertainty and that the design established in this study is only one possibility.

11.2 Answer to research question 2: Economic feasibility of the Cargoloop

The aim of this study was to explore the economic feasibility of the Cargoloop by means of CBA. In doing so, the effect of the Cargoloop on the reference scenario was determined. This effect was determined for the following tariffs of the Cargoloop (which were in turn based on the tariffs of road and air transport) 0.11 €/ton-km, 0.25€/ton-km and 0.39 €ton/km. These tariffs resulted in the following modal shares for the Cargoloop respectively: 77%, 20% and 2%. For the demand of the Cargoloop that was established on the marginal costs a modal share of 92% was found.

In investigating the economic feasibility, the following three CBA scenarios were considered: 1) in the first scenario, the initial investment and exploitation of the project is private; 2) in the second scenario, the initial investment is financed externally but exploitation is private; 3) in the third scenario, the initial investment is financed by government but exploitation of project is private. In neither of the three CBA scenarios the Cargoloop was found as economically viable on the trajectory between the airports of Cologne-Bonn and Paris-CDG. A fundamental factor for explaining why the Cargoloop is not economically viable is that when looking at the number of vehicles that would be annual operational on the route between the airports of Cologne-Bonn and Paris-CDG compared to the annual capacity of the Cargoloop, it could be found that only a small percentage of the capacity of the Cargoloop is utilized on this route. Substantial more cargo would need to be transported to make the Cargoloop economically feasible on this trajectory. This could be realized by obtaining a larger modal share or by expanding the network, so the overall cargo flow will become larger.

Regarding this first suggestion; a larger modal share for the Cargoloop, it was found in CBA scenario 1 that if the modal share of the Cargoloop would be 100% on the route between the airports of Cologne-Bonn and Paris-CDG, the Cargoloop would only be feasible from a tariff of 0.16 €/ton-km or higher. Meaning that the Cargoloop tariff would be higher than that of road transport, ensuring in turn that a 100% modal share of the Cargoloop would not be realistic in practice. When the modal share was approach from the other perspective in CBA scenario 3; estimating the demand of the Cargoloop on the basis of marginal costs, a modal share of 92% was found. A substantial increase in modal share compared to the previously estimated modal shares as the marginal costs was substantially lower than the tariffs used in this study for road and air transport. The marginal costs here was calculated at an annual capacity of 1% (the maximum capacity of the Cargoloop that can be reached on the route between Cologne-Bonn and Paris-CDG) and had a value 0.049 €/tonne-km. A value that is lower than the earlier found 0.16 €/tonne-km and this scenario was therefore also not economically feasible.

Regarding the second suggestion: increasing the overall cargo flow, an interesting finding was the quantity of cargo required for positive NPV in demand scenario 1 (modal share of 77%) of CBA scenario 1. It was found that approximately an overall additional amount of 500,000 tonnes of cargo would be needed to make the Cargoloop economically viable between the airports of

Cologne-Bonn and Paris-CDG. Considering the route between the airports of Cologne-Bonn and Paris-CDG, which passes by Liège because of the possibility of including this airport into the future network, obtaining a positive NPV in this scenario might be realistic when the airport of Liège would be included on this trajectory. In realizing this, the airport of Liège would need to meet the required additional amount of 500,000 tonnes. The latter could be considered as realistic as Liège belongs to the top ten largest cargo airports in Europe and knowing that approximately 900,000 tonnes of cargo are transported between the airports of Cologne-Bonn and Paris-CDG which also both belong to this top ten of largest cargo airports. However, no answer could be given on that question yet as more research is needed due to the lack of the available data regarding the transport of air cargo from and to the airport of Liège. Important to note, however, is that this further research of including Liège in the trajectory, is not relevant in the demand scenarios 2 and 3 of CBA scenario 1. The overall additional amount of cargo needed to obtain a positive NPV in these scenarios, looks not feasible by only including Liège. In order to a positive NPV, the route should be extended by including more airports. This, however, will also lead to an adjustment of the trajectory and an increase of the investment costs.

The above finding, in which it is described that adding Liège on the route between the airports of Cologne-Bonn and Paris-CDG could make the Cargooop economically viable, also stresses the importance of including Liège on this Cargoloop route. This would make it more likely that Belgium would agree upon a Cargoloop route through their country as it is required that Liège will be included on the route to make the Cargoloop economically viable.

Furthermore, when comparing CBA scenarios 1 and 2, it could be found that financing the initial investment externally, resulted in a higher net present value (NPV) and benefit-cost ratio (BCR) compared to when the initial investment is privately financed. The longer the duration of the payback term for the external financing, the less negative NPV and BCR became. Following on this, it would be interesting to calculate the amount of cargo that is needed to obtain a positive NPV in demand scenario 1 of CBA scenario 2. As it was discussed in the previous paragraph, external financing of the initial investment resulted in a higher NPV and BCR compared to these values in CBA scenario 1. It would therefore be expected that the amount of cargo needed to obtain a positive NPV in demand scenario 1 of CBA scenario 2 would be lower than 500,000 tonnes resulting in an even higher probability that this scenario could be economic feasible when including Liège.

It should be noted however, that this CBA is based on the technical specifications that were designed for the Cargoloop in answering the previous research question. These specifications, as mentioned before, are subjected to a certain uncertainty as they could not be verified with other studies since no other studies were available regarding this. Moreover, also the maintenance costs and implementation costs were calculated on reference projects and their representativeness also comes with a degree of uncertainty. This in turn means that the outcome of the CBA should not be interpreted as 'decisive' because changes in the design or the costs are likely and could possible lead to other outcomes in the CBA scenarios.

11.2.1 Discussion of results research question 2

The variables that determined the demand of the Cargoloop
The demand of the Cargoloop in this study is based on the generalized costs as described before. These generalized costs in turn, are calculated based on the tariffs of the transport modes, the travel time and the VOT. The use of only these three variables for determining the demand can be considered as a relatively simple approach. By including more explanatory variables into this formulation of the generalized costs, the demand of the Cargoloop could be predicted more precisely. Especially including the loading and unloading time would be relevant since the speed of the Cargoloop and air transport are close to each other, but it is however, expected that the overall travel time including loading and unloading of the cargo for the Caroloop would be substantial faster compared to air transport due to a smaller vehicle size. By including this variable, the Cargoloop would probably also obtain higher modal shares, principally in demand scenarios 2 and 3, then the one found in this research. Which could in turn lead to a possible other outcome of the CBA scenarios.

The included economic benefits
In this CBA, the following external costs were included in the project: travel time savings, greenhouse gas emissions, noise nuisance, air pollution, congestion and safety. It was already aforementioned, that this CBA can be considered as an indices CBA, meaning that only the basic elements are included. It is however, possible to include the external costs of more effects such as reliability, comfort or security. Especially the factor reliability would be interesting to consider in this project. It is expected by moving autonomously through a closed environment, in which the transport will not be affected by for example the weather conditions, on-time delivery can be established. By elaborating the CBA further in detail and including more effects, a detailed insight of the pros and the cons of the Cargoloop could be obtained.

Operational costs of the Cargoloop
The operational costs of the Cargoloop consist of the maintenance costs and the energy costs. The maintenance costs are based on a reference study in which the maintenance costs of Maglev were calculated. The operational costs on the other hand are based on only in-house expertise. Both values could not be verified, as no research had been carried out into the costs before. With the use of these values in the CBA, uncertainty must be taken into account as the probability that the values used in this study will deviate from the observed values in practice is substantial.

Critical variables
In the sensitivity analysis it was found that the investment costs, the expected growth of the cargo and the discount rate could be considered as the critical variables of the project and additional research on these variables may be beneficial before accepting the project. Finding these variables as critical variables and referring back to the way in which these variables are substantiated in this study and considering their crucial effect on the economic feasibility of the Cargoloop, highlights the importance of doing more research into these variables. It was already described in Section 10.2 that there is a lot of uncertainty in both variables about their representativeness for the Cargoloop. This combined with the fact that it is a critical variable in the CBA, ensures that more research is required in order to obtain a more reliable outcome of the CBA in which the variables are clearly substantiated.

Three CBA scenarios

In exploring the economic feasibility of the Cargoloop, three CBA scenarios were created. There are however, also other possibilities to finance the initial investment such as by a public-private-partnership. In which a part of the initial investment is financed by the government and the other part externally. This would be an interesting scenario to explore as this would also be a realistic scenario since this combination was at first also a requirement of the government during the investment of the Betuwe route, however, due to the absence of commercial parties, the government decided to waive this condition. Since the Betuwe route is still not economically feasible, it might be expected that the government would not agree upon a financial construction that resembles the one of the Betuwe route.

11.3 Results placed in theoretical framework

The framework of Feitelson & Salomon (2004) was chosen as theoretical framework within this study. This political economy model of transport innovations showed that the adoption of innovations is related to the technical, economic, social and political feasibility of the innovation. It is insufficient if the innovation is only technical feasible, only supported from a political perspective or solely has a positive benefit-to-cost ratio. Rather, it is the combination of the several forms of feasibility that at least need to be met to ensure the adoption and diffusion of a transport innovation.

Exploring any form of feasibility described in the framework of Feitelson & Salomon would contribute to today's body of knowledge. However, in practice, it would not be possible to explore them all within this study due to the limited amount of time. It was therefore decided to only focus on the economic feasibility in this study.

This research showed that the Cargoloop on the trajectory between the airports of Cologne-Bonn and Paris-CDG is not economically viable. However, it did show that by including Liège it could potentially be economically feasible. By finding these results the research contributed to the study into the feasibility of the Cargoloop. According to Feitelson & Salomon, however, it not possible to say something about the overall feasibility of the Cargoloop since this is also based on the technical, social and political feasibility. A next step, after investigating whether the Cargoloop would be economically feasible by including Liège on the trajectory between the airports of Cologne-Bonn and Paris-CDG, would be to examine the 'perceived distribution of the benefits and costs', which is now possible as the benefits and costs are calculated. Followed by exploring the social feasibility of the Cargoloop which is directly affected by this 'perceived distribution of benefits and costs'.

12

Limitations, recommendations and reflection

This chapter discusses the limitations and recommendations for further research. Moreover, it reflects upon the study. In Section 12.1 the research limitations and recommendations are discussed, followed by the reflection in Section 12.2.

12.1 Research limitations & recommendations

Several limitations were identified during the research and will be discussed here. It is important to acknowledge these limitations as they could influence the results and the interpretation of the results. The limitations are divided into the two parts of this study: the design of the Cargoloop and the economic feasibility of the Cargoloop.

12.1.1 Limitations regarding design of the Cargoloop

- *The diameter of the tube is based on the supply side of the express freight market.*
  In this study, the diameter of the tube was based on the dimensions of the EURO pallet and the largest freight boxes transported by integrators. This was done because no information was available about the average height or dimensions of the air cargo transported between airports. It would however, been better if the diameter of the Cargoloop would be determined based on analysis of the dimensions of the cargo that is transported in this market as it could be better estimated which part of market you would be able to serve with your vehicle.
    - Recommendations for further research: Explore what the diameter of the tube would be if it would be determined based on the demand side of the express freight market.

- *The future use of loading units is unknown*
  It is unknown, what the trends of loading units in the future are. It was however considered important for the Cargoloop to be able to transport pallets if the transport mode would be integrated as well as possible on the route between Cologne-Bonn and Paris-CDG. This assumption had a crucial impact on the design of the Cargoloop. However, it is unknown whether pallets will still be used for a long time. Choosing the diameter of the tube is however, crucial for the size of the vehicles that move through it.
    - Recommendations for further research: Because it is a new mode of transport and the choice of transporting has such a crucial impact on the diameter of the tube, it would be recommended to investigate what the trends are for future loading units. So that the design of the Cargoloop fits as well as possible into the future.

- *Design might be biased to what is considered as effective from a scientific perspective*
  The design of the Cargoloop is based on the input from the transport experts and in-house expertise from Hardt Hyperloop. However, no input from the industrial sector is used to design the Cargoloop. This could lead to a possible mismatch between the design from a scientific perspective and the required design from an industrial perspective.
    - Recommendations for further research: To investigate the vision of the industry on the design of the Cargoloop to better design the Cargoloop on the needs of the industrial sector

- *Technical specifications could not be verified*
  The technical specifications of the Cargoloop are based only on in-house expertise and logical reasoning. It would however been better if these specifications could be verified. As these specifications such as energy usage are crucial later in the study when the CBA is carried out.

- *Initial route is determined on available but limited data*
  The initial route of the Cargoloop is determined on the available but limited data of Eurostat. It appeared that the amount of cargo transported was not enough in some scenarios to make the Cargoloop economically viable. It could be the case that on another route within Europe more cargo is transported. In that case, it would have been better to use that route then for this study.

