MSc Thesis

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Competitive potential of Hyperloop from a travellers' perspective

A stated choice experiment under future contexts to determine travellers' trade-offs

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By

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Preface

Dear reader,

First of all, thank you for taking the time to read my thesis report.

My deep interest in the potential of innovative technologies got me to study the Hyperloop. Coming from Delft University, I got into the workings of the Hyperloop through contact with other students and lecturers. At first, its potential seemed unmatched to me. However, after more deliberation and research towards it, more of its issues started to surface in my periphery. Understanding these issues in relation to its potential puzzled me. The education offered at the faculty of Technology, Policy and Management provided me with the toolkit to solve at least a part of this puzzle. Specifically, my enthusiasm for the course 'Statistical Analysis of Choice Behavior' by Eric Molin and Caspar Chorus led to the final research objective.

My thesis has greatly benefitted from the help of several people, who I would like to thank. Eric, the dedication you show towards your thesis students is immense and does not go unnoticed. Your tailored advice has brought me what I needed during different stages of the research, thank you. Gerdien, your energetic attitude and feedback has motivated me many times, especially during the covid-lockdowns, thank you. Kristel, many thanks for your kind help with the many challenges that are inherent to research, I truly enjoyed our weekly meetings. Kees, your no-nonsense attitude, view on innovation and ability to shed a different light on my work was very helpful, many thanks. Last but not least, Katie, Just & Luc, my friends, many thanks for your patient words and the many discussions we had.

Finally, I would like to express my gratitude to the faculty of Technology Policy and Management, where I've spent the last six years of my life. I could have never anticipated the interests I would develop for the topics which are taught and studied at TPM. Hopefully, I'll be able to visit for other purposes in the future.

Lukas Marthaler,
Delft, July 2021

Summary

Reaching the Paris Climate Agreement goals by 2050 is currently one of the largest societal challenges we are facing. Much is to be gained in the transport of people and goods, which accounts for 25% of the total carbon emissions in Europe. Presently, Air Passenger Transport (APT) hinders carbon emission reductions due to its large environmental impact and evermore growing market share (Van Goeverden et al., 2017). So far, the environmentally friendly high-speed rail only competes with APT up to approximately 600-800 kilometers. Hyperloop as kickstarted in 2015 by Elon Musk has the potential to substitute APT beyond that range, with electric propulsion of magnetically levitating passenger capsules within semi-vacuum tubes.

However, research towards Hyperloop's potential travel demand has remained sparse as of now. Within the financial appraisal of infrastructure projects, forecasted travel demand of the infrastructure is a vital aspect. Namely, ticket revenues and societal value through environmental benefits and travel time savings can result from travel demand. So far, only straightforward analyses have been done to forecast potential Hyperloop demand, using data from previous travel surveys that do not include Hyperloop. Used data does not cater to travellers' overall (dis)like for Hyperloop, or travellers' trade-offs including Hyperloop-specific transport mode attributes. Moreover, since potential Hyperloop implementation lies in the future, various future contexts surrounding travel behavior could also influence its competitive potential.

To account for these issues, this research estimates future Hyperloop travel demand by conducting a Stated Choice Experiment (SCE) amongst Dutch travellers. Here, future decision-making contexts and travellers' (dis)like for Hyperloop are included.

Using the results from the SCE, Hyperloop market shares are estimated for three separate introduction scenarios. Currently, multiple visions by experts in government, academia and industry surround the Hyperloop. These visions form the basis of the formulated introduction scenarios (see figure 0.1). Introduction scenarios differ mainly on their envisioned purpose and related competitive potential of the Hyperloop.

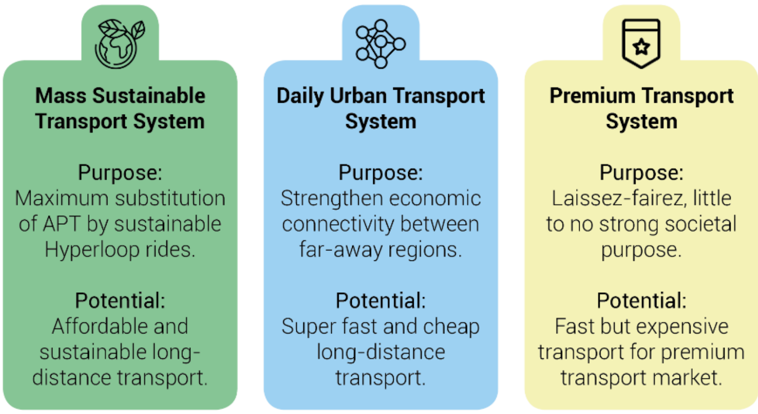

Figure 0.1: Hyperloop introduction scenarios

The resulting main research question was formulated as follows:

To what extent will different Hyperloop introduction scenarios and future decision-making contexts influence travellers' choices between APT, Hyperloop and other transport modes?

Methodology
Demand forecasting under different introduction scenarios is supported by estimating traveller's sensitivity to important decision-making factors (i.e. transport mode attributes). These are found in the high-speed rail versus APT competition literature. Since the life-cycle sustainability performance of the Hyperloop is yet unclear, travellers' sensitivity to sustainability performance was also included. The final list of transport mode attributes included travel time, access-egress travel time, travel cost and sustainability performance. Based on expert interviews, transport forecasting literature, policy documents, two future contexts were selected: carbon social norms (CSN) and Hyperloop market penetration. Roughly speaking, CSN relate to flight-shaming and Hyperloop market penetration to social effects surrounding market penetration levels.

Travellers in the SCE were asked to state their choice between APT, Hyperloop or another transport mode, based on variations in these mode attributes and future context situations. Furthermore, travellers' perception and familiarity with Hyperloop, current travel behavior and socio-demographic characteristics were measured. Identifying differences between travellers allows for further substantiation of the environmental impact of Hyperloop, understanding of Hyperloop preferences and gain marketing insights for Hyperloop developers. Lastly, several questions were asked to evaluate the usability of future contexts in Stated Choice Experiments.

Data collection was done between the 10th of May and the 31st of May 2021, through an online survey. Respondents were mainly recruited through the (in)direct network of the researcher. In total, the survey was opened 428 times. After data cleaning 223 complete responses remained. The sample showed to be highly educated, quite young (mainly students and young professionals), skewed towards low-income travellers, containing many frequent flyers and very familiar with the Hyperloop compared to other recent research. It is expected that the sensitivity to travel costs, sustainability performance and preference for Hyperloop and APT were somewhat biased upwards because of that. Overall, most findings were in line with expectation.

Travellers' sensitivities and preferences
The results show that travellers have a preference for Hyperloop and care much for travel costs, sustainability and (access-egress) travel time. The future contexts had little impact on travel behavior.

When all else is equal, travellers prefer to use Hyperloop over APT and other transport modes. Especially travellers who perceive Hyperloop as safer, more exciting and more sustainable have a stronger preference for Hyperloop. Moreover, travellers proved to be more cost-sensitive than time-sensitive compared to previous Dutch research. High-income and business travellers showed to care significantly less about travel costs.

In contrast with previously observed travel behavior, travellers did alter their stated choices according to the sustainability performance of Hyperloop. However, frequent flyers still showed to care less about the sustainability of Hyperloop and prefer APT over other transport modes. This result also emerged through the identification of two distinct traveller classes: an economic traveller class (56%), and a sustainable traveller classs (44%). Frequent flyers are more likely to belong to the economic traveller class, which cared most about travel time and costs. The sustainable traveller class, on the other hand, showed to care much more about sustainability performance and has a strong dislike for APT.

The future contexts showed to have some, but little impact on traveller decision-making. Travellers somewhat sooner opt for the more sustainable transport mode under situations where friends/family/colleagues *often* critique the usage of carbon-heavy transport modes. Also, travellers showed to mostly perceive Hyperloop as safer, more comfortable and easier-to-use under high market penetration situations. Interestingly, older travellers (60+) showed to be less sensitive to market penetration effects, expectedly due to their low need for peer observation information or social affirmation. Overall, respondents were able to familiarise themselves quite well with future contexts. Of the expected challenges, imagining the future context into one's social environment proved to be the hardest.

Scenario analysis

Scenario analysis shows that it matters greatly how the Hyperloop is introduced into the transport landscape, with much difference in Hyperloop market share between introduction scenarios. To maximise the societal benefits such as economic and sustainability benefits, Hyperloop ticket subsidies or additional taxation of APT is required. The future contexts show some effect on market shares, although not much. Overall, the Hyperloop is very competitive with regards to APT and other transport modes. Market share percentages per introduction scenario and future context are presented under figure 0.2.

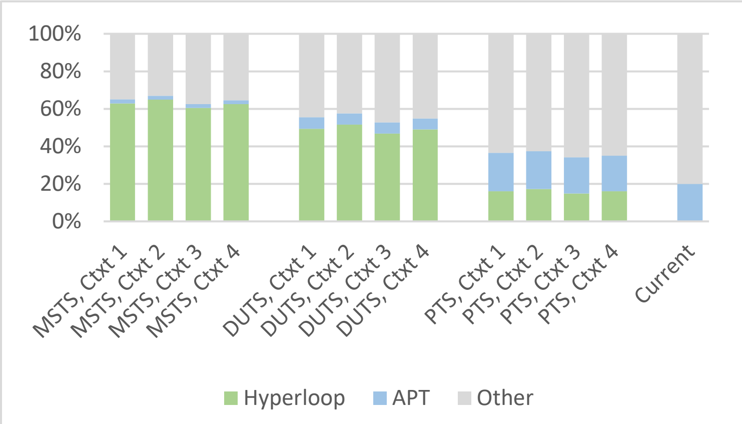

Figure 0.2: Market shares of Hyperloop introduction scenarios, per future context

The Mass Sustainable Transport System (MSTS) introduction scenario ensured the highest potential Hyperloop market share. This was the scenario with the most frugal and environmentally friendly Hyperloop system with relatively long (access-egress) travel times but low (i.e. heavily subsidised) ticket prices and high taxation of APT ticket prices to discourage flying. The Daily Urban Transport System (DUTS) scenario ensured the second most market share for Hyperloop, which is characterised by a dense network of Hyperloop hubs, high Hyperloop speeds, low Hyperloop and APT ticket prices but also an environmentally unfriendly Hyperloop system. Lastly, as the name indicates, the Premium Transport System (PTS) introduction scenario proved to attract mostly business and higher-income travellers. This scenario is mostly characterised by high Hyperloop ticket prices and APT in its current form. Still, Hyperloop proves to be quite competitive to APT under this scenario due to its shorter access-egress travel time.

The future contexts presented in this study show to have some, but marginal effects on the mode choice behavior of travellers. Only when future contexts have an impact in favour of the same transport modes, market shares shift several percentage points.

Policy and design recommendations

The results of this research are useful to Hyperloop developers, consortia and governments looking to make Hyperloop a success. The following recommendations are aimed at drawing as many travellers as possible to the Hyperloop.

- *Focus on Hyperloop ticket price instead of (access-egress) travel time*

Reducing Hyperloop travel time and access-egress travel time has little impact on its market shares. Instead, ensuring high subsidies for Hyperloop tickets and additional taxation of APT ticket prices should be prioritised over Hyperloop travel speed reductions.

- *Ensure Hyperloop life-cycle sustainability*

It is recommended to ensure life-cycle sustainability for Hyperloop and position it as sustainable under marketing efforts. Travellers show to switch to other transport modes if Hyperloop does not perform better environmentally compared to APT. A positive sustainable impact of Hyperloop could especially generate much market share amongst the identified sustainable traveller segment.

- *Target business travellers first in marketing*

Business travellers display the highest adoption rate of Hyperloop under every introduction scenario, due to their relative insensitivity to ticket price. Since this relatively small traveller segment, 7% of the Dutch population, makes up 32% of all flights at Schiphol Airport, much environmental gain comes from this marketing focus. Especially since business travel managers have become keener to reduce the environmental impact of their employees' travel behavior (Klein-Schiphorst, personal communication, 2021).

- *Accentuate Hyperloop safety, excitement and peer observation*

Results indicate that travellers who perceive Hyperloop as safer than APT will more likely choose Hyperloop over APT. Similarly, travellers who perceive Hyperloop rides as more exciting than flying, have a higher preference for Hyperloop. A marketing focus on these travellers' perceptions could therefore increase the level of Hyperloop adoption.
Moreover, it has shown that (especially younger) travellers react positively to positive Hyperloop experiences by family and friends. Marketing campaigns should therefore also focus on revealing the (positive) experiences of travellers to another.

Limitations and future research

Several limitations and recommendations for future research are mentioned in the report. The following limitations and future research recommendations are deemed most impactful.

This research focused solely on the substitution of APT by Hyperloop, including only travellers who fly at least on occasion. Future Hyperloop demand forecasts should therefore focus on the additional sources of Hyperloop travel demand. It is expected that Hyperloop could potentially generate induced demand from; additional trips between cities that fall in commuting range because of the Hyperloop, a strong synergy between intercontinental flights and continental Hyperloop rides, non-flyers because of APT's environmental impact and fear of flying.

It is recommended to perform a Stated Choice Experiment with an increased number of future context variables. This research used only two future context variables, which limits more conclusive evidence towards their usability in SCE. Different types of future contexts are expected to be more or less applicable, similar to the amount of future contexts that is doable for respondents. By adding more future contexts in the SCE, the complexity for respondents will likely rise. However, this will enable the researcher to seek the boundaries of respondents' imaginative abilities.

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1. Introduction

1.1 Hyperloop in the European transport environment

Reaching the Paris Climate Agreement goals is one of the largest societal challenges we are currently facing. As decided under the agreement, all signed parties will strive for zero carbon emissions by 2050 (Oztig, 2017). Many possible improvements can be made towards the reduction of carbon emissions, one of which includes reducing the greenhouse emissions from transport. In 2020 the transport of people and goods accounted for 25% of the European greenhouse gas emissions (European Commission, 2020a). Within the passenger transport sector, long-distance travel is increasingly dominated by the environmentally unfriendly air passenger transport (APT), which is evermore growing in market share compared to the car, bus and train. Logically, this has to do with APT's high speed and low ticket prices, putting competitive pressure on other transport modes (van Goeverde et al., 2018).

Kickstarted by Elon Musk in 2013, the new Hyperloop transportation system offers a potentially sustainable alternative transport mode that could compete with APT speed-wise. The Hyperloop transportation system offers transport within a concealed capsule through a grounded tube in a near-vacuum environment, which enables high speeds and high energy efficiency due to reduced air drag (Musk, 2013). Similar to HSR, Hyperloop is propelled using electricity which gives it the potential to produce zero tailpipe emissions in its passenger transport operations. The concept is very similar to magnetically levitating (Maglev) trains, however, Hyperloop capsules are placed in a concrete or metal tube in which a semi-vacuum is applied to reduce air drag, which allows speeds surpassing 1000 kilometers per hour and a drastic increase in energy efficiency (Santangelo, 2018).

In recent decades, only high-speed rail (HSR) with its electric propulsion has proven to be an environmentally friendly competitor to APT in the public transport market (Nash, 2013). The Hyperloop could become a complementary transport mode to HSR, covering distances surpassing roughly 600 kilometers, on which HSR has not proven to be competitive enough for APT (Janic, 2003). An ecosystem of companies, research institutions and the Dutch government have recognised Hyperloops' potential, culminating in the Hyperloop Development Program. Together, these parties have raised €30 million for research towards the 'potential of hyperloop as a high-speed, zero-emissions transport solution' (EIT InnoEnergy, 2020).

So far, Hyperloop has mainly been positioned as a substitution to short-haul flights (<1.500 km) due to its high speed, which enables faster travel over greater distances (Delft Hyperloop, 2019; Taylor et al., 2016; Van Goeverden et al., 2017). The introduction of high-speed rail (HSR) in the past decades was also aimed to reduce short-haul flights but has only managed to do so for trips up to 6 hours, or roughly 600-800 km over land (Mook, personal communication, 2021). As to not substitute the publicly financed and environmentally-friendly HSR, Hyperloop would most likely bring the most societal gain if it covered trip distances starting at 600-800 km (Van de Weijer, 2017), which is why this research will focus on a hypothetical route of 650 km (distance similar to Amsterdam – Berlin).

A well-known proposed Hyperloop connection is the Los Angeles and San Francisco corridor, which is predicted to have a one-way trip time of 35 minutes, compared to a flight time of 1 hour and 15 minutes (Musk, 2013). This substitution potential by Hyperloop is further illustrated by the pre-feasibility study conducted by Schiphol Airport and Hardt Hyperloop, which assumes a 10% substitution of APT by Hyperloop over all flights from the airport (Hardt Hyperloop, 2019b). That important assumption is further used in the projections for Schiphol's economic feasibility of a Hyperloop terminal adoption in its infrastructure. However, the report does not provide further delineation of the assumption, nor does it refer to previous research.

Currently, several visions of Hyperloop's role in the future transportation environment exist in government, academia and industry. See Shetty (2019) for a comprehensive review. These visions form the basis of three formulated introduction scenarios, that are used as reference points in this research. Introduction scenarios differ mainly on their envisioned purpose and related competitive potential of the Hyperloop (see figure 1.1). It is researched what the competitive potential from a travellers' perspective is for these 'visions' of Hyperloop, under different future contexts. Introduction scenarios will be further delineated under chapter 7.

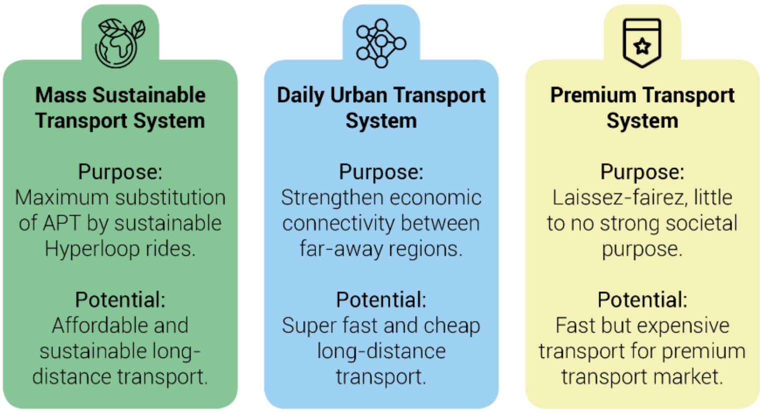


Figure 1.1: Hyperloop introduction scenarios

1.2 Research Problem

Potential Hyperloop travel demands have been researched sparsely so far (Kalrav, 2019), with most research efforts aimed at Hyperloop's technical feasibility (Gkoumas et al., 2020). The few demand forecasts out there mainly keep to straightforward forecasts using data that does not specifically cater to Hyperloop demand forecasts (HTT et al., 2019; Van Goeverden, Janic, et al., 2018). This prohibits accurate analysis towards the competitive potential of Hyperloop.

Currently, travellers' mode preferences are not included in Hyperloop demand forecasts. Especially as a new entrant to the market, travellers' (dis)like for Hyperloop could play a large role in its adoption by travellers. For example, it is expected that perceptions like safety, sustainability, comfort, excitement and status-related factors are relevant to travelers overall (dis)like for Hyperloop (van Wee, personal communication, 2021).

Furthermore, existing forecasts assume that the same trade-offs are made by the traveller with regards to the Hyperloop. Since the Hyperloop cannot be easily categorised within existing transport modes, this assumption might prove invalid. For example, Hyperloop stations are expected to be located near city centers, which is typically an advantage held by HSR over APT. In contrast, Hyperloop capsules do not have to stop at every station on a service line, an advantage typically held by APT over HSR. However, ticket prices of the Hyperloop are expected to be higher than those of both APT and HSR (Van Goeverden et al., 2017). Thus, travellers face an unique transport mode, for which they will likely need to reweigh their decisions.

Moreover, the Hyperloop is expected to operate in 2030 at its earliest (Virgin Hyperloop, 2018), which will likely have an impact on its competitive potential. Namely, changing contexts have an influence on travel behavior (Molin & Timmermans, 2010). To illustrate; Lee et al. (2019) have estimated future adoption rates of pilotless aircrafts. However, they did not account for the future time frame in which pilotless aircrafts could become reality. Thereby, they might have missed critical future contexts in their research. For example, the resistance that nowadays still exists around autonomous vehicles might be lifted due to travellers' experiences with autonomous cars. The same might be true for Hyperloop which will potentially face different contexts surrounding travel behavior, that could either improve or worsen its competitive potential compared to APT.

Accounting for the abovementioned issues, this research aims to estimate future Hyperloop and APT travel demand by conducting a Stated Choice Experiment (SCE) amongst Dutch travellers, which also accounts for Hyperloop preferences and future contexts. The results from the SCE are subsequently applied to scenario analysis, to determine APT and Hyperloop travel demand under the presented Hyperloop introduction scenarios. The different introduction scenarios and future contexts will likely also influence the choice for other transport modes besides Hyperloop and APT. Therefore a base alternative is added to the SCE. This allows the estimation of Hyperloop and APT market shares within the total transport market which also includes trains, buses and cars.

Besides accounting for Hyperloop perceptions and future contexts, this research also aims to define different traveller segments based on their choices between Hyperloop and APT and other transport modes. It is expected that different traveller segments exist, with different levels of Hyperloop adoption. By defining traveller segments, their expected size in society, and their sensitivity to certain scenarios, we can estimate the impact of those scenarios. Thereby, the level of detail will provide a richer image and more possibilities for interpreting the demand forecasts under different Hyperloop implementation scenarios. Another benefit is the marketing focus which can result from better understanding travelers' behavior.

1.3 Research Questions

This research aims to fill the scientific knowledge gap and provide relevant information to society by answering the following main research question:

To what extent will different Hyperloop introduction scenarios and future decision-making contexts influence travellers' choices between APT, Hyperloop and other transport modes?

To answer the main research question formulated, the following sub-questions are formulated which culminate to the answer of the main research question.

1. To what extent do mode preferences, travel time, travel cost, access- and egress time and mode sustainability affect the travellers' choice between APT, Hyperloop and other transport modes?

2. To what extent do the future contexts regarding carbon social norms and Hyperloop market penetration levels influence traveller's choices between APT, Hyperloop and other transport modes?

3. To what extent are respondents able to familiarise *themselves with future contexts in the focal research?*

4. How do Hyperloop perceptions, travel behavior, prior Hyperloop familiarity and socio-demographic variables influence travellers' choice between APT, Hyperloop and other transport modes?

5. To what extent does heterogeneity exist amongst traveller segments regarding their sensitivity to mode attributes and mode preferences?

6. Based on different Hyperloop introduction scenarios, what potential market share are the Hyperloop, APT and other transport modes expected to retain on the focal trip length under different contexts?

1.4 Scientific & master program relevance

Current literature concerning Hyperloop demand forecasts is scarce, keeping to straightforward analyses. This research, therefore, aims to add to this literature by providing more detailed demand forecasts based on different introduction scenarios and the effects of Hyperloop perceptions and traveller characteristics on Hyperloop adoption.

Secondly, by accounting for Hyperloop's future implementation date and the unleveraged potential of context-dependent choice modelling in travel behavior, this research explores the opportunity to assess future transport innovations within future contexts. As illustrated by Molin & Timmermans (2010), many more context variables could be relevant to travel mode choices. To the best of my knowledge, literature so far has not included future travel contexts. Subsequently, this research will evaluate the applicability of future contexts to SCE. It is likely that future -therefore hypothetical- choice contexts might pose a difficult choice situation for participants of the choice experiment, who are not accustomed to the presented context situation. This issue is similar to familiarity effects in 'regular' SCE: respondents make more consistent and predictable choices when dealing with familiar products and services (Molin, 2019d).

Lastly, an interesting synergy between context-dependent choice modelling, identifying traveller segments and the Diffusion of Innovations theory by Rogers (1962) could prove useful to researchers looking to research adoption dynamics of hypothetical transport innovations. As stated by El Zarwi et al. (2017), the prediction of future adoption rates of a not-yet-existing transport innovation is tricky, due to the dynamics of adoption. One such dynamic presented in literature is the effect of observability (Rogers, 1962), which means people can 'test' an innovation by observing experiences from peers, which has not yet been researched using future contexts in SCE. As this research presents this dynamic as a context (see 2.6.2), it enables research towards the influence of peer observation on decision-making by different segments of the population.

The master program Complex Systems Engineering and Management offers methodologies to bridge the gap between technology and society. Exactly that is the aim of this research, to bridge (part of) the gap between current technology-focused Hyperloop developments with the financial-economic focus of society. This is done by using a methodology taught under the master program, followed by recommendations for researchers and stakeholders from society.

1.5 Societal relevance

Results from this study are aimed to guide future Hyperloop feasibility studies and assess important financial decision-making factors for interested governments.

With growing interest from society, this research can help steer feasibility studies revolving around the Hyperloop. The increasing Dutch interest in Hyperloop has culminated in a broad collaboration of companies and governmental parties committed to researching the commercial feasibility of Hyperloop in the coming years (HDP, 2021). A similar feasibility study has already been performed by Hyperloop Transport Technologies in the United States, which has assessed a potential Hyperloop route including its financial feasibility. Demand forecasts and substitution effects have shown to be part of this, which this research aims to perform using current data from Dutch travellers. By providing insights into several important determinants of Hyperloop travel behavior, future feasibility studies will be able to focus their research on those important determinants. For example, if the sustainable performance of the Hyperloop relative to APT proves to be important to travellers, feasibility studies will be able to put more emphasis on that aspect in assessing the feasibility of potential Hyperloop systems.

Demand forecasts via SP experiments are essential for the financial assessment of Hyperloop, as they are used to estimate expected societal benefits and ticket revenues. Societal benefits are an important component in the prominent Cost-Benefit Analysis used by European governments in most of the infrastructure appraisal (van Wee, 2012). Similar to other public transport infrastructure (UNIFE, n.d.; van Wesdorp, personal communication, 2021), Hyperloop implementation is likely dependent on government financial support which is often only granted after thorough financial feasibility assessments (Marcelo et al., 2017). The proposed Hyperloop route between Chicago and Cleveland has already shown the necessity for government grants, which are required to cover capital expenses. Also, operational expenses may require government compensation to bridge the gap between high cost-meeting ticket prices and reasonable ticket prices for travellers (TEMS et al., 2019). Different introduction scenarios will show different levels of Hyperloop demand, which in turn generates value through ticket prices and societal value through factors like travel time savings and environmental benefits per passenger kilometer (TEMS et al., 2019). Besides an aggregate demand forecast, this research also provides traveller segment-specific forecasts. This tells us which groups will use the Hyperloop, APT or other transport modes under what circumstance, which could be of importance to Cost-Benefit-Analyses. For example, the societal benefits of Hyperloop through CO_2 emission savings would be relatively meager if all frequent flyers would stick to APT.

1.6 Report structure

This thesis report is divided into 7 chapters following the introduction. Chapter 2 will delineate the state-of-the-art of relevant literature to the research and the background of the factors deemed relevant to Hyperloop travel behavior. An encompassing conceptual model is provided that visually represents the to-be-researched elements. Chapter 3 will consequently address the 5operationalization of the hypotheses in the central data gathering method, the survey. Chapter 4 is dedicated to the presentation of the sample alongside its representativeness. Chapter 5 is dedicated to the methodology, which includes the Discrete Choice Model estimation. Subsequently, the results are interpreted under chapter 6. Using the results, chapter 7 delineates the scenario analysis under which Hyperloop can be implemented. Lastly, in chapter 8 the conclusion, discussion and future research recommendations are presented.

2. Research background & literature

Chapter 2 has two aims: identify relevant knowledge gaps in the relevant literature (sections 2.1 & 2.5) and retrieve important potential determinants of Hyperloop travel behavior from literature (sections 2.2, 2.3, 2.4, and 2.6). A conclusion is provided under 2.7.

2.1 Hyperloop feasibility & demand forecasting

So far, Hyperloop literature has mostly assessed technological feasibility aspects, which includes systems like propulsion, lift and safety systems of Hyperloop capsules. However, demand forecasts (-(and related financial feasibility) have not yet been covered much (Decker et al., 2017; Gkoumas et al., 2020; Hansen, 2020).

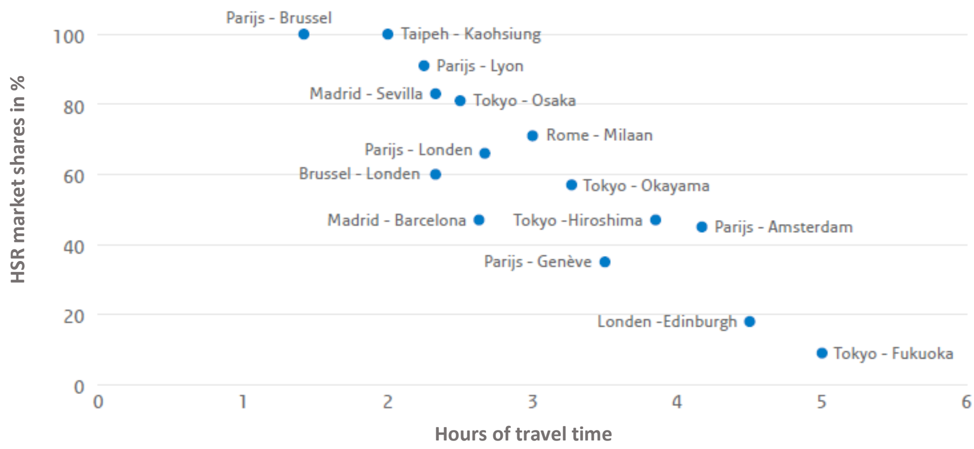
So far, few in-depth demand forecasts have been performed for a Hyperloop link or network (Kalrav, 2019). Closely related to the financial feasibility of the Hyperloop system is the forecasted travel demand it aims to generate ticket revenues and societal value from (Van Goeverden, Milakis, et al., 2018). It appears Hyperloop literature so far has put more focus on the projected short-coming capacity of Hyperloop (Rajendran & Harper, 2020), instead of its potential passenger travel demand. Either transport market shares are simply assumed (Hardt Hyperloop, 2019b; Rajendran & Harper, 2020) or straight-forward logit models using previous Value-of-Time data have been used for demand forecasting (HTT et al., 2019; Van Goeverden, Janic, et al., 2018). For example, van Goeverden, Janic, et al. (2018b) use Europe-wide data from the 2002 European Dateline-project, taking into account travel times & cost, access/egress time, luggage storage and mode availability.

It could be argued, however, that using data of travel behavior with current transport modes will not reflect future Hyperloop travel behavior. Moreover, travellers' (dis)preference for Hyperloop's is not captured in the used data of their demand forecasts. This cancels out more nuanced analysis towards the preference for Hyperloop which is likely influenced by its perceived safety, comfort and status (Taylor et al., 2016). Lastly, in the demand forecast by van Goeverden, Janic, et al. (2018) it is assumed capital costs are directly covered in Hyperloop ticket prices, which seems overly conservative as most rail operated ticket prices are subsidised by government (Wesdorp, personal communication, 2021).

2.2 HSR – APT competition

History shows the disruptive effect of new competitive transport modes on existing modes, such as the substitution effect of commercially available air transport on intercontinental passenger ships in the 1950s (Gladden, 2020). In recent decades a prominently researched intermodal competition is HSR – APT (Clewlow et al., 2012), which so far seems like a promising parallel to the Hyperloop – APT competition with regards to their intermodal substitution effects (Voltes-Dorta & Becker, 2018). As Hyperloop will most likely induce similar substitution effects, this literature review will draw knowledge and examples from the rich and diverse literature body of HSR (Gundelfinger-Casar & Coto-Millán, 2017).

In general, HSR shows a declining substitution rate on APT with increasing travel times. Figure 2.1 displays this effect, over a compilation of several corridors in which HSR and APT compete (Savelberg & de Lange, 2018). The Y-axis displays HSR market share relative to APT, the X-axis displays HSR travel time in hours. HSR is advantageous to travellers on shorter distances, as on the same trip length APT deals with longer travel time to airports and time spent at the airport (Savelberg & de Lange, 2018). The longer the trip distance, the more time APT has to 'catch up' with HSR due to the airplane's high speeds. Therefore, on longer trip distances, this research deems Hyperloop to be an extension -or complementary transport mode- to HSR due to its comparable speed to APT.