- *Size of the vehicles*
  As aforementioned, it is likely that the vehicles will not have one size but will be able to adjust as efficient as possible to the amount of cargo that needs to be transported. In this research however, a 'fixed' size of the vehicle is assumed.

12.1.2 Limitations regarding economic feasibility of the Cargoloop

- *The expected growth demand is based on only one research.*
  To calculate the expected growth of the cargo, only one research is used. Furthermore, the growth factor described in this study was only for the next 20 years instead of 30 years for which the growth factor is applied within this study. It would have been better to compare several reports about the expected growth demand and to use a growth rate that was established for 30 years.

- *Implementation costs of the Cargoloop are based on the implementation costs of the NEL pipeline*
  Assumption is made about the implementation costs on the basis of the NEL pipeline. In doing so, it assumed that the Cargoloop would be build underground. However, this does not have to be the case in practice. It would have been better if it would be better underpinned whether the Cargoloop would be placed above or underground on the trajectory. Moreover, to calculate the implementation the costs of the NEL pipeline have been doubled to calculate the costs of the Cargoloop as the implementation of the NEL pipeline only consisted of one tube. However, this does not have to be the case in practices, as for example, it would be expected that placing two tubes at the same time underground would be less than double the costs.
    - <u>Recommendation for further research:</u> investigate whether the Cargoloop would be implemented above or underground on this trajectory and what the implementation costs of the Cargoloop would be.
    -
- *The percentage of the amount of cargo that can be transported by the Cargoloop is based on an assumption of the aviation industry*
- During the general analysis of the express freight market in Europe, it was found that 5-15% of the global air cargo has to be shipped by all-cargo aircraft exclusively, due to their dimensions or hazardous characteristics. It is likely that the cargo that can only be shipped in all-cargo aircraft exclusively, will also not be able to be shipped via trucks as the content of a cargo plane is larger than that of a truck. As the height of the Cargoloop is smaller compared to the height of a cargo airplane, it was considered that 15% cannot be transported via the Cargoloop. Applying this percentage to the Cargoloop was not well substantiated as no data was available on the dimension of the air cargo transported.

- *Maintenance costs are calculated based on Maglev*
  The maintenance costs are calculated based on the maintenance of Maglev. In doing so, the assumption is made that the maintenance costs of the Cargoloop could be 25% of the maintenance costs of Maglev. This assumption, however, could not be verified by other studies. However, it would be better if the maintenance costs of the Cargoloop would be determined based on the expected maintenance required for the Cargoloop instead of using a reference case.
    - <u>Recommendation for further research:</u> investigate and calculate what the expected maintenance costs of the Cargoloop would be.

- *Unrepresentativeness of the data used for demand modelling*
  The data used in this study for demand modeling was based on a combination between observed data and the modal share of road transport found in a research of Visser & Gordijn (2014). Whether this modal share is representative for the trajectory between the airports of Cologne-Bonn and Paris-CDG is unknown as no data is available.
    - <u>Recommendation for further research:</u> repeat the demand modelling for a new sample in which data for both, road and air transport is observed.

- *Up to date valuation of external costs of air cargo transport*
  The valuation of the external costs of air transport used within this study are from the year 2000. This could mean that the values are not up to date anymore. This could

therefore impact the effect and the benefits of the Cargoloop on the transport of cargo via air.

Additional recommendations for further research:

- Considering the 500,000 tonnes needed to obtain a positive NPV in demand scenario 1 in CBA scenario 1, it would be interesting to calculate the amount of cargo that is needed to obtain a positive NPV in CBA scenario 2 (initial investment is externally financed). As it was discussed earlier, external financing of the initial investment resulted in a higher NPV and BCR compared to these values in CBA scenario 1. Due to this effect, it would be expected that the amount of cargo needed to obtain a positive NPV in CBA scenario 2 would be lower than 500,000 tonnes resulting in an even higher probability that this scenario could be economic feasible when including Liège.

- The economic feasibility of the Cargoloop was measured in three different ways as explained before. There are however, also other possibilities to finance the initial investment such as by a public-private-partnership. In which a part of the initial investment is financed by the government and the other part externally. This would be an interesting scenario to explore as this would also be a realistic scenario since this combination was at first also a requirement of the government during the investment of the Betuwe route. It would therefore be interesting to investigate what the effect is of a scenario that consist of initial investment by the government as well as externally.

- Investigate what shippers would be willing to pay for transport via the Cargoloop. Exploring what shippers would like to pay for the transport of goods via the Cargoloop would provide an insight into what the profit margin of the Cargoloop could be and how the characteristics of the Cargoloop are valued money wise.

- Design the loading and unloading concept of the Cargoloop._Designing the loading and unloading concept of the Cargoloop would provide a better insight into the travel time used of the Cargoloop including the loading and unloading concept. This in turn, would an interesting variable in the generalized costs for demand modelling.

12.1.3 Recommendations for Hardt Hyperloop

A recommendation for Hardt would be to investigate whether it would be possible to make the diameter of the Cargoloop even smaller. In doing so, the initial investment costs will become substantial lower and the probability obtaining an economically viable project higher. However, it should be noted that this would only make sense if still a large part of the market can then be served by the new vehicle size.

12.2 Reflection on research contribution

12.2.1 Reflection on scientific contribution

So far, only two scientific articles were found in which transporting cargo via the hyperloop is explored and three ideas were initiated by hyperloop companies regarding the possibilities of transporting cargo via the hyperloop. This research has extended the knowledge about transporting cargo via the hyperloop by establishing a potential design for the Cargoloop and exploring the economic feasibility of the Cargoloop on the route between the airports of Cologne-Bonn and Paris-CDG. In doing so, this research has provided a first insight into a potential interesting market for the Cargoloop.

12.2.2 Reflection on social contribution

The current nature of the transport modes is unstainable. The transport sector is subject to environmental challenges such as the need to reduce the greenhouse gases, noise pollution or congestion problems. This aspect is becoming an increasingly important topic, as environmental awareness grows on a global level. This study contributed from a social perspective by investigating a form of cargo transport which meets the sustainability requirements. Moreover, it provided a first insight for the government into the economic feasibility of the Cargoloop. They could consider the outcome of this study as a motivation to further study the possibilities of the Cargoloop.

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APPENDIX A

Detailed step-by-step approach for CBA

The detailed step-by-step approach as described in the 'General Guidance for Cost-Benefit Analysis' in 2013 by CPB Netherlands Bureau for Economic Policy Analysis and PBL Netherlands Environmental Assessment Agency.

STEPS	
1. Problem analysis	• What is the problem or opportunity and how is it expected to develop? • What is the policy objective in response to this? • What are the most promising options?
2. Establish the baseline alternative	• Most likely scenario in the absence of a policy • Effect = policy alternative – baseline alternative
3. Define policy alternatives	• Describe the measures to be taken • Unpick packages of measures to identify individual elements • Define several alternatives and variants
4. Determine effects and benefits	• Identify effects • Quantify effects • Value (monetise) effects
5. Determine costs	• Resources consumed to implement the solution • Costs may be one-off or recurring, fixed or variable • Only costs additional to the baseline alternative

6. Analyse variants and risks	• Identify the main uncertainties and risks • Analyse the consequences for the outcomes
7. Overview of costs and benefits	• Calculate all costs and benefits discounted to the same base year and calculate the balance • Present all effects, including non-quantifed and/or non-monetised effects
8. Presentation of results	• Relevant, understandable clear • Explain: transparency and reproducibility • Interpret: what can the decision-maker learn from the CBA?

The first three steps from the preparatory phase of the CBA. In this phase, it is defined whether and to what extent the CBA will be helpful for the decision-making process. In doing so, first the problem has to be analysed and described. Followed by a description of the most likely situation that would occur if the proposed measure would not be implemented. The last step in this preparatory phase is defining the proposed measure.

The next steps after the preparatory phase, steps 4 and 5, are usually considered as the 'heart' of the CBA. The quality and usefulness of CBA stands or falls on the degree to which it is possible to determine and value the costs and the benefits. First, the effects and benefits will be determined. This will take place in three steps: identifying the effects, quantifying the effects and valuating the effects. The quality of the comparison will increase with the amount of effects that can be valued. When the effects and benefits are defined, the costs will be determined. In doing so, only the costs that arise due to the proposed measure, have to be taken into account.

The following step is the analyse variants and risks. As the future uncertain is and the CBA is partly based on assumptions, the estimated costs and benefits are also subject to uncertainty. The longer the time horizon of the project is, the wider the range of uncertainties. It is therefore important to identify the risks and uncertainties and the impact they could have on the CBA.

Finally, the lasts two steps contain of an overview of the costs and benefits and the presentation of the results. As the costs and benefits often do no occur at the same time, their value should be calculated to a base year, often the year in which the measure is introduced, to be able to compare them. To obtain the present value of the project, a discount rate should be applied. The costs and the benefits can then be added up to find out what the balance is at the base year. Finally, to make use of the insights obtained from the CBA, the results should be presented in a clear and user-friendly manner. In doing so, often the most relevant results of the proposed measure are presented in a table in which the effects, costs, benefits and the overall balance between the costs and the benefits are shown.

APPENDIX B

Interview design

The approach for the semi-structured interviews was as follows: first, the appropriate transport experts were searched. These experts were selected based on their experience and expertise in the transport sector. However, also transport experts that were recommended in earlier interviews were approached. In doing so, only transport experts from research institutes were contacted. So, there are no transport experts with a commercial job approached.

Secondly, the transport expert chosen were approached with the question if they would be open and interested in sharing their knowledge on behalf of this study. When their response was positive and a date for the interview was set, they received an introductory document. This introductory document consisted of a description of the goal of this study, background information regarding the hyperloop concept and open questions to give an indication of the direction of the interview. These pre-determined open questions and topics of the semi-structured interviews in this study were based on the information found and gathered through desk research the type of questions asked, and topics discussed during the semi-structured interviews were varying according to their expertise of the experts. An example of such an introductory document is shown on the next page. That these pre-determined open questions were only meant as an indication and that they were free to come up with their own input, was explicitly mentioned in the mail conversations on for hand.

When the interview took place, the way the data would be processed in the study was always mentioned on for hand and it was also asked if this was all right for the interviewee. The previously send questions formed often the guideline through the interview. However, there was enough room to deviate from these open questions. The interview always ended with the question where they would see the first Cargoloop route in Europe.

When the interview had taken place, a point-by-point summary consisting of quotes used in the interviews was made. This was then sent back to the interviewee to confirm the correct interpretation of his/her words. After conformation of the right interpretation, often combined with any adjustments, the findings were used in this study.

In total five interviews were executed with experts in the fields of transporting cargo via air, high-speed rail and road.

Feasibility study of the hyperloop within the logistics market in Europe

The aim of this research is to investigate the feasibility of the hyperloop within the logistics market for high-value and time-sensitive goods in Europe. This study will be exploratory in nature and an economic feasibility study will be carried out. However, in order to so, getting input from field experts is crucial.

Purpose of this document

This document has been written in order to provide a more detailed context as preparation for the semi-structured interviews with experts in the logistics sector. The outcomes of these sessions will serve as a foundation for getting more insight into the current logistics network in Europe. It should be noted that this document has been prepared based on initial desk research and serves as the foundation for further discussions with experts in the field.

Research context

A quick scan of the European logistics market shows that demand for reliable, flexible and fast delivery is growing, putting substantial pressure on the current infrastructure. Besides that, there is also the need to accommodate these flows in a sustainable manner.
Based on initial desk research, it has been found that, under certain conditions, a small-scale (i.e. 1.4 diameter), cargo-only hyperloop application could offer a solution to these problems.
However, in order to assess the economic feasibility of this small-scale Cargoloop, the current logistics network for high-value and time-sensitive goods in Europe needs to be clarified together with experts within the logistics sector. In doing so, the focus will be on the following topics: network, bottlenecks and trends within the logistics sector.
Per research topic, several main research questions have been defined. Below in table 1, there is a detailed overview of the research topics and corresponding research questions.

Network	**Description** Based on initial desk research it is found that a lot of air cargo is transported via road instead of air within Europe. However, hardly any data can be found about the transport of express freight via road. Getting more insight into the current freight network via road is crucial to define how a European Cargoloop network should look like. **Research Questions** 1. How does the cargo network of road transport in Europe look like? 2. What are the logistics hotspots in Europe? 3. What factors influence the decision whether to transport the cargo via road or any other transport modes? 4. What kind of loading units are used for the transport of cargo via road? 5. How to combine a hub network into a static network? How do you make it workable for everyone while everyone has their own network?