Source: Fons & Savelberg (2018)
Figure 2.1: HSR vs. APT competitive distances

Total travel time is an important determinant of APT-HSR substitution (Savelberg & de Lange, 2018). However, the APT-HSR competition shows to be quite complex (Raad voor de leefomgeving en infrastructuur, 2020). Determining factors for competition in several APT-HSR corridors have mainly been attributed to travel time, travel cost, service frequency, reliability, access/egress time, comfort and overall service levels (Dobruszkes et al., 2014). However, a different mixture of the abovementioned factors plays a determining role for every corridor, which causes complexity in demand forecasting.

To research the complex HSR-APT competition in different corridors, several research approaches have been applied. Mostly, two types of research approaches have been applied: ex-ante and ex-post studies (Dobruszkes, 2011). Ex-ante studies of HSR versus APT substitution have been performed for many countries looking to invest in HSR, mainly through Stated Choice experiments (Pagliara et al., 2012). Bergantino & Madio (2020) have investigated substitution effects for different corridor lengths and traveller segments. Their results reconfirm Janic' (2003) observation that HSR – APT substitution is less profound on longer trip distances. Besides the same diminished substitution on longer distances, Zhang et al. (2018) have also underwritten complementarity between HSR-APT. They found HSR could function as an access/egress transport mode for APT, which is addressed by yet another stream of literature (Clewlow et al., 2012; Kroes & Savelberg, 2019).

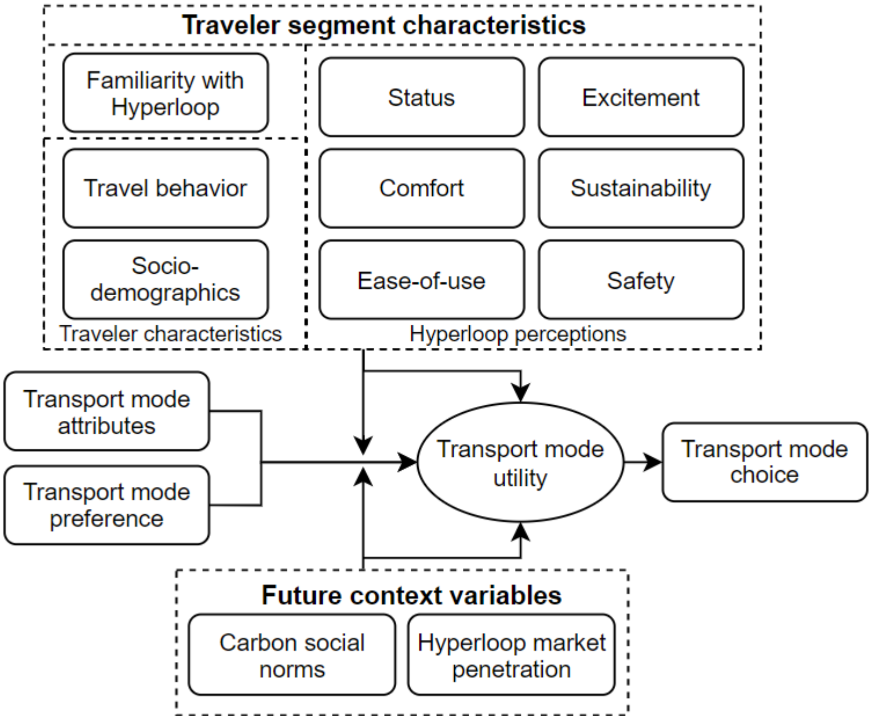
After the implementation of a transport service comes the ability to observe substitution effects ex-post. Park & Ha (2006) were able to calibrate their ex-ante SP research with ex-post revealed demand, which presented less profound APT demand reduction than expected before implementation. Expectedly, this could be attributed to delays and reservation cancellations in the opening months of the HSR service, due to operational difficulties. Again, this shows the complexity circumventing projected substitution by newly introduced transport modes. Behrens & Pels (2012) have investigated the Paris-London transport market for HSR-APT with transport data ranging from 2003 to 2009. They found travel time, frequency and access travel time to be most important to the competition. Furthermore, they found more consistency among business travellers than leisure travellers with regards to their sensitivity to ticket prices.

Cross-elasticities have been shown to help in understanding the complex relationship between transport mode changes and resulting competitive potential. They have been applied in several HSR-APT studies (Behrens & Pels, 2012; Bergantino & Madio, 2020; Gundelfinger-Casar & Coto-Millán, 2017; Park & Ha, 2006). Cross-elasticities relate to 'the measure of responsiveness of the demand for a good towards the change in the price of a related good' (The Economic Times, n.d.), where price can also relate to other measures of mode competitiveness. In other words, if Hyperloop's attractiveness increases, how much will the market share of APT on the same corridor decrease? Cross-elasticities thus differ from price-elasticity; Even though certain traveller segments have shown to be relatively indifferent to price changes, their reaction to travel time changes can induce significant cross-elasticities (Bergantino & Madio, 2020).

2.3 Conceptual model

The conceptual model (figure 2.2) represents the to-be-researched factors of the decision-making process of a traveller. The presented factors are delineated under the following sections. On the left stand the transport mode attributes and preferences for transport modes (section 2.4.1), which have an impact on transport mode utility. Subsequently, the characteristics of traveller segments are expected to impact this sensitivity to mode attributes and mode preference (sections 2.4.2 & 2.4.3). Traveller segment characteristics are based on their perceptions of Hyperloop, familiarity with Hyperloop before the survey, their socio-demographic attributes (age, gender, income, etc.) and travel behavior (travel purpose & frequency). The future contexts, carbon social norms and hyperloop market penetration, are also expected to influence travellers' sensitivity to mode attributes and preferences (section 2.6).

Figure 2.2: Conceptual model



2.4 Hyperloop – APT competition

The competition between Hyperloop and APT is expected to show similarities to the HSR-APT competition (Voltes-Dorta & Becker, 2018). Here, mode attribute, perceptions and traveller characteristics are expected to impact travellers' choices.

2.4.1 Mode attributes

Arguably the most prominent attributes in choice modelling of travel behavior focused are **travel time and costs**. These are typically used as displayed travel mode characteristics, otherwise called observed mode attributes (de Lapparent & Ben-Akiva, 2014). As mentioned under 2.2, travel time and costs have been widely accepted as determinants of travel behavior in the HSR-APT competition (Behrens & Pels, 2012; Bergantino & Madio, 2020; Park & Ha, 2006). Several interviews with experts (see appendix C for an overview) showed that travel time and costs are expectedly the most important attributes to Hyperloop's competitive potential. If Hyperloop can balance its high speeds with reasonable ticket prices, it could potentially attract many travellers from APT (Boersma, personal communication, 2021).
However, it remains quite uncertain what the eventual Hyperloop travel time and costs will be. Therefore, this research will address the effect of various travel times and costs on Hyperloop competitiveness. Hyperloop travel time will heavily depend on the structural design, taking into account factors like curve radius, cruising speed, acceleration and passenger comfort (Santangelo, 2018). Travel costs will depend on capital costs of the infrastructure, subsidies by governments and customer demand (HTT et al., 2019; van Goeverden, Milakis, et al., 2018; Marges, personal communication, 2021). Furthermore, APT ticket prices will possibly increase due to increased taxation of CO2 emissions of airplanes in the future (Krenek & Schratzenstaller, 2020).

Secondly, **access-egress travel times** will likely also play a large role for Hyperloop besides in-vehicle travel time, due to its potential placement near or inside city centers (van Wee, personal communication, 2021). This is also supported by literature; travellers derive much utility from short access and egress time from- and to a transport mode (Behrens & Pels, 2012; Clever & Hansen, 2008). Moreover, a distinction can be made between access-egress travel time and travel time spent in the vehicle since these are valued differently by travellers (Román et al., 2007; Wardman & Chintakayala, 2012). As it is still unsure how dense the Hyperloop station network will be and whether Hyperloop stations will be located inside or near city centers (Taylor et al., 2016), this mode attribute will also be a focus of this research.

Thirdly, the **sustainability** aspects of travel are expectedly relevant to Hyperloop travel behavior. As of now, observed APT travel behavior has not yet been much impacted by sustainability concerns. Even though a large group of travellers nowadays shows to care about the environmental consequences of air travel, their behavior is still lacking behind. Broad evidence has been found for the complex attitude-behavior gap to explain this discrepancy in air travel behavior (Alcock et al., 2017; Juvan & Dolnicar, 2014; Kroesen, 2013; Mkono, 2020). The attitude-behavior gap postulates that an increasingly pro-environmentalist attitude shows little impact on actual flight behavior (Alcock et al., 2017; Juvan & Dolnicar, 2014). This can subsequently be explained by factors like strong habitual behavior or the convenient appeal of APT (Mkono, 2020).

In recent years, however, a growing base of environmentally-conscious travellers has been found in travel behavior research (Higham et al., 2016). Moreover, it has recently been shown that environmental consciousness amongst air travellers has grown due to the effect of flight shaming (Chiambaretto et al., 2021; Gössling et al., 2020). This indicates the momentum which is in place for a sustainable and competitive transport mode.

However, it is yet unclear how the Hyperloop will balance its competitive speeds with the full life-cycle environmental benefit. Purely looking at its direct energy efficiency, it is more environmentally friendly than HSR and APT. In contrast, it is still unclear how large the environmental impact of the Hyperloop will be when taking into account its building emissions (Sane, 2020; Taylor et al., 2016; Van Goeverden, Milakis, et al., 2018). It is therefore of interest how travellers react to the environmental performance of Hyperloop compared to APT, which relates to its competitive potential.

2.4.2 Hyperloop perceptions

Travellers will have certain perceptions (otherwise called unobserved mode attributes) of certain travel modes which are expected to affect the overall preference for that travel mode (McFadden, 2001). Expectedly important perceptions related to Hyperloop are status, excitement, ease-of-use, comfort and safety. As mentioned under 2.1, previous Hyperloop demand forecasts have not included Hyperloop perceptions, as they used data from previous choice experiments in which Hyperloop was not presented as a travel mode (HTT et al., 2019; Van Goeverden, Janic, et al., 2018).

New or expensive transport modes have the potential to be considered a **status** symbol. The same is expected for the Hyperloop due to its expensive and innovative image among travellers (Van Wee, personal communication, 2021). For example, the bicycle was considered a status symbol during the late 1800s in The Netherlands, as it was too expensive to obtain for many citizens (Lesisz, 2004). This makes it a 'positional good', which means its usage is associated with a high status amongst someone's social environment (Garcia-Sierra et al., 2015).

Closely related to the status of Hyperloop usage, is the **excitement** to use the new Hyperloop system. Bennett & Vijaygopal (2021) have researched travellers' perceptions of pilotless aircrafts and their effects on willingness-to-use. They found that the excitement to use the futuristic transport innovation proved to be an important determinants of travellers' preferences. As the Hyperloop poses similar characteristics related to innovation, it is expected that excitement will be present as well.

Ease-of-use is an important aspect throughout a wide body of literature. Rogers (2003) refers to it as the complexity of the product, which relates to its perceived understandability and ease-of-use. Another model which explains people's adoption of technology, the Technology Acceptance Model, underwrites ease-of-use as one of the key adoption determinants (Featherman & Fuller, 2003). The Hyperloop will likely be positioned next to or inside existing railway stations or airports, which makes it easily accessible by public transport (Mook, personal communication, 2021). However, the exact placement across all airports and railway stations is yet unsure, similar to its ticketing systems (Boersma, personal communication, 2021), which leaves open some degree of imagination with regards to its perception of ease-of-use.

The **comfort** of a journey inside a Hyperloop capsule could also influence travellers' preference for APT. The perceived comfort of HSR trains provides a competitive advantage over APT in travellers' choices, due to the large difference in seating comfort (Mertens, personal communication, 2021). Similarly, the prospected interior designs of Hyperloop have shown to be luxurious, comparable to the comfort level of HSR seating. However, some discomfort might also occur for Hyperloop travellers due to its rapid acceleration. Hyperloop capsules are expected to accelerate to approximately 700 km/h (Bonsen, personal communication, 2021), which might create a similar discomfort to that experienced during the acceleration of airplanes.
This creates a trade-off for travellers, as to which of the two factors will determine the overall perceived comfort level.

Furthermore, the perceived **safety** of Hyperloop might be an issue for potential Hyperloop passengers, relating to its tubular infrastructure, high speeds and vacuum environment. Not surprisingly, safety and risk perception are therefore expected to be one of the major challenges to public acceptance of the Hyperloop (Delft Hyperloop, 2020). Interestingly, several sources of flight fear arise from features that are also present in the Hyperloop: fear of crashing, fear of confinement, fear of panicking, fear of not being in control (Bennett & Vijaygopal, 2021; Howard et al., 1983). Fear of heights and fear of instability also prove to be important to flight fear, however, these aspects are not expected to be present in a Hyperloop journey. However, a possible additional fear factor for Hyperloop could arise from the fact that capsules are remotely controlled by an outside control center. This means there is no pilot physically present in the transport mode to act in the case of an emergency, which can create a sense of risk amongst travellers (Bennett & Vijaygopal, 2021).

2.4.3 Traveller characteristics

To address differences in underlying preferences for transport modes -otherwise called tastes- (Ben-Akiva et al., 2019), travel behavior research has often included the socio-demographic characteristics of **age**, **education**, **gender** and **income** (de Lapparent & Ben-Akiva, 2014; Lu & Pas, 1999), just as **trip purpose** (Behrens & Pels, 2012) and **flight frequency** (Bergantino & Madio, 2020).

Bergantino & Madio (2020) have shown the different estimated adoption levels of a new HSR transport service among socio-demographic groups and trip purpose. Higher age, income and education groups showed higher levels of a modal switch from APT to HSR than dissimilar groups. Intuitively this seems right, as high-income and older travellers are willing to pay more for low travel times and high comfort (as provided in most HSR services) than younger and less affluent travellers. For the new and possibly dangerously-perceived Hyperloop, however, older travellers might react less open to adoption as older people are typically more risk-averse than younger people (Dohmen et al., 2018). As Hyperloop is predicted to be an expensive transport mode (Van Goeverden et al., 2017), similar effects are expected with regards to income and trip purpose. Previous research has found that higher-income and business travellers sooner opt for fast travel modes which are often more expensive (Behrens & Pels, 2012; Bergantino & Madio, 2020). Moreover, in recent years many business travel managers have put more focus on reducing the environmental impact of their employees' travel behavior (Klein-Schiphorst, 2021). This trend could further stimulate Hyperloop adoption if it proves to be a more sustainable transport mode. Moreover, travel frequency is expected to cause a preference for APT over Hyperloop. Frequent travellers of one transport mode have shown to be less willing to switch to new transport modes. This overall preference for one transport mode could be explained simply by habits or by acquired discounts due to their travel frequency (Bergantino & Madio, 2020).

2.5 Contexts in travel behavior research

Besides the mode attributes and traveller segment characteristics, this research also aims to research the impact future contexts on travel behavior. This section delineates the current use of contexts and a caveat for the use of future contexts in this research.

2.5.1 Current use of contexts

Whereas alternatives in Discrete Choice Modelling are always presented alongside their attributes (e.g. travel time and cost), it is assumed contexts are the background under which attribute-based choices are made (Oppewal & Timmermans, 1991). Contexts have been defined as the "entire framework and set of factors describing the objective and subjective circumstances that surround and influence action by an individual and/or a group" (Goulias & Pendyala, 2014, p.101). For example, a traveller in 1970 will have likely had no problem opting for a carbon-heavy transport mode as long it was cheap, whereas a traveller in 2030 might feel shamed by his peers when opting for the same cheap carbon-heavy transport mode.

To research the impact of choice contexts surrounding decision-makers, Oppewal & Timmermans (1991) have discussed the incorporation of contexts into Discrete Choice Modelling. In such application, contexts can be presented explicitly to respondents and subsequently varied in one choice experiment. Thereby, the experiment enables the researcher to estimate the effect of the respective contexts on decision-making, possibly offering an answer to one of RUM's persistent critiques.

Within the overarching domain of choice modelling, it appears context-dependent choice modelling has positioned itself as a niche that applies to several knowledge fields. Travellers mode choice literature, however, still shows a relatively sparse adoption of context-dependent choice experiments (Molin & Timmermans, 2010) with the main adoption keeping to trip purpose (Behrens & Pels, 2012; Bergantino & Madio, 2020; Gonzales-Savignat, 2004). Examples from other fields include urban park preferences during week and weekend days (Bertram et al., 2017), truck routing choices for different truck sizes (Arentze et al., 2012) and the influence of weather on Park & Ride facilities (Bos et al., 2004).