Bottlenecks	**Description** The Cargoloop cannot make a difference in the freight transportation market, if the current conditions within this rail market are not considered. Questions within this topic will help defining the current bottlenecks in the logistics market and how the Cargoloop could address these bottlenecks. **Research Questions** 1. What are the current bottlenecks within the logistics network of cargo transported via road? For example, infrastructure, reliability or punctuality? 2. What are the current bottlenecks regarding, for example, ground handling? 3. What are regulatory bottlenecks for road transport?
Trends	**Description** By introducing the Cargoloop, a new service will be offered in the current logistics market. By doing so, the trends in the logistics market should be taken into account. Questions within this topic will help providing more insight into the expected future and trends of the logistics market. **Research Questions** 1. What are the expectations regarding the future cargo transport of trucks? 2. What are the expectations regarding the regulation of cargo transported via road? 3. Which are upcoming logistics hotspots for road traffic in Europe?

Approach

The freight transportation sector covers several industries. From large logistics hubs handling different freight streams up to e-ecommerce players trying to deliver packages to their customers. A potential European Cargoloop network could therefore affect a substantial amount of businesses. However, first, the current logistics market in Europe need to be examined. Interviews are used as a foundation to get a better picture of this market in Europe.

APPENDIX C

Output of semi-structured interviews

Air	Expert
"The importance of the hub is determined by the integrator which is located at the hub"	A
"Important question: is their enough to consolidate?"	A
"An advantage of an express hub is that there are no night restrictions. An example is Köln"	A
"Use of airway bill depend on the costs"	A
"Problem in air freight, the trucks are long standing still"	A
"KLM focuses more on belly load"	A
"Alibaba has recently started with using Liège as a hub"	A
"Integrators fly a lot. They often have a fleet with smaller planes with which they transport e-commerce. They also fly within Europe"	B
"Belly of an airplane is 1.60 high. Most of loading units are pallet with boxes but also small containers adapted to the form of the belly"	B
"You cannot put express packages in the belly of continental flights, since the bellies are the too small. Besides that, it causes a delay on the passengers' network"	B
"Noise is often a bigger problem than CO2 emissions, mainly due to the costs"	B
"Logistics chain of integrators in Europe: in the evening the fly to one central point, where they sort everything out and the next morning, they fly the packages to their destination. This only happens from Monday to Friday"	C
"Express delivery started with transporting documents, nowadays spare parts, products that are missing, expensive-ecommerce and many more small shipments are transported by express operators"	C
"Full freighter: you have the certainty that your product will be transported by air though the schedules may be adapted to changing market demands"	C
"Combination carriers usually fly on time, but there is less certainty since the capacity for cargo is based on the number of passengers and their amount of luggage"	C

"Using ULD in airplanes is only because of fast in and out cargo and to bundle cargo that has specific dimensions"	C
"10-15% of the freight does not physicaly fit into the belly of an airplane"	C

High-speed rail	**Expert**
"Perishable goods are nowadays also transported via barge due to the improvement in the quality and possibilities of containers, such as the temperature control. There is a trends towards these smart containers."	D
"Transport of consumer goods goes almost always in containers and is realized through a shuttle concept"	D
"Over the past few years the number of scheduled services is strongly increased. In other words: the number of origins and destinations are increased"	D
"The shuttle concept has also disadvantages, such as that sometimes there are also empty wagons"	D
"When do people choose for rail? When the destination is far way or when a lot of goods need to be transported"	D
"Over long distances rail is more reliable than transport via road since rail is less influenced by elements such as congestion"	D

Road transport	Expert
"Trucking is used to get an aircraft full"	B
"Trucking is used to transport freight from the hub to other destinations"	B
"If you travel more than 500 km, you need to have two drivers, change of vehicle or change of trailer"	C
"Possible upcoming coalition agreement: one needs to pay for the use of highways. This can also be called 'road pricing', which is based on the type of truck, distance and time"	D

Cargoloop	Expert
"Cargoloop network should at least be connected to one of the aviation hubs"	A
"Search for natural consolidation nodes"	A
"Interesting for consolidated flow: München and Frankfurt. They are both hubs of Lufthansa"	A
"Link between hubs of integrators (DHL, UPS, FedEX)"	A
"From integrator hubs to other airports"	B
"Amsterdam – Frankfurt - Paris"	B
"Amsterdam - Paris - Madrid"	B
"Amsterdam – Luxembourg – Milan"	B
"Why would integrators change to the Cargoloop? Costs, capacity, offer a sustainable mode for their customers, reliability and night restrictions/closure of ai	
"Neutral infrastructure is needed. In view of the high investment, it is best to offer infrastructures such as airports, road, rail and also the Cargoloop in a neutral form"	C
"Start connecting the four main airports (Amsterdam, Paris, London and Frankfurt) with the integrator hubs (Brussels, Cologne, Leipzig and Liège)	C
"There are no night restrictions now in Liege, this area is not developed as much so they are kind of 'happy' with the attraction of more economic activity"	
"Cargoloop will be interesting for high-quality goods; goods that can also be flown"	D
"An interesting market for the hyperloop could be a market in which has a production processes that does not want/need to have stocks".	D
"Eurotunnel might also be interesting. A lot of congestion in both ways"	B
"Maybe one consolidation point in the North of Europe and another one in the South of Europe. There is a lot of congestion on this route between the North and the South of Europe."	A
"Cargoloop would be interesting on the 'big' routes, to feed the hubs"	C
"Structure of distribution centres in the Netherlands: there are several logistics hotspots, these are located in such a way that they just follow the market. In the Netherlands, however, these locations are quite good distributed"	D
"Transport of containers from the port of Rotterdam to the hinterland by hyperloop is not interesting. There is still a lot of transport capacity left that can be used in a more efficient way."	D

General	Expert
"The use of loading units makes the transport between national and international much easier"	D
"Challenge to get people out of their fixed pattern but it will help by focusing on time savings"	B
"Future inefficiency: Brexit"	A
"Transport of express freight will increase due to the growth in the ecommerce an it will become more international"	A
"An interesting analogy is to look into the possibilities for freight transported by HSL"	A
"There is no compensation for cargo which arrives late unless this has been contractually arranged"	C
"Interesting projects are HSL projects"	C
"Reliability and predictability are more important than speed"	C
"Transport choices are made base on costs, sustainability and reliability. From that, reliability is more important"	D
"Challenge to get people out of their fixed pattern but it will help by focusing on time savings."	B

APPENDIX D

General reference scenario as input for design policy alternative

The next step in the preparation for the CBA is the establishment of the reference scenario. As already mentioned, the Cargoloop could offer a solution for the current bottlenecks found in the express freight industry. However, as the market and the design for the Cargoloop are not defined yet but input of the existing express freight market is necessary for doing this, a general reference scenario of the existing express cargo industry in Europe is described in this chapter. So that this can serve as a basis for the design of the Cargoloop. The analysis is carried out on the basis of desk-research and semi-structured interviews with experts in the industry. In doing so, the following topics are discussed: products, transport modes, loading units, network, trends and bottlenecks. Most of the express delivery is made possible by road an air transportation, but also high-speed rail is familiar with the transport of express deliveries in Europe.

5.1 Products

As aforementioned, most of the express deliveries are transported via air or road. However, there are also some examples of express services via high-speed rail and the transport of express deliveries with high-speed rail is gaining more and more interest. To get an insight into the type of products that fall under this express delivery market, the products transported via air, high-speed rail and trucking are described in this section.

5.1.1 Aviation

All products transported by air are characterized by their time-sensitivity and high value. Air cargo represents less than 1% of the volume of world trade, while it accounts for more than 35% of the value (IATA Cargo Strategy, 2018). According to Brandt & Nickel (2019) goods that are transported via air have usually one of the following properties:

- *urgent:* these are goods that need to be as fast as possible on their destination. Typical goods are spare parts, living animals or parcels and mail.
- *perishable:* these are goods that spoil quickly when they are not transported in controlled, often refrigerated environments. Typical goods are fresh food, flowers or medicines.
- *valuable*: these are goods of high value which need to be transported in a safe manner. Typical goods are jewels, banknotes or art.

- *dangerous:* these are goods which, if not properly handled, can endanger the environment. Typical goods are batteries or chemicals.

There is thus a wide range of different types of cargo that is transported, which all have their different handling requirements. In this wide range of products, a distinction can be made between the 'traditional air cargo' and 'express cargo' (often parcels) (Merkert, Van de Voorde, & de Wit, 2017). The difference between those two groups is that 'express cargo' mainly exists of parcels and is offered by companies who provide shipping from door-to-door, while 'traditional air cargo' exists of larger shipments and often requires tailor-made solutions (such as the transport of large spare parts). 5-15% of the global air cargo has to be shipped by all-cargo aircraft exclusively, due to their dimensions or hazardous characteristics (Transport experts B & C; Kupfer, et al., 2017).

5.1.2 High-speed rail

The freight transported by rail can be divided into several segments. A rough segmentation based on the frequency and time-sensitivity is shown in table 23 As can be seen from this table, the market segment that is transported via high-speed rail is the service market, which contains of parcel and letter mail, express cargo and courier goods.

Market segment	Typical transport time	Typical frequency	Dominating railway service
Bulk market - Raw materials	Less than one day	Continuous	Unit-trains
Base market - Raw materials - Semi-finished products	National: Day 0-1 International: Day 1-3	Daily Several times / week	Wagonload traffic
Product market - Semi-finished products - Finished products	Overnight 17:00 – 07:00	Daily	Combined traffic
Service market - Parcel and letter mail, express cargo	Overnight Same day	Daily Several times / day	High-speed rail freight

Table 27 - Market segments, customer requirements and main railways services addressing each segment (Source: Railway Group KTH)

Courier services typically consist of the transport of the smallest goods, while express cargo is usually transports larger cargo (Troche, 2005). It should be noted however, that due to the improvement and quality of containers, such as temperature control, and a trend towards the use of these smart containers, perishable goods are nowadays also transported via barge (Transport expert D).

5.1.3 Road transport

The type of products transported via road freight transport are diverse. According to Eurostat, the most common groups of products transported via road freight transport are:

- metal ores and other mining and quarrying products
- food, beverages and tobacco
- mineral products
- agricultural products
- secondary raw materials
- grouped goods: mixture of different type of goods that are transported together (parcels for example)
- chemicals
- wooden products
- basic metals

From these products, food, beverage and tobacco are transported the most by road freight. Followed by the products of agriculture which contain for example the transport of animals and grain.

5.2 Types of transport modes

The type of transport modes used for the transport of express cargo differ because of the different transport modes used. However, also within a certain transport mode, the type of modes used for the transport of express freight can differ. In this section, the type of transported modes used for transport via air, high-speed rail and trucking are described.

5.2.1 Aviation

When transporting air cargo, a difference can be made between airlines that see the transport of air cargo as a by-product and airlines that only focus on the transport of air cargo (Kupfer, 2013). Combination carriers (e.g. KLM and British Airways) represent the former group by transporting both passengers and freight. Whereas, integrators (e.g. UPS and FedEx) and full freighters (e.g. CargoLux) correspond to the latter group and only focus on the transport of cargo (Transport expert A). The main difference between those two cargo-only airlines, is that an integrator mainly focusses on express freight such as parcels and offers transport from door-to-door, while full-freighters only take care of the larger shipments (Kupfer, 2013; Merkert, Van de Voorde, & de Wit, 2017). There is however no strict separation, as integrators propose also less time-sensitive transport of ‘general parcels’ and ‘traditional air cargo’ providers propose more time-definite transport.

These different carriers also use different ways to transport the air cargo. Integrators and full freighters use cargo-only airplanes for the transport the air cargo. Combination carriers, however, can either transport the air cargo in the belly of passenger airplanes or use a combination aircraft, in which the cargo capacity can be adjusted by adding or removing passenger seats (Feng, Li, & Shen, 2015; Kupfer, 2013). It should be noted however, that the express packages cannot be put in the belly of continental flights, as the bellies of these type of planes are too small to carry all the cargo. Besides that, it would case a delay on the passenger network (Transport expert B). There are pros and cons for both means of transport. When you use a full freighter, you have the certainty that your product will be transported by air but the flight schedules may be adapted to changing the market demands. Integrators, however, are an exception to this rule as integrators fly a lot. They often have fleet that consists of smaller airplanes with which they transport their freight (Transport expert B). Combination carriers, on the other hand, usually fly om time but there is less certainty that your cargo will be transported as the capacity for cargo is based on the number of passengers and their amount of luggage (Transport expert C).

5.2.2 High-speed rail

The transport modes used for high-speed rail can be divided into two types of vehicles: 1) vehicles that are derived from the conventional rail freight, 2) vehicles that are derived from the passenger transport. An overview of the different vehicle categories is shown in figure 9.