2.5.2 Hypothetical Bias & Familiarity of contexts

One of the largest criticisms circumventing Discrete Choice Modelling (DCM) is hypothetical bias, which is a broad term entailing that 'the intentions which are stated in these experiments are not the behaviors which are observed (or revealed) in actual markets' (Beck et al., p.1, 2016). From literature concerning hypothetical bias, Beck et al., (2016) conclude that much unclarity exists regarding the sources of hypothetical bias. However, they do mention the influence of unfamiliar (e.g. hypothetical) products and services on the hypothetical bias which comes to no surprise. Namely, it is known that familiarity levels of products in Stated Choice Experiments contribute to the consistency of choices by respondents and therefore the overall validity of SCE based market predictions (Molin, 2019d). Vice versa, the unfamiliarity of products can lead to either under- or overestimation of varied elements in SCE (Ben-Akiva et al., 2019).

Besides the unfamiliarity of the Hyperloop, this research introduces future contexts (see section 2.6) which are expected to be unfamiliar to respondents. Presented contexts currently aren't reality which might be difficult for respondents to accurately imagine. Whereas the context of carbon social norms is normative of nature, the market penetration context contains both normative and informative elements. As they are different, respondents might also be able to imagine both to a different degree. It is expected that mainly the effect of normative elements are hard to accurately imagine for respondents. Namely, many conditions and actions can influence the level of adherence to social norms, which makes it a complex subject (Gavrilets & Richerson, 2017; Vandenberg et al., 1994). This underpins the complexity of social norms and their effect on people.

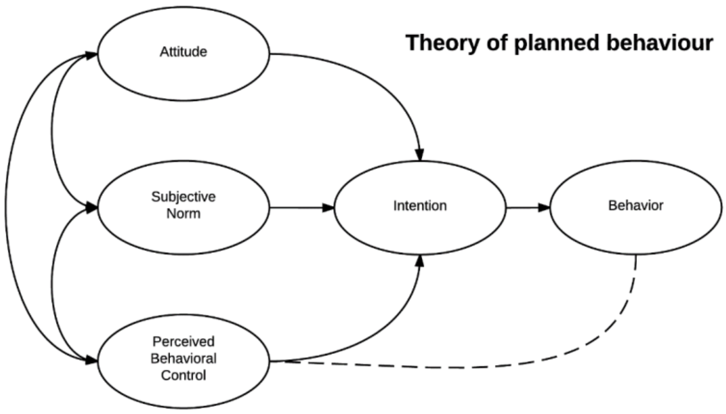
To investigate respondents' ability to imagine the future contexts, questions are asked to evaluate the difficulty respondents experienced with regard to context variation in choice sets. Thereby, this research can provide insight into the usability of future contexts in DCM.

2.6 Future Hyperloop contexts

From transport forecasting literature (Banister & Hickman, 2013; Bartholomew & Ewing, 2009; Borken-Kleefeld, 2014; Curry et al., 2006; Tuominen et al., 2014), interviews with transport experts and transport policy documents (European Commission, 2020), several trends were identified as relevant to the future transport market in which Hyperloop could be implemented. Following a series of interviews with transport experts (see appendix C for an overview of the experts) and a filter on trends that could be deemed a context in this study, the following future contexts were deemed to be most relevant to this study.

2.6.1 Carbon Social Norms

In recent years, social norms surrounding the negative effects of transport carbon emissions have gained in strength with an increased focus on personal accountability of carbon emissions (Gössling et al., 2020). Whereas flight shame highlights the negative parts of the carbon emissions of airplanes, train-bragging relates to the low carbon emissions of trains. Both terms relate to critical social norms aimed at reducing the carbon footprint of passenger transport (Korkea-aho, 2019). This research will alternatively propose 'carbon social norms' which is deemed to be a social driver behind 'flight shame' and 'train-bragging'.



Source: Ajzen (1991)

Figure 2.3: Theory of planned behavior

Carbon social norms relate to subjective norms as described in Theory of Planned Behavior (Ajzen, 1991) (see figure 2.3). Subjective norms refer to the belief someone has about the extent to which significant others want him or her to perform a behavior. Importantly, the subjective norm in this research, carbon social norms, is deemed to be a descriptive norm: 'opinions and actions of significant others provide information that people may use in deciding what to do themselves' (Rivis & Sheeran, 2003, p. 120). In other words, descriptive norms relate to 'if everyone thinks badly of carbon emissions, I also ought to think badly of carbon emissions'. This research operationalises carbon social norms as 'how *often* one's significant others express themselves in opposition towards traveling with carbon-heavy transport', thereby referring to the strength of the social norm.

Generally speaking, social norms shows to impact travel behavior (Garcia-Sierra et al., 2015). More specifically, social norms show potential for increasing support of carbon-related policies. Namely, Araghi et al.(2014) show higher support by a traveller for carbon compensation in APT ticket prices, when many others participate in compensation as well.

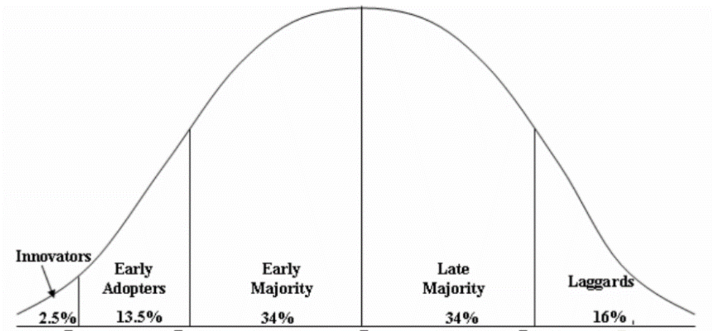
However, the impact of carbon social norms on actual flying behavior has not been measured yet. Much global attention has been given to the effect of carbon social norms (e.g. flight-shaming) on travellers' perspectives on air travel (Al Jazeera, 2019; China Daily, 2019; The New York Times, 2019). Even though carbon social norms show to be entering social norms, the effect on actual travel behavior has so far remained limited (Gössling et al., 2020).

It could be argued that carbon social norms haven't evolved towards established social norms yet (Gössling et al., 2020) and could, just like any cultural movement, have a swift and impactful rise in society (van Wee, personal communication, 2020). A rise of carbon social norms could prove especially impactful on the travellers' choices between APT and Hyperloop in the future. Namely, the full life-cycle sustainability of Hyperloop is yet to be determined and the electrification of many other transport modes offers sustainable alternatives to the focal transport market.

2.6.2 Hyperloop Market penetration

As Hyperloop stands to become a new entrant on the transport market, dynamics surrounding market penetration could prove important to its adoption by travellers. Market penetration can be defined as 'the extent to which a given technology or practice has entered a given market' (Kartha et al., 2005, p.150). A wide body of literature has identified different innovation adopter categories amongst consumers who each have different perceptions of the same product in different stages of its market penetration. Similar to most innovations, Hyperloop is also expected to be perceived differently by adopter categories (Magnusson & Widegren, 2018). It is expected that Hyperloop perceptions under varying market penetration stages will differ mainly due to social status, peer observation and peer pressure effects which vary under different market penetration levels.

Surrounding innovation, there are differences between categories of adopters with different product demands and needs. Rogers (1962) distinguishes five categories: innovators, early adopters, early majority, late majority and laggards. Figure 2.4 presents the different adopter categories and their respective size. Whereas early adopters of a technology are generally very familiar with technology innovation**,** eager to innovate (Bennett & Vijaygopal, 2021) and more willing to take risks (William H. Geoghegan, 1994), the late majority will likely postpone adoption for more security and competitive prices. Adopter categories and their demands will differ per innovation (Lancaster & Taylor, 1988), however, several effects from previous innovations are expected to be present in Hyperloop adoption as well.



Source: Rogers (2003)

Figure 2.4: Adopter category sizes

Early adopters can be roughly generalised as younger, more affluent and highly educated (Lancaster & Taylor, 1988; Munnukka, 2007; Rogers, 1962) and have shown to care much for social status gains (Filieri et al., 2017). Since a trip with a 'positional good' is associated with high status amongst someone's social environment (Garcia-Sierra et al., 2015), the Hyperloop might stand to gain a rapid adoption amongst early adopters (Boersma, personal communication, 2021).

The late majority, however, waits for close-to-home successes before adopting innovation (William H. Geoghegan, 1994), which relates to observability (Rogers et al., 2005). Observability means people can witness others use an innovation, which has also been termed peer observation (Sahin & Rogers, 2006). Observation and consultation of friends, relatives and co-workers have shown to be common under situations of high-risk perception as a risk-mitigating strategy (Featherman & Fuller, 2003; Mitchell & Vassos, 1998; Roselius, 1971).
Similarly, adopters can test the ease-of-use of an innovation by observing peers. The penguin theory intuitively describes these effects: no penguin wants to be the first in the water to find out whether predators are waiting in the water (Herbig & Kramer, 1993). Therefore, positive experiences of one's peers could prove to be important to Hyperloop's adoption. Interestingly, it has shown that the need for peer observation is less profound for experts to the concept (Martin et al., 2007), which means that travellers who are already **familiar** with the Hyperloop will probably experience less effect of different market penetration levels. This coincides with the finding of Planing et al. (2020) who have found that familiarity with Hyperloop significantly increases willingness to use the Hyperloop.

Moreover, peer observation also relates to peer pressure and the descriptive subjective norm, as opposed to the injunctive subjective norm induced by carbon social norms. Colloquially speaking, this means people want to behave like others which is why they tend to observe and copy behaviors of role models or peers (Featherman & Fuller, 2003; Garcia-Sierra et al., 2015). For example, Garcia-Sierra et al. (2015) argue that the use of public transport could be promoted by reinstating the fact that many people already use it, thereby imposing a descriptive norm on other travellers: 'if other people behave in such way, I should behave likewise'.
In conclusion, if the effects of peer observation and peer pressure prove to be strong among travellers, it is expected that an increase in Hyperloop adoption has an accelerating feedback effect on itself, especially for the late majority.

2.7 Summary

The literature review has provided the background and focus areas for this research. So far, Hyperloop feasibility studies have mainly focused on technological aspects and could be improved upon by more accurate demand forecasting. This research aims to fill this gap by researching several traveller decision-making factors that currently apply to the high-speed rail versus air passenger transport competition: travel time, access-egress travel time and travel costs. Besides these traditional decision-making determinants, the sustainability performance of Hyperloop is expectedly also important to travellers. Furthermore, this research aims to understand Hyperloop's competitive potential per traveller segment. Traveller segments in this research vary based on their perceptions of Hyperloop and APT, current travel behavior and familiarity with Hyperloop.

Another central part of this research is the application of future contexts, under which travellers' choices can differ. Literature shows that future contexts have not yet been applied to demand forecasting of transport innovation. Two future context variables are expected to influence Hyperloop's competitive potential: Hyperloop market penetration and carbon social norms. Since these (possibly unfamiliar) future contexts might be troublesome to travellers in this research, a self-evaluation for familiarisation with contexts is performed.

3. Stated choice experiment: Survey

To answer the research questions, this research wil conduct a Stated Choice Experiment (SCE). This chapter presents the survey that was conveyed amongst Dutch travellers using an online survey. The content of the SCE is based on the theory and methodological topics highlighted under chapter 2. First, the operationalisation of mode attributes into attribute levels is shown under 3.1. Choice sets are constructed using the attribute levels and nested under the context design as delineated under 3.2. Lastly, the part of the survey which relates to the characteristics of the traveller is delineated under 3.3. The final survey is presented under appendix F. The survey was created using Qualtrics, a licensed survey tool.

3.1 Operationalisation

3.1.1 Recap: mode attributes

Two types of travel time were identified: In-vehicle **travel time** and **Access-Egress (A-E) travel time**. Both rely on the eventual design of Hyperloop, with regards to tube design and Hyperloop hub placement. The **travel costs** of Hyperloop will mostly depend on capital costs of the infrastructure, subsidies by governments and customer demand. For this research, APT travel costs are varied according to various fuel tax levels by the government. Finally, the life-cycle **sustainable performance of Hyperloop** will depend on many factors like infrastructure design and operations.

3.1.2 Attribute levels

Table 3.1 presents the operationalization of attributes which have been used in the Stated Choice Experiment. Attribute levels were selected to represent Hyperloop-APT choice situations that are as likely as possible to become reality, which is desirable for choice experiments (Ben-Akiva et al., 2019). The APT sustainability level and A-E travel time were fixed to reduce the complexity and size of the survey, as those aspects have shown to be problematic for the consistency of respondents in SCE (Caussade et al., 2005).

To measure non-linear effects of attributes, three attribute levels must minimally be chosen per attribute (Rose & Bliemer, 2009) which is done in this research. Namely, the utility function as presented under 3.1.1. assumes linear parameters, however, travellers might show increasing or decreasing sensitivity as mode attributes increase. For example, a ticket price difference between €150 and €200 might be perceived to be less severe than the same ticket price difference between €100 and €150.

Table 3.1: Operationalisation of attributes

Attributes	**Levels**		
Hyperloop			
Travel Time (hrs:min)	00:50	01:30	02:10
A-E Travel Time (hrs:min)	00:30	01:00	01:30
Travel Costs	€100	€150	€200
Sustainability relative to APT	Less sustainable	Equally sustainable	More sustainable
APT			
Travel Time (hrs:min)	00:50	01:30	02:10
A-E Travel Time (hrs:min)	04:00		
Travel Costs	€50	€100	€150
Sustainability	Fixed		

Hyperloop in-vehicle travel time is dependent on the average speed of the transport mode. Varying average Hyperloop speeds are reported in track proposals worldwide, ranging from 500 kilometers/hour up to 1000+ kilometers/hour. Hyperloop speed is dependent on factors including air resistance in the tube, the comfort of the passenger and track design (Bonsen, personal communication, 2021). Accounting for different travel speeds, Hyperloop average travel times on a track of 650 kilometers are expected to range between 55 minutes and 1 hour 15 minutes. To compensate for a bias in Value of Time (VoT) as delineated by Fosgerau & Börjesson (2015), the APT and Hyperloop travel time range is widened up to 2 hours 10 minutes. The VoT values were calibrated using values from the Dutch VoT study by Kouwenhoven et al. (2015). **APT in-vehicle travel time** is varied in the same way for the same reason of preventing VoT bias and because APT travel times were found to be comparable to Hyperloop travel time. Appendix A presents the calculation of Hyperloop travel times from various sources.

A-E travel time of APT is fixed to 4 hours in accordance to Kroes & Savelberg (2019), which exists of two hours check-in time and two hours travel time from- and to the airport. As airports are typically located outside of city centers, the latter assumption seems realistic. **Hyperloop A-E travel time** varies between 30 minutes and 1 hour 30 minutes which resembles differences between a sparse and dense network of Hyperloop stations. The average within that range, 1 hour A-E travel time, resembles a network density that is similar to the Dutch HSR station network (Savelberg & de Lange, 2018), which consists of 13 train stations. An important assumption here is that time spent at Hyperloop stations is marginal. This is done based on the fact that Hyperloop will likely use an on-demand traffic management system, which means passengers can book a ride last-minute and step inside one of the capsules which depart every few minutes (Virgin Hyperloop, n.d.). Simultaneously, data from airport security in the USA shows people only wait 15 minutes in airport security lines on average (TSA, 2019). Altogether, in combination with advancing security technology, time spent at Hyperloop stations can be reasonably be expected to be of marginal influence on A-E travel time.

Hyperloop ticket prices are still uncertain since much is still unknown about Hyperloop financial feasibility (Marges, personal communication, 2021). Financial feasibility relates to travel demand under certain situations, capital and operational costs of the system and government investment (HTT et al., 2019; Taylor et al., 2016; Van Goeverden, Janic, et al., 2018). Ticket price ranges as posed in literature and feasibility reports range between €0,15 per and €0,45 per kilometer, where the latter is a cost-meeting ticket price without subsidies. To compare, HSR ticket prices generally range between €0,15 and €0,25 (HTT et al., 2019; Van Goeverden et al., 2017). As it's expected that Hyperloop ticket prices will be subsidised by governments to at least some extent, this research varies Hyperloop ticket prices between €0,15 and €0,30 per kilometer. This approximately amounts to €100 and €200 respectively on a track of 650 kilometers.
The lowest **APT ticket price** level has been determined by using Dutch booking websites and selecting the cheapest ticket, which was found to be about €50. The highest APT ticket prices were based on the assumption of increased flight taxes on top of normal ticket prices. Many countries have already adopted flight taxes to compensate for CO2 emissions of flights which currently vary between €3 and €22 (Krenek & Schratzenstaller, 2020). Chancel & Piketty (2015) mention a flight tax of €20 for economy class and €180 for business class, which indicates the large range over which proposals for flight taxes vary in literature. Tax levels APT ticket prices mainly seem to be focused on compensation of CO2 emissions per flight (Chancel & Piketty, 2015; Krenek & Schratzenstaller, 2020). However, this study also takes into account the possibility of heightened APT ticket prices up to €150. This would resemble a situation that discourages flight behavior as mentioned by Peeters & Melkert (2021), which would likely entail much higher taxation rates.

Hyperloop sustainability is varied through three ordinal levels: less, equally, or more sustainable than APT. The perception of sustainability by respondents is intangible and can be influenced by several factors, which gives it characteristics of a complex variable. As the sustainability of the Hyperloop is not the sole research topic, methods that objectify such a complex variable -bridging experiments or Hierarchical Information Integration (Molin, 2019a)- are left out of scope. Therefore, the sustainability level remains relatively straightforward.

3.1.3 Context levels

The future contexts are both varied using two attribute levels, both roughly corresponding to *low* and *high* levels (see table 3.2).

Table 3.2: Context variable operationalisation

Carbon social norms
Your friends/family/colleague's *rarely* express themselves in opposition towards traveling with carbon-heavy transport modes
Your friends/family/colleague's *often* express themselves in opposition towards traveling with carbon-heavy transport modes
Market penetration levels
Roughly *1 out of 10* of your friends/family/colleague's sometimes travels by Hyperloop and experiences it as positive
Roughly *9 out of 10* of your friends/family/colleague's sometimes travels by Hyperloop and experiences it as positive

An important note, here, is that the Hyperloop experiences of travellers' social environment are framed as positive under the market penetration context. In reality, experiences by peers can be either positive, negative, or anything in between. However, as to prevent confusion for respondents, a direction is given to the context of market penetration. The variation lies in the *number* of people that have had an experience with the Hyperloop. It is not specified how the remaining 9 of out 10 friends/family/colleagues perceive traveling by Hyperloop in the case of low market penetration levels, which remains part of the perception of the respondent.

3.2 Experimental design

The experimental design is constructed using the abovementioned attribute levels. The experimental design consists of two parts; the choice sets which vary the attribute levels in alternatives, followed by the context profiles under which the choice sets are nested.

3.2.1 Utility functions

The utility functions of alternatives in the Stated Choice Experiment have been specified as follows:

$$V_{Hyperloop} = ASC_{Hyperloop} + \beta_{HL_{TT}} * TT_{Hyperloop} + \beta_{HL_{AET}} * AET_{Hyperloop} + \beta_{HL_{TC}} * TC_{Hyperloop} + \beta_{HL_{sustainability}} * ST_{Hyperloop} \quad (6)$$

$$V_{APT} = \beta_{APT\_TC} * TC_{APT} + \beta_{APT\_TC} * TC_{APT} \quad (7)$$

Where:

$V_{Hyperloop}$ = Utility of Hyperloop
β_{HL_TT} = parameter for the variable 'Hyperloop travel time'
$\beta_{HL_{AET}}$ = parameter for the variable 'Hyperloop access-egress travel time'
β_{HL_TC} = parameter for the variable 'Hyperloop travel cost'
$\beta_{HL\_Sustainability}$ = parameter for the variable 'Hyperloop sustainability'

V_{APT}	= Utility of APT
β_{APT_TT}	= parameter for the variable 'APT travel time'
β_{APT_TC}	= parameter for the variable 'APT travel costs'

Notice here, that no parameters for APT sustainability and access-egress travel time are added to the function in the experimental design as those are fixed in the Stated Choice Experiment. However, these factors will be included in the survey.

3.2.2 Choice sets

Choice sets are the central part of a SCE, in which respondents are asked to state their preference between two (or more) alternatives. The combination of the attribute levels into alternatives of the choice sets is delineated in this section.

An important characteristic of the central SCE is that alternatives are labelled, which means respondents are faced with an option between two specific alternatives (i.e. 'Hyperloop' and 'Airplane') instead of two unlabeled alternatives (i.e. 'mode 1' and 'mode 2'). This is done to address the overall preference of respondents for one of the transport modes. Consequently, in the model estimation, constants are added to reflect this overall preference. See function 4 for the model specification. Moreover, mode-specific attributes are specified as their levels are different. This allows for the estimation of attribute-specific parameters which provides information on the difference of sensitivity to attributes between alternatives. For example, time spent in the Hyperloop might be perceived as less of a nuisance due to its spacious interior.

The choice sets (for example see figure 3.1) are constructed using a simultaneous procedure, in an orthogonal and fractional factorial design. Ngene, a software tool for choice modelers, is used to generate the choice sets whilst preserving attribute level balance and orthogonality.
Attribute level balance means attribute levels occur an equal number of times over the entire

Uw vrienden/familie/collega's uiten zich **zelden** negatief tegenover reizen met transportmiddelen met een grote CO2-uitstoot
Grofweg **1 op de 10** van uw vrienden/familie/collega's reist wel eens met de Hyperloop en ervaart dat als positief

	Hyperloop	Vliegtuig
Reistijd	1u30min	0u50min
Voor/Na reistijd	1u00min	4u00min
Totale reiskosten	€200	€50
Milieuvriendelijk	Minder milieuvriendelijk dan vliegtuig	Milieuonvriendelijk

Welk vervoermiddel heeft uw voorkeur in deze keuzesituatie?

- Hyperloop ○
- Vliegtuig ○

Stel u maakt een reis van ongeveer 650 kilometer in de bovenstaande situatie; Zou u dan reizen met uw hierboven geprefereerde vervoermiddel of met een ander vervoermiddel?

- Hierboven geprefereerde vervoermiddel (Hyperloop of vliegtuig) ○
- Ander vervoermiddel (elektrische auto, trein, bus) ○

Figure 3.1: Choice set example

experimental design. This ensures that attribute levels are observed an equal number of times by respondents, which prevents different standard errors for effects coded parameters due to imbalance. Orthogonality relates to the absence of correlations among attributes, which are problematic for model estimation (Molin, 2019b). Roughly speaking, when orthogonality is not preserved, the model cannot estimate respondents' sensitivities to attributes anymore if their variation is specified too much alike (i.e. highly correlated).
Fractional factorial designs are subsets of full factorial designs. Full factorial designs contain all the possible combinations of all selected attribute levels, which would sum up to 3^6 choice sets. To reduce the size of the experiment whilst retaining as much information as possible on trade-offs between attributes, fractional factorial designs are applied (Gunst & Mason, 2009).

In appendix B the Ngene syntax is presented which has been formulated to generate the choice sets. As the context nesting design increases the number of choice sets presented to respondents, blocking was needed. Running the Ngene syntax generated 18 choice sets, which were blocked into 6 blocks of 3 choice sets. The number of choice sets after nesting under the context design was 12 per respondent. The optimal number of choice sets per respondent in a SCE is 9 to 10 due to issues related to learning and fatigue by respondents (Caussade et al., 2005). However, as the recruitment strategy mostly relies on voluntarily participating respondents from within the network of the author, twelve choice sets are not expected to be a problem. After running multiple designs in Ngene, the design with the least amount of dominance-based purely on attribute levels is picked. As the overall traveller preference for Hyperloop over APT is still unknown and given that the central SCE is labelled, problems related to dominance were not expected to arise (Bliemer et al., 2017).

Lastly, to estimate market shares of out-of-scope transport modes, a base alternative is presented to respondents after each choice set (Molin, 2019b). This presented the option to either pick the preferred transport mode in the choice set (i.e. APT or Hyperloop) or to opt for another mode (i.e. base alternative) for the posed trip of 650 kilometers. To get a feeling of which transport modes would be the 'other mode' for most respondents, another multiple-choice question was posed to respondents after completion of the choice sets in which they could indicate their most likely base alternative. Given the time frame in which Hyperloop might be implemented, these could be either electric car, self-driving car, train or bus. Here, respondents were asked to assume that every vehicle is electrically propelled, given the current developments in the electrification of cars and buses.

3.2.3 Context nesting design

The 6 choice set blocks -consisting of 3 choice sets each- are nested under the context profiles, resulting in six different survey versions. See table 3.3 for coding of the context levels and table 3.4 for the nesting design. Appendix F presents one of the six nested survey versions. Every respondent is posed with three choice sets under each of the four context profiles so that multiple trade-offs are

Table 3.3: Coding of context levels

Coding	**Carbon social norms**
C0	Your friends/family/colleague's *rarely* express themselves in opposition towards traveling with carbon-heavy transport modes
C1	Your friends/family/colleague's *often* express themselves in opposition towards traveling with carbon-heavy transport modes
	Market penetration levels
M0	Roughly *1 out of 10* of your friends/family/colleague's sometimes travels by Hyperloop and experiences it as positive
M1	Roughly *9 out of 10* of your friends/family/colleague's sometimes travels by Hyperloop and experiences it as positive

observed under every context profile. Thereby, the effect of variating context levels is measured per respondent. Another possibility would be to show different sets of context profiles to different respondents, however, this would beg the question if you are measuring heterogeneity in context sensitivity or intra-person effects of contexts. Finally, it was made sure that every block was presented an equal number of times in the SCE, to make sure every choice set was observed an equal number of times in the total survey design.

Six different survey versions were distributed amongst respondents. The survey software Qualtrics ensured that every version was distributed an equal number of times amongst respondents. Table 3.4 shows the six survey versions and the choice sets which were shown to respondents. Every survey version followed the same sequence of context profiles, which are shown in the left-most column. Every number under the survey version represents a choice set block containing 3 choice sets.

Table 3.4: Nesting choice sets under context profiles

Context profiles	**Survey version**	**1**	**2**	**3**	**4**	**5**	**6**
C0 & M0	**Choice set blocks**	1	2	3	4	5	6
C0 & M1		2	3	4	5	6	1
C1 & M0		3	4	5	6	1	2
C1 & M1		4	5	6	1	2	3

3.3 Final survey design

This section will delineate the formulation of other research elements besides the choice experiment. The final survey design is built up of 8 consecutive parts as presented in figure 3.2. See appendix F for the full survey as presented to respondents. Appendix A.2 several Hyperloop assumptions regarding safety and comfort which were presented to respondents under part 2 of the survey.

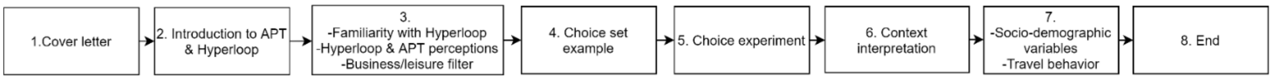


Figure 3.2: Survey flow

3.3.1 Traveller characteristics, Hyperloop familiarity & perceptions

To investigate the background characteristics of classes of the LCCM, several relevant traveller characteristics identified from literature and expert interviews are included in the survey (see table 3.5). Questions regarding these characteristics were distributed over the survey to improve their effectiveness and the flow of the survey. For example, the assessment of Hyperloop & APT perceptions was done following the introduction, to see how respondents respond to the introduction and to engage respondents by presenting the first 'task' of the survey.
Important to note is the business/leisure filter in the third part of the survey, which is a question that assigns respondents to either a trip that is made for a business purpose or leisure purpose. Respondents who reported to have a minimum of one business flight per year were asked to do the choice experiment in the context of a business trip, others were asked to imagine themselves on a non-business trip. Alongside the questions regarding socio-demographic variables in the 7th part, respondents are asked *how often* they make a business or leisure flight, which is similar but different from the formulated filter question.

Table 3.5: Traveller characteristics, familiarity and perceptions

	Background variable
Traveller characteristics	Age
	Gender
	Education
	Income
	Employment
	Travel purpose
	Business/ Non-business travel frequency
Hyperloop familiarity	Familiarity with Hyperloop
Hyperloop perceptions	Excitement perception
	Sustainability
	Safety perception
	Comfort perception
	Social status perception
	Ease-of-use perception
APT perception	Sustainability

Hyperloop and APT perceptions were measured on a 1 to 5 Likert scale. In general, larger Likert scales produce more variation concerning responses from respondents. However, the score people assign to perceptions will likely not differ much by using a 7-point Likert scale as opposed to a 5-point scale (Dawes, 2008). Moreover, as this part is not the central focus of the research and 7-point scales are likelier to frustrate respondents, (Babakus & Mangold, 1992), 5-point scales are used.

Questions regarding Hyperloop perceptions were formulated in comparison to APT as this allows for easier interpretation in later stages: *How safe do you deem a ride in the Hyperloop to be in comparison to the airplane?* Besides the perceptions defined under 2.3.2, Hyperloop sustainability perception is also measured amongst these questions. This is done to measure the overall effect of Hyperloop's potentially sustainable image, even though sustainability is varied in the choice sets. Namely, respondents could potentially have such strong sustainability perceptions that counterbalance the presented sustainability performance levels in the choice experiment.

3.3.2 Context interpretation

Three aspects of the usability of future contexts were examined; the overall apprehension of the presented contexts by respondents, the ability to imagine future contexts for their social environment and the ability to imagine context level differences. Respondents were asked to report their ability to imagine and apprehension on a 5-point Likert Scale (1 = Very bad, 5 = Very good).

Besides the usability aspects of future contexts, another question is asked to reveal respondents' change in Hyperloop perceptions by increasing market penetration levels. Respondents were asked to what extent they perceived the following statements under the context of high Hyperloop adoption amongst their friends/family/colleagues:

'Traveling by Hyperloop is safe'
'Traveling by Hyperloop gives me little social status in this context'
'I experience social pressure to travel by Hyperloop'
'Traveling by Hyperloop is easy'
'Traveling by Hyperloop is comfortable'

3.3.3 Improvements from the test sample

The survey was tested in 14 cases which were done by a diverse group of colleagues, family, friends and business acquaintances. Mainly their age and travel purposes varied, which provided different insights into possible improvements for the survey. The following improvements were made accordingly with their feedback:

-Context levels were specified to 'friends/family/colleagues', instead of 'social environment' to increase the ease of interpretation for respondents
-The length of the trip (=650km) was emphasised more as it was not clear and proves to be very important to business travellers due to company policies for different trip lengths.
-Questions regarding Hyperloop perceptions were moved to the front to improve survey flow.
-The question regarding the interpretation of the market penetration context (see 4.3.2) was clarified.
-The base alternative question was formulated differently to emphasise its reference to the presented choice situation.
-An assumption was presented to respondents that all base alternatives are propelled electrically to prevent confusion for respondents who currently do not have access to electric cars.
-The cover letter and introduction to Hyperloop & APT were shortened to improve on reading flow.
-Introduction text on the Hyperloop was altered to be formulated more neutral, thereby attempting to reduce the steering of respondents.

4. Sample characteristics

Chapter 4 addresses descriptive statistics of the survey sample. Section 4.1 describes the intended population of the research together with the recruitment strategy. 4.2 delineates the data cleaning procedure that reduced the raw data to a usable data set. Subsequently, the representativeness of the sample is discussed under section 4.3. Section 4.4 delineates on two preliminary observations: the observed transport mode choices and perceptions of the sample.

4.1 Population & recruitment strategy

The final survey was distributed amongst the intended population, which are Dutch travellers who minimally on occasion travel by airplane. Even though the Hyperloop is very likely to cross international borders, the considered population is strictly Dutch to avoid the influence of intercultural or geographic effects on the data which is out of scope. The Dutch population considered for this research consists of travellers who, under normal circumstances (i.e. before the Covid-19 pandemic), at least occasionally travel internationally within Europe per APT for either business or other purposes. The main purpose of the research is aimed at the substitution by Hyperloop on airplane trips, which is why non-flyers are not considered to be part of the population.

The respondent recruitment strategy aimed to find a varied and substantial sample consisting of different socio-demographic segments to increase the validity of the model estimations. Most of the respondents were recruited from the personal network of the researcher via social media. Moreover, 1500 leaflets (see figure 4.1) were distributed amongst low-cost housing to attempt to reach more low-income travellers. Low-cost housing included gallery flats in The Hague, Rotterdam and Capelle aan den Ijssel. Lastly, several professionals working in the business travel industry shared the survey within their network, which was aimed to target business travellers as they were expected to be underrepresented otherwise.