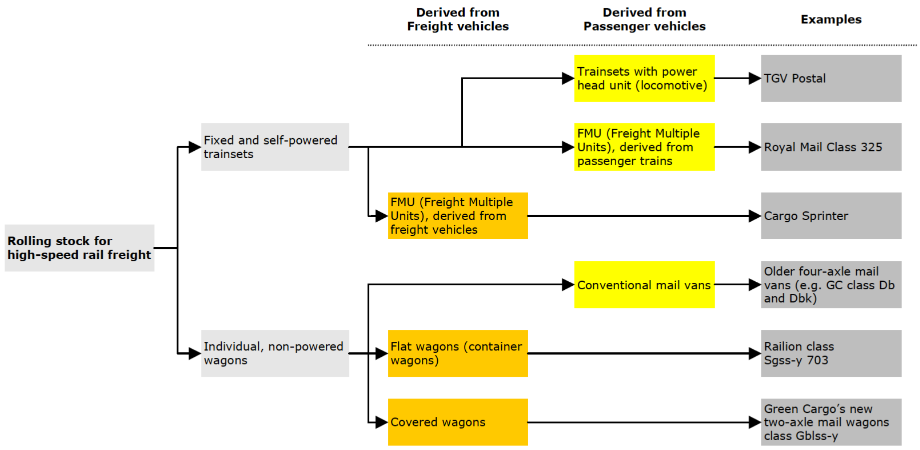

Figure 14 - Categorization of vehicle concepts for high-speed rail freight (Source: Troche (2005))

Another way of categorizing the type of vehicles used transporting freight via high-speed rail is the to look at the train configuration. In doing so, three different types of freight trains can be defined: 1) loco-hauled trains of individual wagons (example: 'classical' mail trains), 2) fixed train set with an integrated power unit (example: TGV Postal), 3) multiple units with a distribution of the power underfloor (example: Royal Mail Class 325) (Troche, 2005).

There are thus a lot of different type of freight trains. To give some more insight about the capacity of a high-speed train for freight, the TGV Postal and the freight version of an ICE train are used as an example. The loading capacity of TGV Postal train is 61 tons. The payload of the freight version of an ICE train, however, can differ as this is not a fixed train set. This train could consist of 6-12 freight car, which have an approximately payload of 8 tons per freight car.

5.2.3 Road transport

When transporting cargo via road transport, various types of trucks can be used. These trucks all differ in their length, loading units used but also in the combination of a tractor unit and the number of trailers carried. The type of truck used mainly depends on the type of cargo transported via the truck. For example, a tipping truck is only used for the transport of loose bulk goods such as sand, stone and gravel and a container truck is used for the transport of containers.

When looking at the transport of express freight most of the time, often standard trailers are used. This a combination of a tractor unit and a trailer to carry the freight. The have a length of 13.60 meters and can carry up to 24 tons (DHL, 2015)

5.3 Network

The network used to transport the express freight differs between the modes of transport. This is partly due to the infrastructure that these different modes use. In this section, the type of network used for transport via air, high-speed rail and trucking are described.

5.3.1 Aviation

The network of the air cargo industry is worldwide, goods are shipped all over the world. However, the network of the various types of cargo airlines can differ in for example a hub-and-spoke network or a point-to-point network. The airports on which the airlines fly, depend on the type of cargo airline. As for example, combination carriers often see air-cargo more as a by-product and their destinations are therefore based on the passenger demand. While full freighters on the contrary, often serve only a particular geographical market. Finally, integrators such as UPS or FedEx often serve a global network (Kupfer, 2013). In this case, the importance of the hub is determined by the integrators that is located at the hub (Transport expert A). European hubs of integrators are Paris-Charles de Gaulle (FedEx), Cologne – Bonn (UPS) and Leipzig (DHL).

When zooming in at a European level, it can be found that the largest EU cargo airports can mainly be found in the “blue banana”[2]. In this blue banana there are, however, four airports that have a leading position regarding the volumes of cargo and the number of passengers that are transported. These four airports are: Amsterdam, Frankfurt, London Heathrow and Paris Charles de Gaulle. These airports are also known as ‘balanced airports’, in which the division of freight and passenger transport is balanced. However, this ratio is not always balanced. When looking at the other airports with respect to the volumes of cargo and passengers transported, it can be found that besides the ‘balanced’ airports, there are three more types of airports: 1) ‘cargo oriented’ hubs: these are hubs which handle large cargo volumes and only few passengers. Examples are: Leipzig, Cologne, and Liège 2) ‘passenger first’ hubs: these are hubs that transport a lot of passengers but have low cargo activity. Examples are: Madrid, Munich and Rome 3) ‘cargo believers’ hubs: these are small airports for cargo and passenger transport, however they are focusing on the cargo activity. An examples is Maastricht.

An interesting phenomenon, certainly in Europe, is that most of the freight is not flown between hubs but is trucked under an airway bill. Large intercontinental hubs (such as Frankfurt, Amsterdam, London Heathrow and Paris Charles de Gaulle) are frequently supplied of freight transported via trucking. Which in turn is done to get the aircraft full (Transport expert B). When the airports are relative close to each other, as they are in western Europe, and can be reached with trucks within hours, the catchment areas of various European cargo airports can overlap to a large extent (Merkert et al., 2017). This results in a strong competitiveness. Important to note however, is that this is not the case with integrators, besides trucking they also do fly within Europe. In the evening, integrators fly to one central point where they sort everything out. The next morning, they fly the packages to their destination (Transport expert C).

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[1] blue banana is a corridor of urbanization in central and Western Europe.

J. Visser & Gordijn (2014) investigated the transport of air cargo via road from Schiphol in 2010. Based on this analysis it was found that trucking mainly takes place on the distance between 200 and 600 kilometers. Going more into detail it was found that on distances below 400 km100% of the air cargo is trucked, and on distances between 400 and 600 kilometers 92% of the air cargo is trucked. This is the distance range in which the other three large hubs (Frankfurt, Paris Charles de Gaulle and London Heathrow) lie and thus confirms the findings of Merkert et al. (2017). Ultimately, Visser & Gordijn argue that the share of road transport decreases to 45% at a distance of 2000 kilometers. Research of Boeing (2018) adds that the typical routes that are flown in Europe are short-haul, which are between 900 and 1200 kilometers. The reason why there is so much trucked depends according to transport expert A on the costs.

5.3.2 High-speed rail

When the destination is far away and when a lot of goods need to be transported, rail is often chosen as the mode of transport. Rail in general is over long distances more reliable than for example road transport as it is less influenced by elements such as congestion (Transport expert D).

When looking at the European network for high-speed rail it can be seen that there is extensive high-speed rail network for passengers. The required infrastructure for high-speed freight is thus there, however, it is still not managed to exploit its potential. Mainly because the existing infrastructure is only focused on the transport of passengers, which often not consist of the same locations as were the freight activities are. There are a few examples where high-speed rail is successfully integrated in the express delivery market, however these isolated phenomena and not all initiatives have been a lasting success (Troche, 2005).

An example of a successful integrated high-speed freight is for example the TGV Postal, which carried mail for over thirty years between Paris, Mâcon and Cavaillon. In those thirty years, between 6 and 8 high-speed trains per night transported mail. Another example is the Parcel-Intercity, which transport freight during the night between among others, Hamburg and München. This high-speed freight service is still operational (Troche, 2005).

In providing these services, high-speed rail makes use of the shuttle concept. This means that there are a number of scheduled services. This concept, however, also has as disadvantage that sometimes there are also empty wagons (Transport expert D).

5.3.3 Road transport

According to research conducted by Nowakowska-grunt & Strzelczyk (2019) road transport has the largest share in the transport of cargo in the European Union. Road transport is characterized by the flexible services. There is therefore no such thing as a 'freight road network' because trucks are able to drive anywhere and are not dependent on specific infrastructure such as airports or railway stations in the case of air and rail transport. This also enables trucks to delivery door-to-door service in order to realize this it is however, important that the roads are connected to the nodes or terminals.

When looking from a modal split perspective, it can be found that trucks completely dominate over distances lower than 500km (Engström, 2016). An insight that also has been found in the aforementioned research of J. Visser & Gordijn (2014) regarding the transport of air cargo via road. In the study of Engström (2016), an explanation for this domination on this short and medium distance is given. He argues that the dominance on the short and medium distances is due to the long handling that is needed for the goods at the terminal. Another explanation of transport expert C is that when you travel more than 500 km, you need to have two drivers, a change of vehicle or a change of trailer.

5.4 Loading Units

For most of the express cargo transported, some type of loading unit is used to simplify the loading and unloading process and the transport. Besides that, the use of loading units makes the transport between national and international transport much easier (Transport expert D). In addition, these loading units are often also used as protection of the packages from damage and prevent the loss of parcels. However, there are also exceptions as some of the goods can be handled 'item by item'. The type of loading units used by aviation, high-speed rail and trucking are described in this section.

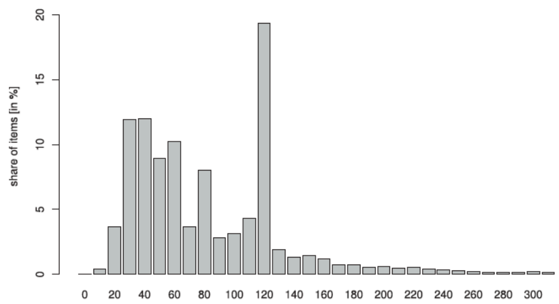
5.4.1 Aviation

There are several types of loading units for air cargo. The loading units come in a large diversity of shapes and dimensions. The basis of the design of the loading units is, however, to fit the best as possible in the aircraft. A disadvantage of this, however, is that most of the loading units do therefore not leave the aviation industry and thus cannot be used intermodal (Troche, 2005) .

When talking about unit load devices in aviation, mainly two types of units are used: pallets and containers. A pallet is the most 'general' loading unit, on which the freight is tied with a net. Containers on the other hand can have more different shapes and are often designed in such a way to fit the rounded shape of an aircraft body (Transport expert B). The development in the field of smart containers is rapid, in addition to 'general' containers, there are, for example, also temperature-controlled containers in which temperature-sensitive goods are transported. In order to move these loading units easily within the aircraft, 'rolling floors' are used (Troche, 2005)

The majority of the shipments transported via air are box-shaped but irregular forms, such as barrels occur also frequently. Therefore, loading units are used to bundle the cargo and ensure a fast in and out transport (Transport expert C). As the shipments can be small, often multiple items are consolidated onto a pallet, as pallets are generally preferred over containers. Containers are again preferable to be chosen when it comes to smaller, valuable items. However, overall pallets are transported the most by cargo airlines (Transport expert B). The dimensions of these typical wooden pallets are defined in ISO standards, however, the size of the 'typical wooden pallet' is dependent on the originating geographical location. For Europe this is the standard EURO-pallet with a dimension of 800x1200 millimetre.

In Figure 15 and Figure 16 the distribution of item lengths and item widths of cargo transported by a European airline are shown. This analysis is based on a dataset with more consisting of more than 400 flights with over 3500 shipments in 2014 (Brandt & Nickel, 2019).



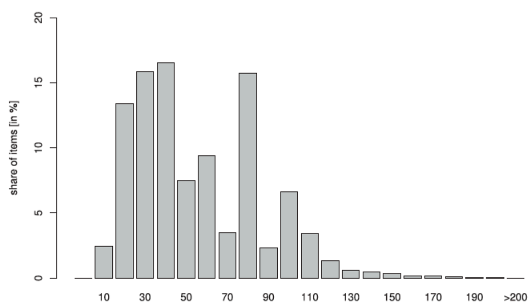


Figure 15 - Distribution of item lengths (rounded to next 10 cm). Figure 16 - Distribution of item widths (rounded to next 10 cm).

Based on the figures above, it can be seen that almost 20% share of the items transported via the European airline has a length of 120 cm and around 15% of the items has a width of 80 cm. This indeed confirms that the EURO pallet is transported the most by this European airline.

5.4.2 High-speed rail

When looking at the loading units for high-speed rail, several types of loading units can be found: standard ISO containers, swap bodies and rolling bins. The rolling bins are used for the transport the freight and mail. The ISO containers and swap bodies are often used for larger products.

5.4.3 Trucking

As aforementioned the transport of express freight is most of the time carried out by standard trailers. These trailers consist of a tractor unit and a trailer to carry the freight. The loading units used in these types of trucks depends on the type of cargo transported. It can be loose packages for example that are secured with a ribbon or it can be pallets. In doing so, these types of trucks can transport 33 EURO pallets.