Survey distribution was performed over four weeks and most of the responses followed directly after online distribution activities via social media. Moreover, only 8 responses originated from the QR code on the leaflet. Therefore, it is argued that only a small percentage of the responses originated from the distributed leaflets and most respondents were (in)directly linked to the researchers' network.

4.2 Data cleaning

Raw data from the survey was cleaned in order to retrieve usable data for model estimation. The online survey was accessed 428 times in total, however, many of those were either partially completed or closed rapidly after opening the survey. After data cleaning, 223 completed responses remained for model estimation. The following responses were deleted during data cleaning: 172 respondents did not fill out the choice sets, 6 respondents filled out to never fly and 12 respondents quit the survey after the choice experiment thereby reporting missing data for context interpretation & socio-demographic variables. Lastly, 15 respondents were removed as were either unable or unwilling to disclose their income level. As this information is important to understanding the representativeness of the sample and income is expected to influence the focal travel behavior, these respondents were removed from the sample.

Furthermore, non-trading behavior is also addressed in the data cleaning. Non-trading behavior relates to respondents who stuck with the same mode choice throughout the whole choice experiment. This could relate to factors like fatigue, boredom, strategic behavior or a large preference for the selected mode. Except for the case of a large mode preference that resembles actual choice behavior, these effects could bias the results (Hess et al., 2010). In total, 54 respondents displayed non-trading behavior which is a relatively large portion of the sample. Since it could be reasonably expected that many of these respondents had a large preference for Hyperloop, an additional check was done for total response time and variation of respondents' answers. Based on those metrics, 8 out of those 54 respondents were removed from the sample as they completed the survey in under 6 minutes which was comparatively fast and also showed little variation in their answers throughout the survey.

4.3 Representativeness

To address the representativeness of the sample to the population, this section addresses several aspects of the sample together with their expected influence on the results. As there is no publicly available data on the flying population of The Netherlands, no direct comparison is made between the sample and the population. Moreover, 43% of the overall Dutch population never flies (MinIenW, 2018). Since it is expected that low-income people are overrepresented in that group, comparison with available general population data by the Dutch Central Bureau of Statistics is irrelevant.

4.3.1 Selectivity of the recruitment

Participants of the survey were mainly recruited from the (in)direct network of the researcher which is expected to have biased the results towards a high level of familiarity with the Hyperloop. Moreover, the self-selectivity of respondents who were interested in the topic could have further skewed the level of Hyperloop familiarity. Table 4.1 shows the Hyperloop familiarity found in the sample versus that by (Planing et al., 2020), who have collected a representative sample to the overall Dutch population only 10 months before this study. Even though the population of both the studies is not the same, the difference indicates the bias in the collected sample. Importantly, their findings indicate that with increasing familiarity, the willingness-to-use the Hyperloop increases. This suggests that the selectivity in the sample causes more positive perceptions and a higher preference for Hyperloop.

Table 4.1: Hyperloop familiarity of the sample

Familiarity with Hyperloop pre-survey	Count	Percentage	(Planing et al., 2020)	Difference
I did not know it	29	13%	56%	-43%
I had heard of it	86	39%	31%	7,6%
I had heard of it and looked further into it	72	32%	2%	30,3%
I knew much about it	36	16%	11%	5,1%

4.3.2 Traveller characteristics

Age

The age distribution of the sample (see table 4.2) is predominantly young, with more than 50% belonging to the group between 20 and 30 years old. This can be explained by the recruitment strategy which resulted in 85 students in the sample (38% of the total) and many young professionals.

Younger travellers have a higher propensity to fly (Gordijn et al., 2017) and are expected to have a higher chance of belonging to the first adopter group of Hyperloop (Rogers, 1962). The overall preference for APT and Hyperloop over the other transport modes could therefore be biased upwards.

Table 4.2: Sample distribution over age subcategories

Age	Count	%	Merged	Count	%
0-5	0	0%	20-30	121	54%
5 – 10	0	0%			
10 – 15	0	0%			
15-20	0	0%			
20-25	45	20%			
25-30	76	34%			
30-35	16	7%	30 -60	72	32%
35-40	13	6%			
40-45	8	4%			
45-50	3	1%			
50-55	12	5%			
55-60	20	9%			
60-65	16	7%	60+	30	13%
65-70	7	3%			
70-75	2	1%			
75-80	2	1%			
80-85	0	0%			
85-90	2	1%			
90-95	1	0%			
95-100	0	0%			

Education

Table 4.3 presents the distribution of education and income within the sample. As a result of the recruitment strategy, education seems to be skewed towards highly educated people. Very few lower educated and many middle or highly educated travellers participated in the survey, which possibly affects the validity of the results surrounding education levels. Namely, highly educated travellers have shown to be quite environmentally aware (Lassen, 2010) and have shown to be willing to pay more for carbon emission reductions of their travel footprint (Achtnicht, 2012) which might raise the overall sensitivity to sustainability performance levels. Section 6.2 will further delineate on the effects of traveller characteristics on the results. Besides the selectivity mentioned in the previous section, the fallout of the lower educated group seems random which is positive. Merging education subcategories into two large subcategories (non-masters' degree, masters' degree) contributes to the chance of finding significant differences between them.

Table 4.3: Sample distribution over education & income subcategories

Education	Count	%	Merged	Count	%
Basisonderwijs	0	0 %	Non – masters' degree	122	55%
Vmbo-b, vmbo-k, mbo1, LTS	0	0 %			
Vmbo-g, vmbo-t (mavo), havo-, vwo-onderbouw	2	1 %			
Mbo2, Mbo3	2	1 %			
Mbo4	6	3 %			
Havo, Vwo	16	7 %			
Hbo-, wo-bachelor	96	43 %			
Wo-master, doctor	101	45 %	Masters' degree	101	45 %
Income					
< €10.000	51	23 %	Low-income	87	39 %
€10.000 to €20.000	36	16 %			
€20.000 to €30.000	18	8 %	Middle-income	78	34 %
€30.000 to €40.000	30	13 %			
€40.000 to €50.000	30	13 %			
€50.000 to €59.999	11	5 %	High-income	58	16 %
€60.000 to €69.999	10	4 %			
€70.000 to €79.999	13	6 %			
€80.000 to €89.999	2	1 %			
€90.000 to €99.999	4	2 %			
€100.000 to €200.000	16	7 %			
€200.000 or more	2	1 %			

Income

Similar to education, several income subcategories are merged to obtain at least 30 respondents per subcategory. Income seems to be relatively well distributed although somewhat skewed towards the lower-income categories, which could bias the overall sensitivity to travel cost upwards. Since it is known that high-income travellers fly more often and the most important reason to abstain from flying is its travel cost (Kennisinstituut voor Mobiliteitsbeleid, 2018), the flying population is expected to be more represented by higher incomes in reality. Furthermore, 90% of travellers in the lowest income category are students. This explains the combination of high average education level and the large low-income group.

Flight frequency

Flight frequency is higher among lower age, higher-income and highly educated categories (Gordijn et al., 2017; Kennisinstituut voor Mobiliteitsbeleid, 2018), which could explain the relatively high travel frequency of the sample (see table 4.4). The average flight frequency per year for the sample is 1,6[1] whereas the average Dutch flight frequency is 1,3 (Kennisinstituut voor Mobiliteitsbeleid, 2018). As higher travel frequency with a certain mode increases the travellers' preference for that mode (Bergantino & Madio, 2020), this characteristic of the sample might cause a relatively large preference for APT.

There seems to be a contradiction between the large group of low-income travellers (90% students) and the high average flight frequency in the sample. Expectedly, students in the sample likely come from family backgrounds that financially support their travel, which explains this contradiction.

[1] This average includes the non-flyers which were excluded during data cleaning, as the reported Dutch average also includes non-flyers

Table 4.4: Sample distribution over flight frequency subcategories & travel purpose

Flight frequency	Count	%	Merged	Count	%
Other					
Never	0	0%	Less than once per year	59	27%
Less than once per year	59	27%			
1 or 2 times per year	120	54%	1 or 2 times per year	120	54%
3 or 4 times per year	42	19%	More than 3 times per year	44	20%
5 or 6 times per year	1	0%			
More than 6 times per year	1	0%			
Business					
Never	165	74%	Never	165	74%
Less than once per year	29	13%	Less than once per year	29	13%
1 or 2 times per year	17	8%	More than 1 time per year	29	13%
3 or 4 times per year	5	2%			
5 or 6 times per year	3	1%			
More than 6 times per year	4	2%			
Travel purpose					
Business	28	13%			
Non-business	195	87%			

Travel purpose

7% of the total Dutch population occasionally flies for business. However, 43% portion of the Dutch population never flies (KiM, 2018). Therefore, business travellers will likely be more represented than 7% in the flying population, so 13% in the sample seems acceptable.

4.4 Preliminary observations

This section presents the observed choices by the sample and their perceptions of Hyperloop and APT. These observations are important for model estimation and subsequent interpretation of the results.

4.4.1 Observed choices & base alternative

To illustrate the choices made by the sample, figure 4.1 presents the percentage of times Hyperloop or APT has been chosen as the preferred modality, per choice set[2]. No conclusions can be drawn yet, however, the observed choices do indicate an overall preference for Hyperloop over APT.

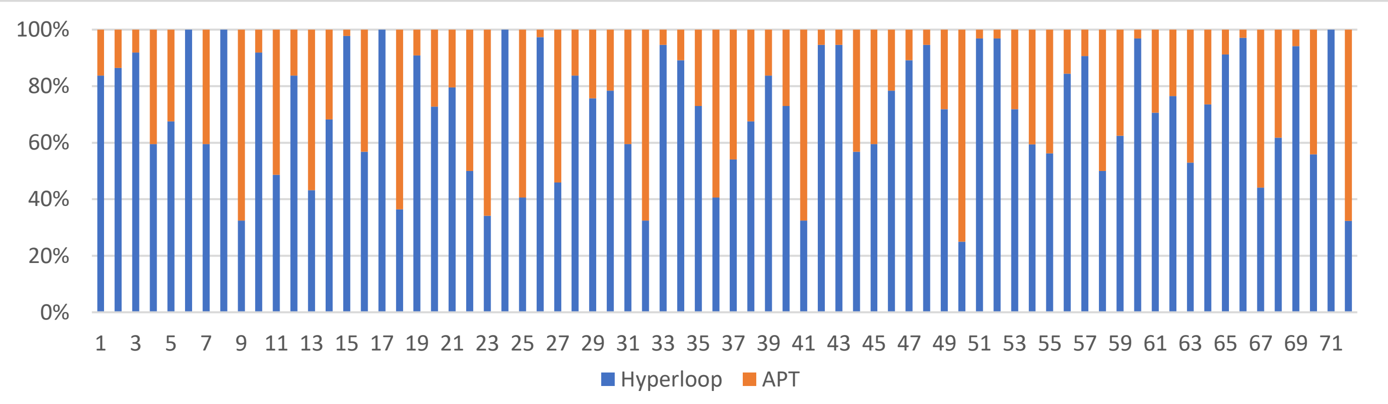


Figure 4.1: Choices made between APT & Hyperloop

[2] Remember: In total, 72 different choice sets were distributed over the respondents.

Figure 4.2 shows the observed choices of respondents between APT, Hyperloop and the base alternative 'Other' transport mode. Importantly, the estimation of a three alternative model including the base alternative 'Other' could potentially mitigate the bias as discussed by Bliemer et al. (2017). By adding the base alternative, the variance of the error term which is linked to utility scales will be introduced 'back again' for choice sets in which only Hyperloop was preferred (under the 2 alternative model). In other words, whereas a choice set in which one alternative is solely chosen shows deterministic behavior (no randomness, 'noise', in decision-making), a choice set on which a mixture of answers has been collected shows probabilistic behavior (including 'noise'). Thereby, by adding the base alternative into those dominated choice sets for model estimation, the probabilistic nature of choice sets is re-introduced for some choice sets, correcting the variance of the error term which is ultimately linked to the utility scales of the parameters (Bliemer et al., 2017).

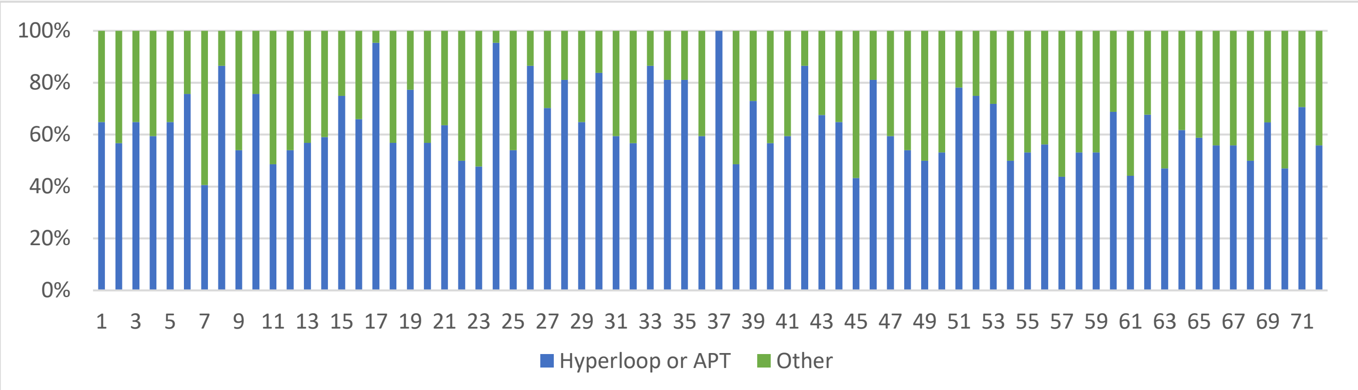


Figure 4.2: Choices made between Hyperloop & APT or base alternative 'Other'

Figure 4.2 also shows that travellers find the base alternative an attractive alternative to Hyperloop and APT on a trip length of 650 kilometers. In 36% of all choice sets, respondents chose the base alternative over Hyperloop or APT which makes sense. Namely, on a trip length of 650 kilometers, car and train have shown to be a competitive transport mode to APT (Goeverden et al., 2019; Janic, 2003). Table 4.5 presents the distribution of transport modes that travellers' selected as a most likely substitute to APT and Hyperloop. Travellers were also able to pick a transport mode of their choosing. Filled in answers by travellers mainly consisted of a combination of already posed alternatives. These were likely travellers who were undecided on the base alternative or did not fully understand the question.

Table 4.5: Preferred base alternative by respondents

	Count	**%**
Car	115	52
Selfdriving car	20	9
Train	76	34
Bus	1	0
Another	11	5

4.4.2 Hyperloop & APT perceptions

To understand travellers' preference for Hyperloop or APT, several perceptions of the Hyperloop relative to APT were measured for every respondent. Table 4.6 presents the average Hyperloop perception of travellers in the experiment.

Table 4.6: Hyperloop perceptions relative to APT

	Score compared to APT (1-5)*	Standard deviation
Safe	3.30	0.83
Comfortable	3.57	0.76
Sustainable	4.32	0.82
Exciting	3.30	0.90
Easy-to-use	3.62	0.86
Social status	3.80	0.85

**1 represents 'extremely less '' than APT', 5 represents 'extremely more '' than APT'*

Travellers in the experiment deem Hyperloop as more safe, comfortable, sustainable, exciting, related to social status and easy-to-use than APT on average. The largest perception difference between travellers is measured for the excitement perception, the smallest difference with regards to perceived comfort. Thus, travellers seem to be most divided on the relative excitement associated with both transport modes.
Interestingly, travellers show to perceive Hyperloop as similarly safe compared to APT on average, even slightly safer. This was not expected since the Hyperloop has not yet been used on a large scale. It can thus be concluded that travellers in the experiment cared less about the mode's track record compared to its design features.
Here, it is expected that the sample has added positively to these perceptions. Namely, the sample is quite familiar with Hyperloop, predominantly young and highly educated. These are typical traits of early adopters, which often have a positive attitude towards technological innovation (Rogers, 1962).

Following the climate-friendly presentation of the Hyperloop in media publications (see for example Kooiman, (2020)), it makes sense that it is perceived as more sustainable. Although the Hyperloop is yet to prove its actual life-cycle sustainability, travellers so far seem to be convinced of its sustainability.
As mentioned in chapter 3, APT sustainability was also measured. In contrast, respondents perceived APT to be quite environmentally unfriendly on a 5-point scale, with an average of 1.7 where 1 is extremely environmentally unfriendly and 5 is extremely environmentally friendly.

Table 4.7: Perceived APT sustainability

	Score	Standard Deviation
APT sustainability	1.70	0.95

4.5 Summary

Chapter 4 has delineated on several characteristics of the sample which are important to take into account during results interpretation. Namely, the sample included many respondents from the direct network of the researcher, which included many technical students or young professionals with an engineering background. It thus makes sense that the sample was already quite familiar with the Hyperloop, somewhat skewed towards low-income categories and predominantly young. Also, the high education level and young average age of the sample has likely added to the large flight frequency for non-business purposes.
Expectedly, the Hyperloop familiarity and high flight frequency among the sample have added to the positive perceptions measured for Hyperloop and APT over other transport modes. Furthermore, the sample characteristics will have likely somewhat biased the results that are averaged over the sample. Namely, sensitivity to sustainability performance is likely biased somewhat upwards (Achtnicht, 2012) and sensitivity to travel cost is likely more prominent because of the large group of low-income travellers (Bergantino & Madio, 2020).

5. Methodology

Chapter 5 delineates the research tools which are used to answer the research questions. First, 5.1 introduces Discrete Choice Modelling (DCM), which is the discipline to which this type of research belongs. Secondly, 5.2 describes three different model types which are used under DCM alongside some of their (dis)advantages. Lastly, under 5.3 the application of context-dependent choice modelling is addressed, covering two of its aspects that are relevant to this research.

5.1: Discrete Choice Modelling

This research mainly uses Discrete Choice Modelling (DCM) to answer the research questions, which is often used in travel behavior research (Brownstone, 2001). This section introduces DCM and two types of data which can be used in this discipline.

5.1.1 Introduction to DCM

The basis of DCM in travel behavior essentially lies in travellers' choices. By analysing travellers' transport mode choices, DCM can derive travellers' sensitivities to transport mode characteristics (Train, 2003). Another option for gathering traveller's mode preferences would be to directly ask. However, people, in general, are not able to properly estimate the importance they would assign to certain mode attributes in their choices. Subsequently, analysing people's choices under different choice situations is preferred in economics (Ben-Akiva et al., 2019).

Random Utility Maximisation (RUM) theory is used as the foundation in most DCM and will also be used in this research. RUM theory assumes that travellers maximise the expected utility (i.e. the respective advantage of an alternative over another alternative) which results from their choice (Train, 2003). The representative utility V_i under the decision-rule of RUM is presented in function (1). Parameter β_m represents the weight travellers attribute to mode characteristic m (e.g. sensitivity to travel time), which is multiplied by the performance x_{im} of the transport mode i on that characteristic (e.g. observed travel time of a mode). Consequently, the overall expected utility of an alternative is calculated by the summation (Σ_m^n) over all the utilities per mode characteristic.

$$V_i = \Sigma_m^n \beta_m * x_{im} \qquad (1)$$

Additionally, 'noise' (ε_i) is added to the overall utility to represent the utility of a transport mode that has not been captured by the parameters specified by the researcher (Train, 2003). This could be explained by factors like randomness in people's choices or by other mode characteristics which have not been included in the specified model. The overall utility of an alternative in DCM looks as follows and is thus expected to be maximised by the decision-maker under the RUM theory.

$$U_i = V_i + \varepsilon_i \qquad (2)$$

The data which is used for DCM includes choices, which are composed of two or more alternatives with their respective attributes and attribute levels, from which a decision-maker can choose. Subsequently, Maximum Likelihood Estimation (MLE) is the underlying procedure that estimates parameters that make the choices in the data set most likely (Train, 2003). Colloquially speaking, the MLE tweaks the model parameters which are specified by the researcher to make the choices that are made most likely. For example, if all travellers in a sample almost always choose for the cheap alternative in choice sets, the MLE corrects the cost parameter to be larger because those travellers are very sensitive to costs (in absolute terms).

5.1.2 Revealed Preference versus Stated Preference data

In general, two types of data are used in DCM: Revealed Preference (RP) data and Stated Preference (SP) data.
In short, RP data contains already revealed information about the preferences of the decision-maker because he or she has already made their choices in real life. There are plenty of examples in literature on the competition between HSR-APT which have been analysed with RP data. See for example Behrens & Pels (2012), who have analysed the Paris-London market by analysing observed travel behavior under varying circumstances through the years. Even though RP data is a reliable source of information to obtain travellers' sensitivities, it does not provide the ability to address transport modes that aren't yet reality (Ben-Akiva et al., 2019).
As of now, the Hyperloop system has not been built anywhere for public use which is why this research uses SP data as input for the DCM. SP data is collected through a survey (see chapter 3 for survey design) which obtains information through varying hypothetical situations for which respondents are asked to state their preference for Hyperloop or APT. Besides the advantage of addressing hypothetical choice situations, gathering SP data also allows for more control and flexibility over the varied attributes (Molin, 2019a). Therefore, even in the scenario in which RP travel data would be available for a Hyperloop system, SP data could prove more useful to address several topics of this research. For example, varying sustainability performance levels of the system or extreme travel times which have not been observed in the market yet would be troublesome to gather data for.

5.2 Models

Two different types of Discrete Choice Models are estimated in this research, which are delineated in this section.

5.2.1 Multinomial Logit Model

The Multinomial Logit (MNL) model is the oldest and one of the most prominently used models to derive mode choice probabilities of people (Train, 2003). It is praised for its flexible and practical character which enables its application to several domains (Chorus, 2019). The MNL model is presented below, where V_i is the utility derived for an alternative by the decision-maker i. Consequently, V_i is set out against the sum of utilities, of all alternatives in the focal decision-making process. Most important is the output P_i, which is the probability of the decision-maker for choosing alternative i over alternative j. In this research, i could resemble the Hyperloop, whereas j could represent APT or vice versa. This choice probability enables the researcher to make predictions of market shares of both alternatives under various circumstances, each with its own set of utilities V_i for the alternatives.

$$P_i = \frac{e^{V_i}}{\sum_{j=1}^{J} e^{V_j}} \qquad (3)$$

One way to account for heterogeneity in the MNL model is the addition of interaction effects with background variables to the straightforward model. Thereby the researcher adds a variable that interacts with estimated tastes and preferences. Function 4 shows the interaction effect of age (many more traveller characteristics could be applied here) on the taste of the respondent for mode characteristic m. Thereby the researcher can estimate the difference of tastes for attribute m among specified age groups in the data set.

$$V_i = \Sigma_m^n \beta_m * x_{im} + \beta_{age*m} * x_{im} * age \qquad (4)$$

5.2.2 Latent Class Choice Model

Another tool for observering travellers' taste heterogeneity, is the Latent Class Choice Model (LCCM). However, the LCCM finds taste heterogeneity more independently than the MNL including interaction effects (Alonso-González et al., 2020). LCCM distinguishes several traveller segments, otherwise called classes, which are homogenous within the class, but heterogenous between the classes (Hess et al., 2011). This means travellers within a class are as similar as possible concerning their taste and preferences, whereas travellers from other classes are as dissimilar as possible with regards to those aspects. Consequently, the identified classes each have their own set of parameters, which is a unique aspect of LCCM estimation.

Moreover, the model estimates the probability of a traveller belonging to a certain class based on his or her traveller characteristics. As formulated in function 5, a traveller will have a probability π of belonging to a class S, based on his or her traveller characteristics (e.g. age, income, Hyperloop comfort perception, etc.). Each class has a probability $P(i|\beta_s)$ of choosing alternative i. As the traveller has a different probability to belong to different classes, the sum-product of both entities gives us the overall probability that a traveller will choose for alternative i.

$$P(i|\beta) = \sum_{s=1}^{S} \pi_s \; P(i|\beta_s) \qquad (5)$$

5.2.3 Summary

The abovementioned models each have a different way of measuring taste heterogeneity among travellers. Both models will be estimated to interpret traveller heterogeneity from different perspectives. Whereas the MNL including interactions are more straightforward and are a function of the specified variables of the researcher, the LCCM is broader and emergent of nature and might provide more unexpected findings.

5.3 Context-dependent choice modelling

This section delineates the conceptual integration of contexts into Discrete Choice Models, since future contexts are a central part of this research. Different future states of social environments are presented to the respondent in the Stated Choice Experiment, which gives us insight into their tastes and preferences within those contexts.

Whereas the presented standard utility function (function 2) only assumes effects directly related to varying attribute levels (main effects), utility functions containing contexts also assume interaction effects with those main effects (Oppewal & Timmermans, 1991). Figure 5.1 presents the conceptual model with one of the researched contexts as interaction effect on the main effect. For example: In a context where carbon social norms are strict, it is expected that people will be more sensitive to sustainability performance of transport modes. Thereby, contexts indirectly inf luence mode utility. Similarly, contexts can have an interaction effect with the overall preference a traveller holds over a transport mode. For example, this research expects an increased preference for Hyperloop as market penetration levels increase.

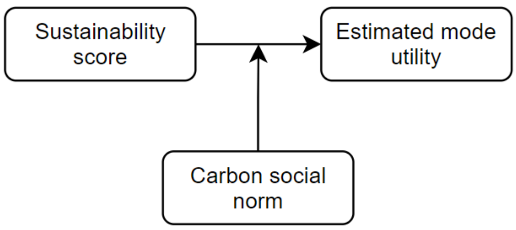


Figure 5.1: Context interaction effect

Importantly, context interaction effects cannot be varied between alternatives in the same choice situation (Molin, 2019c). In other words, no situations occur where a traveller can choose between APT under strict carbon social norms and Hyperloop under relaxed carbon social norms. The focal choice is always made between multiple alternatives under one context. This is in line with intuition, as one traveller is not able to experience two different levels of one context in one future state.

5.4 Model estimation

This section delineates on the model estimation procedure from which the results are derived. Three different models were estimated which an ascending number of estimated parameters, indicating an increasing level of model complexity. Firstly, the basic MNL model (section 5.4.1), secondly, the extended MNL model including interaction effects (section 5.4.2) and lastly a Latent Class Choice Model (section 5.4.3) is estimated. Appendix D presents the model estimation processes, delineation on the model performance indicators used and the PythonBiogeme syntaxes.

5.4.1 Basic model

A future context-dependent MNL is estimated to measure the extent to which mode attributes and future contexts influence travellers' choices between APT, Hyperloop and other transport modes. This model contains mode attribute parameters, context variables and the base alternative. The functions below show the utility functions of the basic MNL model. This section presents the results of the basic model estimation (see table 5.1), that are subsequently interpreted under section 6.1.

$$V_{Hyperloop} = ASC_{Hyperloop} + \beta_{HL\_MP} * MP + \beta_{HL_{CSN}} * CSN + \beta_{HL_{TT}} * TT_{Hyperloop} + \beta_{HL_{AET}} * AET_{Hyperloop} + \beta_{HL_{TC}} * TC_{Hyperloop} + \beta_{HLSE} * HLSE + \beta_{HLSM} * HLSM \quad (6)$$

$$V_{APT} = ASC_{APT} + \beta_{APT_{CSN}} * CSN + \beta_{APT\_TC} * TC_{APT} + \beta_{APT\_TC} * TC_{APT} \quad (7)$$

$$V_{Other} = 0 \quad (8)$$

Where:

$V_{Hyperloop}$ = Utility of the Hyperloop

$ASC_{Hyperloop}$ = Alternative-Specific-Constant of Hyperloop
β_{HL_TT} = parameter for the variable 'Hyperloop travel time'
β_{HL_MP} = parameter for the context variable 'Market Penetration as interaction with Hyperloop'
β_{HL_CSN} = parameter for the context variable 'Carbon Social Norms as interaction with Hyperloop'
$\beta_{HL_{AET}}$ = parameter for the variable 'Hyperloop A-E travel time'
β_{HL_TC} = parameter for the variable 'Hyperloop travel cost'
β_{HLSE} = parameter for first indicator variable 'Hyperloop sustainability equal'
β_{HLSM} = parameter for second indicator variable 'Hyperloop sustainability more'

V_{APT} = Utility of the APT
ASC_{APT} = Alternative-Specific-Constant of Hyperloop
β_{APT_CSN} = parameter for the context variable 'Carbon Social Norms as interaction with APT'
β_{APT_TT} = parameter for the variable 'APT travel time'
β_{APT_TC} = parameter for the variable 'APT travel cost'

V_{Other} = Utility of 'Other'[3]

Firstly, it was tested how the addition of the base alternative, in this case 'other transport modes', affected the model estimation. Interestingly, the model including the base alternative performed

[3] Fixed to zero in model estimation

better than the model excluding the base alternative when looking at the estimated parameters. Namely, the impact of Hyperloop sustainability was more pronounced in the model including the base alternative. Therefore the model including the base alternative was used as the basic model for further model specifications. See Appendix D.3.1 for a more detailed delineation on the addition of the base alternative to the model.

Secondly, it was tested how the addition of the context variables influenced the model performance, by comparing the model performances with and without the future context variables. See Appendix D.3.2 for more delineation on the model specification. The context and sustainability variables were effects coded, see appendix D.1. Overall, the addition of the context variables led to a slightly better model fit (Rho-squared=0.164) compared to the simple MNL model (Rho-squared=0.163). Appendix D.2 provides a short introduction to the Rho-Squared and other model performance indicators used. It was expected that Carbon Social Norms (CSN) would have an impact on the sensitivity of travellers towards Hyperloop sustainability. However, no significant interaction effect was found (p=0.51), which is why the interaction parameter was excluded from the model. Also, the Hyperloop market penetration context showed to have no impact on travellers' preference for APT. The corresponding parameter was therefore excluded from the model. This was not surprising since market penetration levels mainly provide information on the focal transport mode.

Table 5.1: Estimation results basic model

Parameter	**Value**	**Robust Std error**	**Robust t-test**	**Robust p-value**
Constants				
APT	1.12	0.214	5.24	0.00
Hyperloop	3.53	0.243	14.55	0.00
APT parameters				
Travel cost	-0.0164	0.00155	-10.55	0.00
Travel time	-0.00579	0.00184	-3.15	0.00
Hyperloop parameters				
Travel cost	-0.0144	0.00108	-13.39	0.00
Travel time	-0.00728	0.00132	-5.50	0.00
Acces-Egress Time	-0.00682	0.00174	-3.91	0.00
Sustainability 'Equal'	-0.114	0.0601	-1.90	**0.06***
Sustainability 'More'	0.541	0.0620	8.73	0.00
Future contexts				
Market penetration *Hyperloop constant	0.0939	0.0428	2.20	0.03
Carbon social norms *Hyperloop constant	-0.112	0.0473	-2.37	0.02
Carbon social norms *APT constant	-0.103	0.0640	-1.60	**0.11***

**Not significant at 5% significance level*

5.4.2 Extended model

The extended MNL model includes interaction effects to measure the effect of Hyperloop perceptions and familiarity, travel behavior and socio-demographic variables on the choice between APT, Hyperloop and the base alternative. Functions 9, 10 and 11 display the utility functions which were used in the extended MNL model. The model estimation results from the extended model are presented in this section (see table 5.3) and subsequently interpreted under section 6.2.

$$V_{Hyperloop} = ASC_{Hyperloop} + \beta_{HL\_MP} * MP + \beta_{HL_{CSN}} * CSN + \beta_{HL_{TT}} * TT_{Hyperloop} + \beta_{HL_{AET}} * AET_{Hyperloop} + \beta_{HL_{TC}} * TC_{Hyperloop} + \beta_{HLSE} * HLSE + \beta_{HLSM} * HLSM + \beta_{Inc.ASCHyperloop} * Income + \beta_{Inc.TC} * Income * TC_{Hyperloop} + \beta_{NBFF.HLSE} * NonbusinessFlightFrequency * HLSE + \beta_{NBFF.HLSM} * NonbusinessFlightfrequency * HLSM + \beta_{TP.TC} * Travelpurpose * TC_{Hyperloop} + \beta_{Age.HLMP} * Age * MP \quad (9)$$

$$V_{APT} = ASC_{APT} + \beta_{APT_{CSN}} * CSN + \beta_{APT_{TT}} * TT_{APT} + \beta_{APT_{TC}} * TC_{APT} + \beta_{Inc.ASCAPT} * Income + \beta_{NBFF.ASCAPT} * NonbusinessFlightfrequency + \beta_{Safety.ASCAPT} * Safety + \beta_{sustainability.ASCAPT} * Sustainability + \beta_{Excitement.ASCAPT} * Excitement + \beta_{APTsustainability.ASCAPT} * APTSustainability \quad (10)$$

$$V_{Other} = 0 \quad (11)$$

Table 5.2 presents the coding of the traveller characteristics in the extended model. Here it is assumed that income, flight frequency and age subcategories are continuous variables.