5.5 Trends

The practical elements of the available transport modes are now discussed. However, in order to determine the niche and the technical specifications of the Cargoloop, it is relevant to take the trends in the different industries into account. In this way, the Cargoloop can respond even better to the current dynamics of the transport market. To get an insight into main trends found in literature regarding air transport, high-speed rail and road transport, these are described in following sections.

Before describing these trends per transportation mode, first various trends that apply to general freight transport will be discussed. According to van Wee & Annema (2005), four ‘megatrends’ can be seen the past few years in the transport of freight:

1. The global growth and the international interdependence of economies
2. Mass individualization and the 24-hour economy as megatrend in consumption
3. Special concentration and economies of scale
4. Technological trends, both in terms of digitalization and within the transport sector, leading to cost reductions and improved services.

These impacts will have an impact on the transport of goods, as companies are constantly striving to improve their logistics chain.

5.5.1. Aviation

The strong growth of air cargo in the recent years has led to strong competition in the sector, particularly in Europe (Kupfer, 2013). The expected growth calculated by Boeing (2018) for intra-Europe between 2018 and 2037 is 2.3%. However, the growth pattern is not the same for all airlines as the growth coincided with certain routes and specific types of freight. In addition to this, some routes have to deal with a strong imbalance between inbound and outbound flows. On the contrary to passenger transport, which is most of the times bi-directional, in freight transport an incoming flight at an airport does not need to be followed by an outgoing flight, due to the difference in the production and consumption areas of the cargo. For combination carriers, this results in capacity issues, but full-freight operators are confronted even more with the geographical imbalances in freight flows. When they cannot respond creatively to these imbalances, full-freighters have to fly empty or charge low rates (Merkert et al., 2017).

Besides that, this increase in air freight has also led to an increasing shortage of capacity at large international hubs. In order to solve this shortage of capacity, freight operations are often the first to be considered in transferring these operations to other regional airports. A complete transfer does often not take place immediately, but a specific part of the freight operation is located first (Kupfer, 2013). This shift however, increases to competition between airports even more. First, because of the distance between a national and regional airport is often small and therefore airports do not often have a unique catchment area. Second, due to due to the relative independent character of air freight and the strong bargaining position of airlines. This footloose character of air freight is due to the fact that cargo airlines, with the expectation of the integrators, do not need to invest in infrastructure at an airport itself. This results in relatively low sunk costs, which in turn ensures that airlines can change airports while not having excessive costs (Kupfer, 2013).

Finally, also a consolidation trend can be found. In order to achieve potential benefits of scale, freight forwarders strive to consolidate as much of the air freight as possible into a single hub (Transport expert A). In this way, they can group and transport the largest possible amount of freight while minimizing the costs. Moreover, it allows freight forwarders to deal with the diversity of the products in terms of value, volume and weight in a more efficient way. This is a remarkable difference compared to the past, when air cargo often consisted of small volumes and high costs. In addition, this consolidation trend also results in shifts in the value chain. As for example, the case of Amazon, which started as an online web shop but has developed itself in the past years more and more into a fully-fledged delivery company. By having their own fleet of aircraft, Amazon integrated their distribution of products by air for the US domestic and could can thus make it losses of transport costs as low as possible (Merkert et al., 2017).

5.5.2 High-speed rail

As already mentioned in the introduction, recent studies have shown interest in the transport of express delivery via high-speed rail (Mcdermott & Lacasse, 2015; Strale, 2016; Liang, Tan, Whiteing, Nash, & Johnson, 2016; Schumann, Moensters, Meirich, & Jaeger, 2019). This attention is mainly due to the sustainable character of rail transport. In doing so a trend can be seen in combing the transport of express freight with passenger transport by utilizing the remaining passenger transport capacity with express delivery services.

These investigations have also revealed into an initiative: the Euro-Carex. This project contains of a high-speed rail for freight between major European airports (Amsterdam, Brussels, London, Cologne, Frankfurt, Paris and Liège). In doing so, flights could be removed between those airports (Strale, 2016). The operational test began 2012 and the first commercial service was scheduled for 2018, however, it has not gotten this far yet. It is unknown how this project will continue.

5.5.3 Road transport

When looking at trends with respect to the demand for road transport, several trends were found by Nowakowska-grunt & Strzelczyk (2019). First, due to the industrial production structures there is a decrease in the demand of mass cargo transport. On the other hand, an increase can be seen in the demand for express services and on time. Secondly, a change can be found in the production locations, which results in turn into a change from the 'main' transportation routes. Thirdly, an increase in the level of urbanization resulting in an increasing demand for transport services to for example retail chain outlets. These outlets are in turn, characterized by their dispersed locations throughout the city. Fourth, the change in the geographical exchange of goods and the international economic cooperation, which results in an increasing demand for international transport. Fifth, an increase in the retail structures, which results in an increasing demand of transport from the production plant to the logistics centers, followed by the transport from the logistics centers to the commercial companies. Finally, the last change found was the increasing development of e-commerce resulting in an increasing demand for domestic services. These changes, however, all result in an increase demand for deliveries, especially in the demand for light commercial vehicles.

In addition to this increasing demand for trucks, a counter-movement can also be observed. In this movement is dominated by making cities greener and more sustainable. In doing so, large trucks are prevented in the cities and are replaced by smaller, sustainable vehicles. For road transport this would mean that the cargo transported via the trucks should on the outskirts of the city be transferred into these smaller, more sustainable vehicles.

Another movement that was mentioned by transport expert D, was the possible upcoming collation agreement in which one needs to pay for the use of highways. This is can also be called 'road pricing', which will be based on the type of truck, distance and time.

Drawbacks

The trends of the available transport modes are now discussed. However, in order to determine the niche and the technical specifications of the Cargoloop, it is also interesting to take the drawbacks in the different industries into account. It was already mentioned in the introduction that there is a lack of express transport capacity by air and road transport. Other main drawbacks found in literature regarding air transport, high-speed rail and road transport are described in this section.

5.6.1 Aviation

A first drawback of transport via air are the negative impacts on the environment resulting in noise annoyance, local air pollution and greenhouse gas emissions.

As already mentioned in the introduction, a large part of the cargo is carried on overnight flights due to the limited capacity at airports during the day. However, flight during the night can be seen as a drawback by the people living in the area around the airport. The noise annoyance can cause a poor night sleep, which in turn can result in health issues. The number of flights that is flown during the night however, is different for every airport. Some airlines have enough capacity during the day to transport all their cargo, which is often the case for the larger airlines. However other airlines do attach importance to night flights as they are crucial for specific activities. This often the case with airlines that serve more regional airports and in particular this is the case with integrators. As they often serve the entire supply chain and no value can be added to the goods during the night. Therefore, these shippers are often interested in being able to send the goods at the end of the day and to arrive at the destination airport as early as possible from the beginning of the following day. These types of hubs are therefore also not bounded by night restrictions (Transport expert A).

Also, the consolidation trend, as mentioned earlier, is a drawback of air transport. Freight forwarders strive to consolidate as much of the air cargo as possible to be able to group most of the air cargo and minimize the costs. Due to this, the trucks that transport air cargo under an airway bill are often long standing still (Transport expert A).

Another drawback is the uncertainty of the transport of air cargo. The transport of air cargo is characterized by a higher capacity uncertainty compared to passenger transport. Freight forwarders have to pledge the use of cargo capacity on specific flights about twelve to six months ahead. This results in high fluctuations in the management of the capacity as the actual goods often differ from the booked order. This difference becomes even more due to the fact that freight forwarders do not have to pay for unused capacity. In other words, there is no penalty if the amount of capacity is booked wrong. This results in freight forwarders booking even more than necessary (Transport expert C; Feng et al., 2015).

5.6.2 High-speed rail

As already emerged from previous research, high-speed rail is currently used only to a limited amount for the transport of freight. Over a long-time, high-speed rail had a strong position in the transport of these goods. However, high-speed rail has lost a lot of the transport of freight to both road and air transport (Troche, 2005). According to Strale (2016)this has to do with the following disadvantages of high-speed rail:

- Incomplete infrastructure: The existing high-speed rail tracks are constructed for the transport of passengers and not for the transport of freight. Besides that, also the current high-speed rail trains are not designed for the transport of freight. Moreover, when looking from a geographical perspective as the existing high-speed lines are based on the transport of passengers, the network is so designed that they link cities. This, however, are often not the same locations as the freight activity locations.
- Inadequate exploitation: As the existing high-speed rail tracks are focused on the transport of passengers, many tracks at night are closed for maintenance. During the day, however, some high-speed lines are already congested, and passenger transport has the priority resulting in no capacity for high-speed freight.

- High costs of high-speed rail: The cost of the infrastructure, the use of high-speed rail technology and the obligatory security measures ensure that the costs of high-speed rail are very high.
- Lack of existing freight services: Since there is a lack of examples of high-speed rail dedicated to freight services, the risks of beginning a freight service are high.

5.6.3 Road transport

When looking at the bottlenecks of freight transport via road, several disadvantages can be found. As already mentioned in the introduction, a large disadvantage of road transport are the congested roads, which lead to unreliable delivery times (Kennisinstituut voor Mobiliteitsbeleid, 2018). Secondly, transport via road is slow on long distances and the regulation for drivers ensures even slower transport times due to mandatory stops (Liang et al., 2016).

APPENDIX E

Defining route of project alternative

Potential first route

The potential of the Cargoloop becomes present when a network is realized, and the network effects can be considered. However, in order to realize a network, routes need to be built link by link. In doing so, it is important to know whether a link on its own is profitable. In order to investigate the economic feasibility of the Cargoloop, a first route in this section is defined. This has been done based on first defining the largest cargo airports in Europe. Based on that information, data is collected to find the largest cargo flows within these airports.

Defining largest cargo airports in Europe

Based on the semi-structured interviews, a link between two airports could be an interesting first route. To determine this link and to find out where the largest cargo flows between airports in Europe are, data from Eurostat is used. Since there are many airports in Europe and many more links between airports, there is first looked at which airports in Europe handle the most cargo to limit the amount of data. This assumption is based on the idea that large cargo airports will be connected to links where most of the cargo is transported. In doing so, the Eurostat data of '*freight and mail air transport by main airports in each reporting country*' is used. This dataset contains the cargo flows between airports in different time periods for different measurement units such as among others: flights or tonne. Important to note is that *'mail'* and '*freight*' are defined as follows in the Reference Manual on Airport Statistics from Eurostat (2017):

Mail: "*Dispatches of correspondence and other objects carried on an aircraft, which have been dispatched by and intended for delivery to postal administrations. Express freight and express parcel shipments are excluded.*"

Freight: *"Any property carried on an aircraft other than mail, stores and baggage. For statistical purposes, freight includes express freight and parcels and diplomatic bags but not passenger baggage. All trucking operations using an air waybill should be excluded."*

With respect to this last sentence which states that all trucking operations using an air waybill should be excluded, in the Reference Manual on Airport Statistics from Eurostat it can be found that the use of air waybill data is not used for any country as input for freight data. In addition, this is double checked through personal contact with Eurostat to find out whether air waybill data was used/know and this was not the case. This also means that much more freight could be transported on the relevant link, as semi-structured interviews showed that almost everything is being trucked within Europe.

In selecting data from the dataset *'freight and mail air transport by main airports in each reporting country'* in Eurostat, there were several options to select: the reporting geopolitical entity, type of schedule (scheduled flights, non-scheduled flights), the period of time, the transport coverage (national, international), the traffic and transport measurement and the unit of measure. Summarized in an overview, the following elements were chosen for the different options:

Reporting geopolitical entity:	All airports
Type of schedule:	Total
Period of time:	2017
Transport coverage:	Total transport
Traffic and transport measurement:	Freight and mail loaded and unloaded
Unit of measure:	Tonne

Important to highlight are the choices for the period of time and the traffic, transport measurement and unit of measure. Concerning the period of time of the dataset, the possibilities of the datasets are months, quarters or years. For this study, the time period of a year is chosen. The data for over a year gives a general overview of the demand and is less sensitive to fluctuations in, for example, seasonal freight or other external factors. When diving more into the data sets of a year, the dataset of 2018 proved to be less complete than the dataset of 2017. Therefore, the dataset that contained the amount of tonnes loaded and unloaded throughout 2017 is used to determine the top ten air cargo airports in Europe.

Regarding the traffic and transport measurement, the option '*freight and mail loaded and* unloaded' instead of '*freight and mail on board'* or '*freight and mail commercial air flights*' is chosen. On page 14 in the Reference Manual on Airport Statistics from Eurostat (2017), the variable *'freight and mail loaded or unloaded'* is described as:

> *Freight and mail loaded and unloaded*
> *All freight and mail loaded onto or unloaded from an aircraft. Includes express services and diplomatic bags. Excludes passenger baggage. Excludes direct transit freight and mail.*
>
> *It is recommended to exclude the weight of containers in the freight data reported.*

The main reason why the other two variables were not chosen is because of 1) in '*freight and mail on board*' is also direct transit freight and mail is included, which could provide a distorted picture of the direct flows between the two airports, and 2) data of '*freight and mail commercial air flights'* is only provided in the amount of flights and does not give any indication of the amount of cargo that is begin transported. Besides that, it is important to note that there was no data on the type of containers or the number of containers, therefore the weight of the containers has not been removed from the freight data.

With respect to the unit of measure, there were two options to choose from: tonne or flights. In this study the option of tonne is chosen since there is no data available on the type of aircraft flown, which makes it difficult to calculate the amount of cargo transported on the basis of the number of flights. Therefore, the unit of tonne gives a good insight in the amount of freight transported. A disadvantage, however, is that it gives no insight into the dimensions of the cargo or weight of the different packages, that have been transported. Since this could give a better insight into whether the diameter of the chosen Cargoloop is of the right size.

A final note, about the data selection procedure is the differences in the methodologies applied on a national level to collect the air transport data. In the Reference Manual on Airport Statistics from Eurostat (2017) page 36 onwards, these methodologies per nation are described and differences can be found on the data transmission level, the information source of the data suppliers and in the data suppliers to Eurostat. The assessment of the data mus take account of these different methodologies.

This selection of the dataset which, at the time of extraction was updated for the last time on 15 july 2019, resulted in the following top ten of airports that handle the most cargo:

Airport	**Freight and mail loaded and unloaded in 2017** ***(in tonnes)***
Frankfurt Main airport	2.193.413
Paris-Charles de Gaulle airport	2.161.317
London Heathrow airport	1.791.576
Amsterdam/Schiphol airport	1.778.168
Leipzig/Halle airport	1.130.499
Luxembourg airport	892.659
Koeln/Bonn airport	822.153
Liege Airport	695.785
Milano/Malpensa airport	589.534
Brussels airport	530.138

Defining the first potential route within Europe

The above list has been used as a basis for finding data of the amount of freight transported over the various links. In doing so, an origin-destination matrix was created with all airports both, as origin and as destination. To obtain the cargo transported on the various links between all the airports, the database of Eurostat was used again. This time, the dataset of '*detailed freight and mail air transport by reporting country and routes'* was used. This dataset contains of several sub datasets, which all show the data from a different reporting country. Since the top ten airports are not located in one country, the data had to be extracted multiple times from different datasets. In addition, in this dataset, also different choices could be made with regard to the characteristics of selecting data. Summarized in an overview as before, these options were chosen for the different characteristics.

Airport pairs:	All airports pairs based on top 10 cargo airports
Period of time:	2017
Traffic and transport measurement:	Freight and mail loaded, Freight and mail unloaded
Unit of measure:	Tonne

Important to highlight here is the choice for not choosing the dataset in which the data of freight and mail loaded and unloaded were combined and added up together but making a distinction between data with only loaded freight and data with only unloaded freight. In this way, the amount of freight on the links is not undirected but directed, so there is not only data from the link in general but also about the direction in which the freight is transported. This is done based on the idea that when cargo is transported via the Cargoloop, it will always go in only one direction. In other words, combining two flows that go from A to B and B to A is not possible with a Cargoloop. Rather, there will be a separate tube for each direction.

Based on the formulation of '*freight and mail loaded and unloaded'* and the fact that this dataset contains no transit freight, the assumption has been made that the amount of freight loaded at the reporting country on a route, should be all freight unloaded on that same route at the reporting country. However, as mentioned earlier, in the Reference Manual on Airport Statistics from Eurostat (2017) from page 36 onwards, the methodologies applied on a national level to collect the air transport data differ. In the data collecting process there are differences on the data transmission level, the information source of the data suppliers and in the data suppliers to Eurostat. This therefore also results in a high probability that the amount of cargo loaded at airport A is not equal to the amount of cargo unloaded at airport B on the route from A to B, or vice versa. When comparing these two flows with each other for the ten airports, this was indeed the case: the amount of freight transported almost always differed from the airport where the loading took place compared to airport where the unloading took place. The volume of these differences, however, differed from one link to another. In order to deal with these differences, the average of the flow 'loaded' mail and freight at airport A to B and the 'unloaded' mail and freight at airport B from A is taken.

Origin/Destination	Frankfurt	Paris-CDG	London-Heathrow	Amsterdam-Schiphol	Leipzig-Halle	Luxembourg	Cologne-Bonn	Liège	Milano-Malpensa	Brussels
Frankfurt	-	13.676	9.828	0	13.778	0	0	0	2.124	0
Paris–CDG	3.829,5	-	3.594,5	3.665	15.487,5	0	34.899	3.441	21.234	2.942
London-Heathrow	4.999	3.814	-	3.270,5	9.848,5	0	0	0	1.628	5.230
Amsterdam-Schiphol	0	6.666,5	4.411	-	15.335	0	0	0	5.678,5	0
Leipzig-Halle	16.085	16.834	2.793	11.151	-	0	10.946	0	7.181	27.802
Luxembourg	0	0	0	0	0	-	0	0	14.138	0
Cologne	0	46.550	0	0	9.495,5	0	-	0	0	0
Liège	0	704	0	0	0	0	0	-	0	0
Milano-Malpensa	2.598,5	24.059	8.440	209	10.250,5	21350	0	0	-	0
Brussels	0	375,5	3.305	0	22.823,5	0	0	0	0	-

As can been seen from the above figure, a lot of data is missing. It is remarkable, however, that mainly a lot of data is missing on the shorter routes, this could be explained by the fact that indeed no freight is flown between on the shorter distances, and trucking with an air waybill found place.

Based on this origin-destination matrix it can be found that the route from Cologne to Paris and from Paris to Cologne the most amount of freight is transported. This is an interesting finding, because based on the ranking of the top ten airports, Cologne does not belong to the upper half.

Based on the demand analysis of the air cargo transport market in Europe, the link between Cologne and Paris-CDG is chosen as a first initial route. However, the desk research and the semi-structured interviews revealed that most of the air cargo within Europe is trucked under an Airway bill instead of flown between airports. This would mean that a much higher amount of cargo is transported between the airports of Cologne and Paris-CDG. As the Cargoloop is competing with both, transport via air and road, on this route, the amount of cargo that is transported under an Airway bill should also be taken into account when determining the cargo flow.

APPENDIX F

Share of road transport per distance research Visser & Gordijn (2014)

Afstand	Aandeel vervoer over de weg via trucking, Schiphol geloste goederen	Aandeel vervoer over de weg via trucking, Schiphol geladen goederen
0-200 km	100%	100%
200-400 km	100%	100%
400-600 km	92%	91%
600-800 km	94%	94%
800-1000 km	87%	84%
1000-1200 km	41%	64%
1200-1400 km	83%	74%
1400-1600 km	87%	84%
1600-1800 km	50%	48%
1800-2000 km	47%	45%

APPENDIX G

Amount of air cargo trucked

Origin-destination matrix with amount of tonnes air cargo trucked within Europe in 2017. To obtain the amount of trucked air cargo, the trucking distance between the airports mentioned in table 6 needed to be determined. When the distance between each airport was determined, combined with the share of road transport per distance class described in table 9, the amount of tonnes air cargo trucked was obtained. Below in the table is the origin-destination matrix with the amount of tonnes air cargo trucked within Europe in 2017 (zeroes meaning no data available).

Road	**Frankfurt**	**Paris-CDG**	**London-Heathrow**	**Amsterdam-Schiphol**	**Leipzig - Halle**	**Luxembourg**	**Cologne-Bonn**	**Liège**	**Milano-Malpensa**	**Brussels**
Frankfurt		157.274	55.692		158.447				33.276	
Paris-CDG	44.039		41.336	42.147	87.762		401.338	344.100,	120.326	294.200
London-Heathrow	28.327	43.861		37.610	10.885				5.944	60.145
Amsterdam-Schiphol		76.664	50.726		240.248				6.276	
Leipzig-Halle	184.977	95.392	3.087	174.699			125.879		40.692	424.284
Luxembourg									221.495	
Cologne-Bonn		535.325			10.919					
Liège		70.400								
Milano-Malpensa	40.709	136.334	30.815	231	58.086	334.483				
Brussels		37.550	38.007		357.568					

APPENDIX H

Performance characteristics of transport via air, road and Cargoloop

First, the distance in kilometers of air transport is presented, followed by the distance of road transport and the Cargoloop, which are the same. Next, are the travel times presented of each mode of transport in hours.

Distance in km of air transport										
	Frankfurt	**Paris-CDG**	**London-Heathrow**	**Amsterdam-Schiphol**	**Leipzig-Halle**	**Luxembourg**	**Cologne-Bonn**	**Liège**	**Milano-Malpensa**	**Brussels**
Frankfurt		449	655		301				490	
Paris-CDG	449		347	398	739		388	275	598	252
London-Heathrow	655	347		371	879				937	351
Amsterdam-Schiphol		398	371		522				797	
Leipzig-Halle	301	739	879	522			361		694	544
Luxembourg									483	
Cologne-Bonn		388			361					
Liège		275								
Milano-Malpensa	490	598	937	797	694	483				
Brussels		252	351		544					

Distance in km of road transport and Cargoloop										
	Frankfurt	Paris-CDG	London-Heathrow	Amsterdam-Schiphol	Leipzig-Halle	Luxembourg	Cologne- Bonn	Liège	Milano-Malpensa	Brussels
Frankfurt		563	788		410				654	
Paris-CDG	563		475	485	932		475	396	888	297
London-Heathrow	788	475		570	1047				1330	402
Amsterdam -Schiphol		485	570		628				1085	
Leipzig-Halle	410	932	1047	628			492		837	667
Luxembourg									704	
Cologne-Bonn		475			492					
Liège		396								
Milano-Malpensa	654	888	1330	1085	837	704				
Brussels		297	402		667					

Travel time in hours of air transport										
	Frankfurt	Paris-CDG	London-Heathrow	Amsterdam-Schiphol	Leipzig-Halle	Luxembourg	Cologne-Bonn	Liège	Milano-Malpensa	Brussels
Frankfurt		0.56	0.82		0.38				0.61	
Paris-CDG	0.56		0.43	0.50	0.92		0.48	0.34	0.75	0.31
London-Heathrow	0.82	0.43		0.46	1.10				1.17	0.44
Amsterdam-Schiphol		0.50	0.46		0.65				1.00	
Leipzig-Halle	0.38	0.92	1.10	0.65			0.45		0.87	0.68
Luxembourg									0.60	
Cologne-Bonn		0.48			0.45					
Liège		0.34								
Milano-Malpensa	0.61	0.75	1.17	1.00	0.87	0.60				
Brussels		0.31	0.44		0,68					

Travel time in hours of road transport										
	Frankfurt	**Paris-CDG**	**London-Heathrow**	**Amsterdam-Schiphol**	**Leipzig-Halle**	**Luxembourg**	**Cologne-Bonn**	**Liège**	**Milano-Malpensa**	**Brussels**
Frankfurt		5.6	7.9		4.1				6.5	
Paris-CDG	5.6		4.8	4.9	9.3		4.8	4.0	8.9	3.0
London-Heathrow	7,9	4.8		5.7	10.5				13.3	4.0
Amsterdam-Schiphol		4.9	5.7		6.3				10.9	
Leipzig-Halle	4.1	9.3	10.5	6.3			4.9		8.4	6.7
Luxembourg									7.0	
Cologne-Bonne		4.8			4.9					
Liège		4.0								
Milano-Malpensa	6.5	8.9	13.3	10.9	8.4	7.0				
Brussels		3.0	4.0		6.7					

Travel time in hours of Cargoloop										
	Frankfurt	**Paris-CDG**	**London-Heathrow**	**Amsterdam-Schiphol**	**Leipzig-Halle**	**Luxembourg**	**Cologne-Bonn**	**Liège**	**Milano-Malpensa**	**Brussels**
Frankfurt		0.80	1.13	0.62	0.59				0.93	
Paris-CDG	0.80		0.68	0.69	1.33		0.68	0.57	1.27	0.42
London-Heathrow	1.13	0.68		0.81	1.50				1.90	0.57
Amsterdam-Schiphol	0.62	0.69	0.81		0.90				1.55	
Leipzig-Halle	0.59	1.33	1.50	0.90			0.70		1.20	0.95
Luxembourg									1.01	
Cologne-Bonn		0.68			0.70					
Liège		0.57								
Milano-Malpensa	0.93	1.27	1.90	1.55	1.20	1.01				
Brussels		0.42	0.57		0.95					

APPENDIX I

Constraints of variables in RUM MNL Model

Three different kinds of parameters were estimated in this assignment, with the following upper and lower bounds specified in solver:

1. μ (Mu): Solver range: [-1,0]

Transforming to utility space so that a logit model can be estimated. It is set negative so that an increase in costs leads to a decrease in utility.

2. Value of Time (VoT): Solver range: [0,134]

The range for the value of time is based on the value of times found in literature. According to the research of de Jong et al. (2014) it was found that the VoT of air cargo is approximately €133/ton-hour. Therefore, the range of solver is set to 134.

3. Alternative Specific Constant (ASC): Solver range: [-75,75]

This ASC shows the average effect on the utility of the factors that are not included in the model (Koppelman & Bhat, 2006). Only the difference in utility matter.

APPENDIX J

Academic paper

Academic paper based on thesis

The Cargoloop: An economic feasibility study on a cargo application of the hyperloop in Europe.

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ABSTRACT

It is expected that the express delivery market will grow strongly in the coming years. This growth, however, is restricted by the shortage of express transportation capacity. A cargo application of the hyperloop, the Cargoloop, could theoretically offer a solution for the bottlenecks found in the express delivery market. However, so far, little research has been done into the transport of cargo via the hyperloop. The aim of this to study is to explore the economic feasibility of the Cargoloop. In doing so, a cost-benefit analysis is carried out. The overview of the costs and the benefits is investigated for three different CBA scenarios that were different in the way the project was financed. The results showed that there was no scenario in which the Cargoloop is economically feasible. A fundamental factor for explaining this, is that when looking at the number of vehicles that would be annual operational on the route between the airports of Cologne-Bonn and Paris-CDG compared to the annual capacity of the Cargoloop, it could be found that only a small percentage of the capacity of the Cargoloop is utilized on this route. Substantial more cargo would need to be transported to make the Cargoloop economically feasible on this trajectory.

Keywords: Hyperloop – cargo – express freight – design - CBA

1. Introduction

The world in which we live today is more connected than ever. Ordering a package online and having it delivered the next day is nowadays considered to be normal, while only five years ago, this was not so self-evident. This fast and on-time delivery of products is known as 'express delivery'. An increase in demand for this type of service delivery can be observed and it is, combined with trends such a population growth, digitalization, globalization and demographic change, expected that the express delivery market will grow strongly in the coming years (Vakulenko et al., 2019).

This growth, however, is restricted by the shortage of express transportation capacity, which is mainly made possible via road and air (Bi, He, & Ato, 2019). A small selection of the bottlenecks, that are hampering the ability to accommodate the growing demand for express deliveries are: a) the limited capacity at airports which results in a decrease of cargo flights at large airports as passenger flights are often preferred (Liang et al., 2016); b) the congested roads which lead to unreliable delivery times (Kennisinstituut voor Mobiliteitsbeleid, 2018).

The transport sector, however, is not only subject to the increasing demand from a business perspective but also has to react to environmental challenges such as the need to reduce the greenhouse gases, noise pollution or congestion problems. This aspect is becoming an increasingly important topic, as environmental awareness grows on a global level (Meersman et al., 2016). Next to that, also quantitative targets are placed such as an initiative of the European Union to reduce the greenhouse gas emissions of the transport sector by 60% in 2050 compared to 1990. In overcoming these challenges, current transport modalities need to become more sustainable and new solutions for transport are needed. In the past years, several new transportation technologies have been developed with promising solutions for cargo transport. Examples of such technologies are cargo drones, the Cargo Sous Terrain concept or the hyperloop concept (Schodl et al., 2018).

This last concept, transporting cargo via the hyperloop, is explored in this study. The concept of the hyperloop was described in the Hyperloop Alpha paper by Space X in 2013. In this paper, this new transportation system was proposed as an alternative for the rail connection that was planned to be built between Los Angeles and San Francisco. The hyperloop is an autonomous ground-based system that consists of pods within a low-pressure tube, in which passengers and freight can be transported at high speeds of around 1000 kilometres per hour. By reducing the air resistance in the tube, a lot less energy is necessary to put the pressurized vehicles in motion. This in turn, results in speeds comparable to aviation while being more energy efficient than rail, making the hyperloop a sustainable mode of transport. If this new mode of transport could be realized, it would be a major innovative breakthrough for the transportation sector.

A cargo application of the hyperloop, the Cargoloop, could theoretically offer a solution for the aforementioned bottlenecks in the express delivery market. As it will be a cargo solution with dedicated infrastructure, operators do not have to compete with passenger demand, resulting in all capacity being devoted to freight operations. In addition, by moving freight transported via the road to the Cargoloop, the traffic density will decrease and with it the congestion. Furthermore, when looking from the environmental perspective, the Cargoloop complies with the current wishes regarding the environmental awareness.

The introduction of a new mode of transport, however, offers many new possibilities. Everything can be rethought. From the size of the vehicles to the loading and unloading process of the cargo. In addition, the fact that it is a cargo-only application and the transport of passengers need not be taken into account, also offers new insights such as for example the required diameter of the tube. However, if it wants to be a solution in practice, it will need to be explored how the Cargoloop can best tackle the current problems while being a competitive and interesting alternative to existing transport modes.

So far, little research has been done into the transport of cargo via the hyperloop. What is currently lacking is therefore a lot of knowledge about this possible application for cargo transport. It is for example unknown how the design of the application should look like and how this technology could be integrated into the existing network of transport systems. In exploring the possibilities of this new form of transport it was decided to focus on the economic feasibility as this would be a good 'starting point' for investigating the feasibility of the Cargoloop overall based on the framework of Feitelson & Salomon (2004). The aim of this to study is therefore to explore the economic feasibility of the Cargoloop. In doing so, a two-step approach is used. In the first step is the Cargoloop designed, followed by exploring the economic feasibility by means of a cost-benefit analysis.

2. Research method

A widely used technique for estimating ex ante the viability of transport projects, which is also used in this study, is the cost-benefit analysis (CBA). The CBA provides an overview of the effects and risks in corresponding costs and benefits and helps in answering the question whether the costs of a project outweigh the benefits. In other words, to find out whether a project is economically viable. As aforementioned, before this CBA can be carried out, the Cargoloop must first be designed first. For the design of the Cargoloop, desk research, input from interviews with transport scientists and in-house expertise were used. The current express freight market was investigated and on the basis of this analysis, transport scientists for the interviews were selected. In total, four scientists were interviewed. The experts shared their expertise and were introduced with the concept of the Cargoloop. In every interview, the scientists suggested how they would see the introduction of the Cargoloop in the current express freight market. Quotes from these interviews, combined with insights from analysis of the current express freight market, were used to establish the main lines of the design of the Cargoloop. In-house expertise was used to further elaborate the design technically. Ultimately, a potential route of the Cargoloop was estimated through an analysis of the Eurostat database in which the air cargo flows between airports were mapped.

In the second step, the CBA was conducted. In doing so, the potential route found during the development of the design of the Cargoloop was used. A step-by-step preparation approach for the CBA that was proposed in literature, has also been used as guide in this study. This approach consisted of the following steps: problem analysis, demand in reference scenario and policy alternative, determining the costs and the benefits, overview of the costs and benefits, analyse variants and risks and the results of the CBA.

The demand of the Cargoloop was calculated through a multinomial logit model. In doing so, three demand scenarios were created in which the tariffs of the Cargoloop differed: in the first demand scenario the tariff of the Cargoloop was similar to the tariff of road transport (0.11 €/tonne-km), in the second demand scenario the tariff of the Cargoloop was based on the average tariff of road and air transport (0.25 €/tonne-km) and in the third demand scenario was the tariff of the Cargoloop similar to the tariff of air transport (0.39 €/tonne-km).

The overview of the costs and the benefits was presented in three different CBA scenarios: 1) a first scenario in which the financing of the initial investment and exploitation of the project is private; 2) a second scenario in which the initial investment is financed externally but exploitation is private; 3) a third scenario in which the initial investment is financed by the government, but the exploitation is private. The earlier found demand scenarios were used to calculate the outcomes in the first two CBA scenarios. Moreover, within the first scenario, several sub scenarios were included to get an impression of the costs and the benefits under different circumstances. The approach of the latter scenario, however differed from the first two scenarios as not the previous estimated demand for the Cargoloop was used, but the modal share of the Cargoloop was estimated based on the marginal costs. An overview of the structure of the three CBA scenarios is shown below.

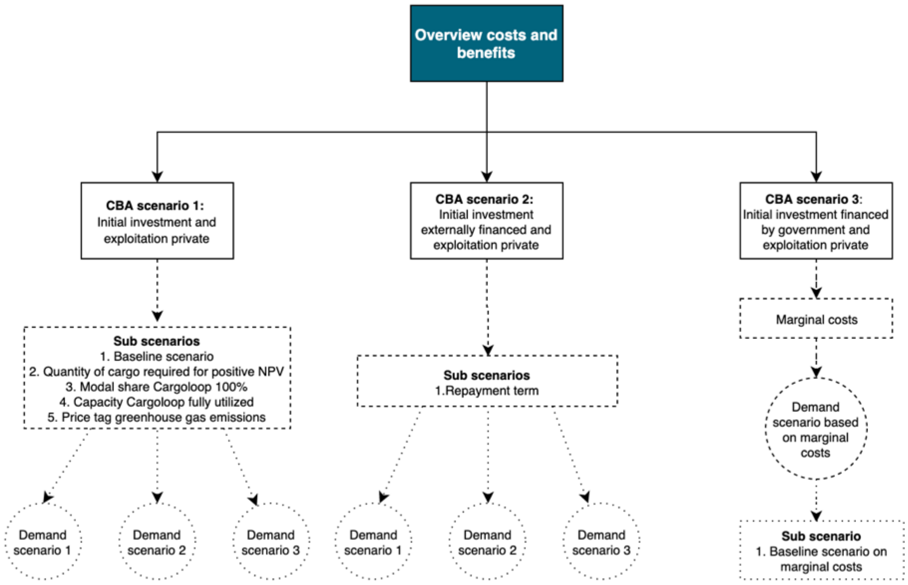

Figure 19 - Overview of the research methods used per step in the CBA approach, the products that result from these methods and the place of the steps in this study

3. Design of the Cargoloop

The process of designing the Cargoloop was divided into three steps: 1) main lines of the design; 2) technical specifications; 3) potential route of the Cargoloop. In the first step, it was found that the Cargoloop could serve as an alternative to the current aviation industry within Europe. In doing so, the Cargoloop would connect airports. It was found this route between two airports, however, is characterized by three important factors: 1) most of the air cargo is not flown between airports but is trucked within Europe; 2) in both modes the transport is mostly done via pallets and the most common used pallet is a EURO pallet; 3) both aviation and road transport deal with a consolidation constraint.

In the second step, the design of the Cargoloop was further elaborated technically. The determination of the tube diameter was crucial for the implementation costs, as the costs grow exponentially with the tube diameter. No information was available about the size of the air cargo transported and therefore the dimensions of the EURO pallet combined with the largest boxes offered by integrators were used as an input. Considering that, a Cargoloop with a 142 cm tube diameter was established. A diameter that is smaller than the required diameter for passenger transport and will therefore thus result in a cargo-only application. When further elaborating the design technically, the speed, frequency, payload, capacity and energy consumption were determined.

In the third step, the route between the airports of Cologne-Bonn and Paris-CDG was found as a potential route for the Cargoloop. The choice for this route was based on the requirement proposed by the experts to find the route that consisted of the largest air cargo flow within Europe. When establishing the route from a geographical perspective, it was decided to choose the route that passes by Liège. This decision was made with respect to the possibility of including this airport into the future network of the Cargoloop, as the airport of Liège belongs to the top ten cargo airports of Europe. On the other hand, the challenge of choosing for this route is that it will almost completely pass through Belgium, while it is not certain whether Liège will be involved. In order to get an agreement to build this route through Belgium, the plausibility that Liège will be added to this route must be clearly mapped out. A first step in order to do so, could be based on the results of the CBA.

4. Demand in reference scenario

As the design of the Cargoloop is determined, the next step in the preparation for the CBA was to establish the reference scenario. As aforementioned, the literature and semi-structured interviews revealed that most of the air cargo is actually transported via road instead of air between airports in Europe. These 'additional' flows should therefore also be taken into account when exploring the amount of cargo transported between airports. Eurostat, however, was not in possession of these data and therefore the study of Visser & Gordijn (2014) was used as a reference case. Visser & Gordijn explored the transport of air cargo by road from and to Schiphol.

The distance of the route chosen between Cologne-Bonn and Paris-CDG is 475 kilometres. In this distance range, Visser & Gordijn found that 92% of the air cargo is trucked. Therefore, this percentage is added to the previously found air cargo flows. Moreover, to establish the reference scenario also the expected growth of the market had to be taken into account. In doing so, it was found that according to the 'world air-cargo forecast 2018-2037' of Boeing (2018) the annual average growth rate of intra-Europe air cargo between 2018 and 2037 is forecasted at 2.3%. Due to simplicity reasons this growth rate defined by Boeing has been adopted as growth rate for the next 30 years. Combining this data resulted in the following reference scenario, shown in table 2:

Total amount of cargo on route Cologne-Bonn – Paris-CDG	**Year 0** (2017)	**Year 10** (2027)	**Year 20** (2037)	**Year 30** (2047)
Air transport *(in x1000 tonnes)*	81.5	102.2	128.3	161.1
Road transport *(in x1000 tonnes)*	936.5	1,175.7	1,475.9	1,852.7
Total ***(in tonnes)***	**1,018.**	**1,277.9**	**1,604.2**	**2,013.8**

Table 1 - Reference scenario for coming 30 years

5. Demand of Cargoloop

The demand of the Cargoloop was calculated through a multinomial logit model. A conceptual overview of the approach used to model the RUM-MNL model can be found in appendix A. In doing so, the following parameters were found on the estimated choice model. These parameters were in turn used to determine the demand of the Cargoloop:

Table 2 - Estimated parameters of RUM MNL model

Variable	**Value**
a_g	16.48
μ	-0.04
ASC_{air} Cologne-Paris	27.9
ASC_{air} Paris-Cologne	39.8

The different tariffs in the three demand scenarios resulted in the following modal share of the Cargoloop per scenario, as shown in table 3.

Table 3 - Outcome of MNL model showing the probabilities in each scenario

	Air transport ***(in %)***	**Road transport** ***(in %)***	**Cargoloop** ***(in %)***
Demand scenario 1	2	21	77
Demand scenario 2	6	74	20
Demand Scenario 3	7	91	2

In the first scenario, where the transport tariff of the Cargoloop is the same as that of road transport, the largest share of the cargo is transported via the Cargoloop. This was an expected outcome, as the travel time of the Cargoloop is much faster compared to road transport. This in turn, will result in a higher utility and thus a larger probability for the Cargoloop.

In the second scenario, the modal share of the Cargoloop is reduced substantial to only 20%. Based on logical reasoning, it was expected that the share would be higher, as the Cargoloop is faster than road transport but cheaper than air transport, this provided the intuition that by opting for a mid-range tariff, it could still obtain a relatively large modal share. That this is not the case, however, can be explained by the VOT. If the earlier found VOT would be higher, the modal share of the Cargoloop in this scenario would also become larger. In other words, this also means that the VOT of the goods transported on this route may not be of such a high standard that the shipper would be willing this mid-range tariff for the transport with the Cargoloop.

Finally, in the third scenario, only 2% of the cargo will be transported via the Cargoloop. This scenario, however, was expected as based on a comparison between distance and travel time of air transport and the Cargoloop, air transport has a shorter distance and a faster travel time, resulting in a higher utility. Whether this is realistic in practice, is another question as it will be likely that the transport via the Cargoloop will be faster due to the smaller size of the vehicle and a more efficient handling procedure. These aspects, however, are not taken into account.

5. Cost and benefits

In defining the effects of the Cargoloop, the following costs and benefits were identified, which were grouped into two categories: 1) infrastructure costs; 2) modal shift. The infrastructure costs are one-off, during the implementation of the Cargoloop. The effects of the modal shift on the other hand were based on the earlier calculated demand for the Cargoloop in the three different CBA scenarios. The following effects were identified, quantified and monetized in this study, shown in figure 2.

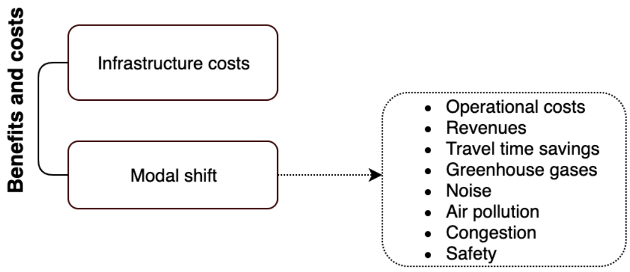

Figure 2 - Identification costs and benefits of the Cargoloop

In this CBA, as can be seen from figure 2, the following external costs were included in the project: travel time savings, greenhouse gas emissions, noise nuisance, air pollution, congestion and safety. This CBA can thus be considered as an indices CBA, meaning that only the basic elements are included. It is however, possible to include the external costs of more effects such as reliability, comfort or security. Especially the factor reliability would also have been interesting to consider in this project. Since it is expected by moving autonomously through a closed environment, in which the transport will not be affected by for example the weather conditions, on-time delivery can be established.

6. Sensitivity analysis

The next step in the preparation for the CBA is an analysis of possible scenarios and risks. The future is uncertain which means that the costs and the benefits of a new alternative will also be uncertain. The ex-ante estimates of the costs and the benefits are thus not exact but are subjected to a margin of uncertainty. In the sensitivity analysis it was found that the investment costs, the expected growth of the cargo and the discount rate could be considered as the critical variables of the project and additional research on these variables may be beneficial before accepting the project. Finding these variables as critical variables and referring back to the way in which these variables are substantiated in this study, highlights the importance of doing more research into these variables as the values were calculated based on a reference project. There is therefore a lot of uncertainty in both variables about their representativeness for the Cargoloop. This combined with the fact that it is a critical variable in the CBA, ensures that more research is required in order to obtain a more reliable outcome of the CBA in which the variables are clearly substantiated.

7. Results

In neither of the three CBA scenarios the Cargoloop was found as economically viable. A fundamental factor for explaining why the Cargoloop is not economically viable is that when looking at the number of vehicles that would be annual operational on the route between the airports of Cologne-Bonn and Paris-CDG compared to the annual capacity of the Cargoloop, it could be found that only a small percentage of the capacity of the Cargoloop is utilized on this route. Substantial more cargo would need to be transported to make the Cargoloop economically feasible on this trajectory. This could be realized by obtaining a larger modal share or by expanding the network, so the overall cargo flow will become larger.

Regarding this first suggestion; a larger modal share for the Cargoloop, it was found in CBA scenario 1 that if the modal share of the Cargoloop would be 100% on the route between the airports of Cologne-Bonn and Paris-CDG, the Cargoloop would only be feasible from a tariff of 0.16 €/ton-km or higher. Meaning that the Cargoloop tariff would be higher than that of road transport, ensuring in turn that a 100% modal share of the Cargoloop would not be realistic in practice. When the modal share was calculated on the basis of marginal costs (CBA scenario 3), a modal share of 92% was found. A substantial increase compared to the previously estimated modal shares. This was expected as the marginal cost was substantially lower (0.049 €/tonne-km) than the tariffs used in this study for road and air transport. The marginal cost here was calculated at an annual capacity of 1%, which was the average capacity of the Cargoloop found in the earlier demand scenarios on the route between Cologne-Bonn and Paris-CDG. This low marginal cost with a relatively large modal share, however, also resulted in not being economically feasible. This was already expected as it was found that 0.16 €/tonne-km is necessary to obtain a positive net present value (NPV).

Regarding the second suggestion: increasing the overall cargo flow, an interesting finding was the quantity of cargo required to obtain a positive NPV in demand scenario 1 (modal share of 77%) of CBA scenario 1. It was found that approximately an overall additional amount 500,000 tonnes of cargo would be needed to make the Cargoloop economically viable between the airports of Cologne-Bonn and Paris-CDG. Considering the route between the airports of Cologne-Bonn and Paris-CDG, which passes by Liège because of the possibility of including this airport into the future network, obtaining a positive NPV in this scenario might be realistic when the airport of Liège would be included on this trajectory. In realizing this, the airport of Liège would need to meet the required additional amount of 500,000 tonnes. The latter could be considered as realistic as Liège belongs to the top ten largest cargo airports in Europe and knowing that approximately 900,000 tonnes of cargo are transported between the airports of Cologne-Bonn and Paris-CDG which also both belong to this top ten of largest cargo airports. However, no answer could be given on that question yet as more research is needed due to the lack of the available data regarding the transport of air cargo from and to the airport of Liège.

The above finding, in which it is described that adding Liège on the route between the airports of Cologne-Bonn and Paris-CDG could make the Cargooop economically viable, also stresses the importance of including Liège on this Cargoloop route. This would make it more likely that Belgium would agree upon a Cargoloop route through their country as it will be ensured that Liège will be included on the route.

Furthermore, when comparing CBA scenarios 1 and 2, it could be found that financing the initial investment externally, resulted in a higher NPV and benefit-cost ratio (BCR) compared to when the initial investment is privately financed. The longer the duration of the payback term for the external financing, the less negative NPV and BCR became.

Following on what is described above, it would be interesting to calculate the amount of cargo that is needed to obtain a positive NPV in demand scenario 1 of CBA scenario 2. As it was discussed in the previous paragraph, external financing of the initial investment resulted in a higher NPV and BCR compared to these values in CBA scenario 1.It would therefore be expected that the amount of cargo needed to obtain a positive NPV in demand scenario 1 of CBA scenario 2 would be lower than 500,000 tonnes resulting in an even higher probability that this scenario could be economic feasible when including Liège.

8. Conclusions

To the best of my knowledge, no research has explored the economic feasibility of the Cargoloop before. This research showed that according to experts in the field, the Cargoloop would be interesting for connecting airports. In doing so, it appeared that it is most relevant to look for the largest air cargo flows in Europe. The design of the Cargoloop was established based on three important factors that were found crucial in connecting airports.

The outcome of the CBA showed that there is no scenario in which the Cargoloop is economically feasible. A fundamental factor for explaining this was the low annual operational capacity rate of the Cargoloop compared to the annual capacity of the Cargoloop. Substantial more cargo would need to be transported to make the Cargoloop economically feasible on this trajectory. By including Liège in the trajectory, it is expected that the trajectory between the airports of Cologne-Bonn and Paris-CDG might be economically viable. It would therefore be interesting in a further research to investigate the amount of cargo transported from and to Liège as no data was available now.

It should be noted however, that this CBA is based on the technical specifications that were designed for the Cargoloop in answering the previous research question. These specifications, as mentioned before, are subjected to a certain uncertainty as they could not be verified with other studies since no other studies were available regarding this. Moreover, also the maintenance costs and implementation costs were calculated on reference projects and their representativeness also comes with a degree of uncertainty. This in turn means that the outcome of the CBA should not be interpreted as 'decisive' because changes in the design or the costs are likely and could possible lead to other outcomes in the CBA scenarios.

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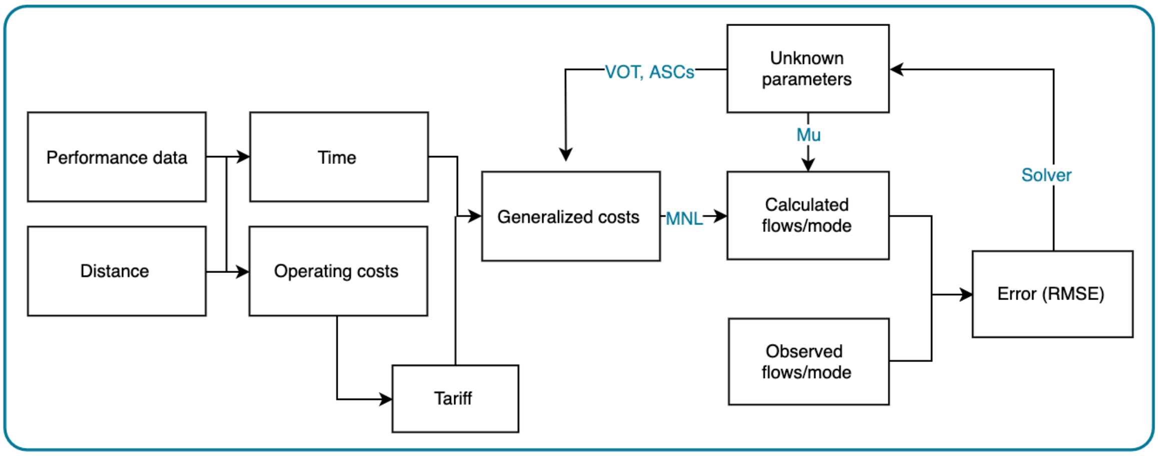
Appendix A


Performance data
Distance
Time
Operating costs
Tariff
Generalized costs
VOT, ASCs
Unknown parameters
Mu
MNL
Calculated flows/mode
Observed flows/mode
Solver
Error (RMSE)