Table 5.2: Coding of traveller characteristics

Coding	Subcategory
Income	
0	Low
1	Middle
2	High
Flight Frequency Non-business	
0	Less than once per year
1	1 or 2 times per year
2	More than 3 times per year
Age	
0	20-30
1	30 -60
2	60+
Purpose	
0	Non-business
1	Business

Interaction effects of interest were added one by one, removing the effects that were not significant. Exceptions were made for interaction parameters that had a p-value (somewhat) above 0.05 but were still deemed too relevant to remove from the model following the article by Amrhein et al. (2019). Appendix D.4 presents a more detailed delineation of the procedure and the final PythonBiogeme syntax used. As expected, the model performance (rho-squared = 0.200) proved to be much better than the model performance of the basic MNL model (rho-squared = 0.164).
A separate model was also estimated which only accounts for the impact of travel purpose on the sensitivity to travel costs. It is therefore not controlled for income or other background variables which showed to affect the estimated parameter for travel purpose. Results from this model are presented under Appendix D.4.4 and used for interpreting Value of Time differences between business travellers and non-business travellers under section 6.2.2.

Table 5.3: Estimation results extended MNL model

Parameter	Value	Robust Std err	Robust t-test	Robust p-value
Constants				
APT	3.02	0.517	5.83	0.00
Hyperloop	3.45	0.423	8.17	0.00
APT parameters				
Travel cost	-0.0176	0.00160	-11.00	0.00
Travel time	-0.00632	0.00190	-3.34	0.00
Hyperloop parameters				
Travel cost	-0.0184	0.00164	-11.19	0.00
Travel time	-0.00771	0.00136	-5.67	0.00
Acces-Egress Time	-0.00708	0.00180	-3.94	0.00
Sustainability 'Equal'	-0.344	0.104	-3.30	0.00
Sustainability 'More'	0.776	0.112	6.90	0.00
Future context				
Market penetration * Hyperloop constant	-0.115	0.0482	-2.40	0.02
Carbon social norms * Hyperloop constant	0.165	0.0552	2.99	0.00
Carbon social norms * APT constant	-0.11	0.0660	-1.67	**0.10***
Traveller characteristics				
Income * APT constant	-0.337	0.0976	-3.46	0.00
Income * Hyperloop travel cost	0.00314	0.00141	2.23	0.03
Income * Hyperloop constant	-0.533	0.220	-2.42	0.02
Non-business flight frequency * APT constant	0.535	0.0908	5.89	0.00
Non-business flight frequency * Hyperloop sustainability 'Equal'	0.245	0.0922	2.66	0.01
Non-business flight frequency * Hyperloop sustainability 'More'	-0.232	0.0978	-2.37	0.02
Travel purpose * Hyperloop travel cost	0.00481	0.000977	4.92	0.00
Age * Market penetration	-0.126	0.0666	-1.89	**0.06***
Hyperloop perceptions & familiarity				
Safety * APT constant	-0.564	0.0953	-5.92	0.00
Safety * Hyperloop constant	-0.189	0.0630	-3.00	0.00
Sustainability * APT constant	-0.284	0.0737	-3.86	0.00
Excitement * APT constant	0.223	0.0798	2.80	0.01
Excitement * Hyperloop constant	0.329	0.0539	6.09	0.00
Familiairity * Hyperloop constant	0.0962	0.0490	1.96	0.05
APT sustainability * APT constant	0.147	0.0616	2.38	0.02

**Not significant at 5% significance level*

5.4.3 Traveller classes model

The estimated traveller classes model (i.e. Latent Class Choice Model) accounts for taste heterogeneity from a different perspective than the extended MNL model with interactions effects (see 5.2.2 for delineation). For a detailed overview of the traveller classes model estimation procedure and considerations see appendix D.5. Table 5.4 shows the estimation results of the traveller classes model, that are interpreted under 6.3.

To estimate the traveller classes model, a large portion of the sample needed to be removed due to non-trading behavior. Four non-trading respondents only opted for APT, whereas 50 respondents minimally chose Hyperloop 10 out of 12 choice sets. Only after the deletion of these respondents and the removal of the context parameter Carbon Social Norms on APT constant (which was already not significant in the MNL models), the model could be reasonably be estimated.

Although the results showed a clear divide between traveller classes, many parameters proved to be not significant. Expectedly, this problem has to do with the large number of (alternative-specific) parameters and removal of non-trading respondents from the sample.

The problematic model estimation of the traveller classes model is why results from the extended MNL model are deemed more appropriate for the subsequent scenario analysis (chapter 7). Namely, the deletion of a specific type of traveller (especially 'Hyperloop fans', non-traders) would cause much less valid market share estimations. Expectedly, mainly Hyperloop market share forecasts would be significantly smaller.

Table 5.4: Estimation results traveller classes model

	'Sustainable traveller'		**'Economic traveller'**	
	Value	p-value	Value	p-value
Constant				
APT	-11.2	0.75*	8.47	0.00
Hyperloop	3.09	0.00	11.4	0.00
Airplane parameters				
Travel time	-0.0350	0.09*	-0.0161	0.00
Travel cost	0.0694	0.76*	-0.0399	0.00
Hyperloop parameters				
Travel time	-0.00476	0.19*	-0.0180	0.00
Travel cost	-0.0182	0.00	-0.0314	0.00
Acces-Egress Time	-0.0152	0.00	-0.0140	0.00
Sustainability 'Equal'	-0.131	0.43*	0.189	0.27*
Sustainability 'More'	1.09	0.00	0.574	0.00
Context effects on Hyperloop constant				
Market Penetration	0.159	0.12*	0.0739	0.52*
CSN on Hyperloop	-0.214	0.03	-0.0490	0.68*

**Not significant at 5% significance level*

6. Interpretation of results

This chapter presents the interpretations of the findings to answer several formulated research questions. The first section will delineate the impact of mode attributes and future contexts on travellers' decision-making (6.1). Sections 6.2 and 6.3 present the differences that exist between travellers, regarding the impact of the mode attributes and future contexts on their travel choices. Lastly, section 6.4 will delineate the familiarisation of future contexts by respondents.

6.1 Impact of mode attributes & future contexts

This section presents the impact of mode attributes on travellers' choices between Hyperloop, APT and the base alternative. The impacts of the mode attributes are interpreted from the basic model results as presented under section 5.4.1. Results from the basic model are the averages over all traveller subcategories and therefore more straightforward in interpretation.

Overall preferences for transport modes

If all else is equal, the estimated constants represent the overall preference of respondents for one alternative over the other alternatives (Molin, 2021). A respondent might for example have an extreme preference for the service he or she receives in an airplane. This would result in a larger overall preference for APT over the other modes.

Table 6.1: Estimated mode preferences

Constants	
APT	1.12
Hyperloop	3.53

Before interpretation, the estimated constants are corrected. Firstly, the APT constant is corrected, since the estimated value (1.12) also inhibits disutility of APT access-egress time and sustainability performance as presented to respondents. Since the utility of these aspects is not inhibited by the Hyperloop constant (because separate parameters are estimated for them), the APT constant must be corrected to evenly compare the mode preferences by travellers. Both aspects negatively impacted travellers' Hyperloop utility, which is why the APT constant is corrected upwards. Here it is assumed that access-egress time and sustainability performance have the same negative impact on the travellers' choice for APT as for Hyperloop. The APT constant subsequently amounts to 2.87. Secondly, the Hyperloop constant is corrected for the average difference between Hyperloop travel costs and APT travel costs in the choice sets, which negatively impact the Hyperloop constant. After correction, the Hyperloop constant amounts to 3.88.
Reasoning with travellers' positive Hyperloop perceptions, they show a preference for the Hyperloop (3.88) over APT (2.86) and the base alternative (fixed to zero). This was not anticipated, since travellers have not been able to test or experience the Hyperloop. The most prominent explanation is the high level of Hyperloop familiarity in the sample, which has a positive effect on the preference for Hyperloop (further delineated under 6.2.3). Namely, even though travellers have not experienced a Hyperloop ride, their purely information-based familiarity with Hyperloop has a positive effect on their preference for Hyperloop. This is further corroborated by LaRiviere et al. (2014) who identified a positive effect of information-based familiarity with the valuation of public goods.

Even though the base alternative is seen as a somewhat viable alternative, the results show an overall preference for APT and Hyperloop over the base alternative. This makes sense, since the base alternative only included transport modes which are more time-consuming than the Hyperloop or APT. Here it should be noted that the high level of flight frequency in the sample has added to the preference for APT (further delineated under 6.3.1).

(Access-egress) Travel time and cost

Unsurprisingly, an increase in travel time and costs negatively impact travellers' choices for the corresponding transport mode. This section will interpret results regarding travel cost and time, whereas section 6.2.1 will further delineate their validity.

With one minute increase of Hyperloop travel time, Hyperloop utility decreases with -0.00728. In contrast, one minute increase in APT travel time decreases overall APT utility by -0.00579 (see figure 6.1). In other words, travellers regard Hyperloop travel time as more burdensome than APT travel time. This does not make sense, since the sample, on average, perceived Hyperloop as more comfortable and safe than APT. This discrepancy could be caused by the standard 4 hours of APT access-egress travel time that travellers' faced in the SCE. Namely, travellers might care relatively less about changes in APT travel time, since they have to spend 4 hours getting to and from the airplane either way.

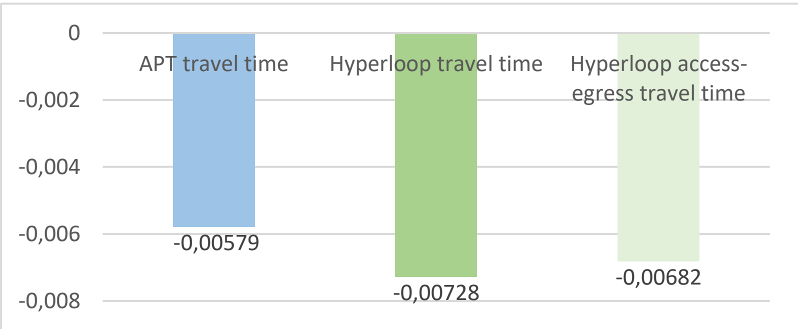


Figure 6.1: Utility decrease per minute of (access-egress) travel time

The time spent from a travellers' home to the Hyperloop is almost equally burdensome to travellers as travel time spent within the Hyperloop. Namely, one minute of Hyperloop access-egress travel time decreases Hyperloop utility by -0.00682, whereas one minute of Hyperloop travel time decreases Hyperloop utility with -0.00728. This finding is not in line with previous research, which has found access-egress travel time to be more burdensome than travel time in the vehicle. (Arentze & Molin, 2013; Román et al., 2007). However, several respondents indicated to have simplified the stated choice task by adding the two types of travel time to derive the total travel time. If this strategy was used by many respondent, the resulting sensitivity to both time variables would be the same.

The travel cost parameters also show a negative effect on utility. With an increased ticket price of one euro, Hyperloop utility decreases by -0.0144. APT ticket prices have a similar impact on travellers' choices, with a -0.0164 utility decrease as the ticket price increase by 1 euro. Although these results are similar, sensitivity to Hyperloop travel costs is somewhat lower. This could be explained by the positive perception of Hyperloop by travellers. In other words, travellers are likely more willing to pay for a transport mode that is more comfortable, safe, easy-to-use, sustainable and related to social status.

Hyperloop sustainability

Lastly, Hyperloop sustainability performance has a sizeable impact on travellers' choices. Figure 6.2 presents the impact of three Hyperloop sustainability performance levels on Hyperloop utility.

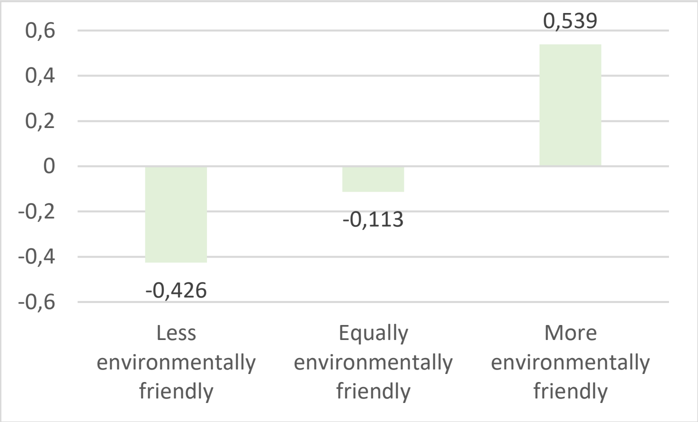


Figure 6.2: Impact Hyperloop sustainability

Interestingly, travellers react somewhat more positively towards a 'more environmentally friendly' Hyperloop, than they react negatively to a 'less environmentally friendly Hyperloop'. Thus, roughly speaking, travellers care more for improved environmentally friendliness, whereas they opt to somewhat 'look the other way' when Hyperloop is less environmentally friendly than APT. This is comparable to the psychological denial strategy of certain air travellers that opt for a cheap and unsustainable transport mode even though they've show to care for the environment (Kroesen, 2013).

Overall, it is somewhat surprising that transport mode sustainability is quite impactful on travellers in this study. These results indicate a sizeable influence of sustainability on actual air travel behavior, which has not been observed by previous research (Alcock et al., 2017; Gössling et al., 2020). This result is most likely explained by the fact that travellers are now confronted with a competitive and sustainable alternative. Thereby, it enables the environmentally aware traveller to act on the environmental impact of APT, breaking through the attitude-behavior gap. c. Here the Hyperloop functions as an actionable alternative, which helps people to act more sustainably (de Vries, 2020). It should be noted here that the high average level of education in the sample has likely added somewhat to the willingness-to-pay for more sustainable transportation (Achtnicht, 2012).

Carbon Social Norms

The difference between strict and lenient carbon social norms show to have a slight impact on travellers' preference for Hyperloop, APT and the base alternative (see figure 6.3). Strict carbon social norms (CSN) represent the situation where friends/family/colleagues *often* critique the usage of carbon-heavy transport modes. Lenient CSN represents *rarely* uttered critique by peers.

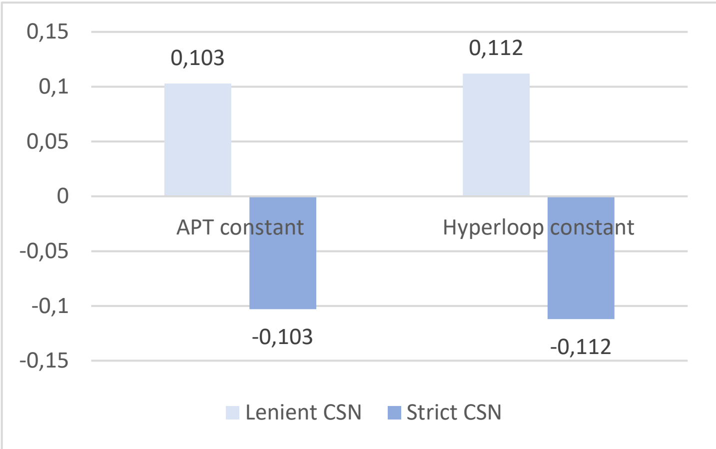


Figure 6.3: Impact carbon social norms on mode preference

Strict CSN negatively impact both travellers' preference for APT and Hyperloop, compared to the base alternative. This is somewhat surprising since Hyperloop was perceived as very environmentally friendly by respondents. However, in the choice experiment, the Hyperloop was presented as an environmentally unfriendly transport mode in two-thirds of the choice situations (Hyperloop being equally or less environmentally friendly compared to APT). It thus seems probable that respondents preferred the (environmentally friendly) base alternative under strict CSN circumstances. Remember here, that the base alternative consisted of electric cars, electric buses and trains.

Furthermore, it was expected that strict CSN would have a direct positive impact on travellers' sensitivity to the Hyperloop sustainability performance. However, no such effect was found to be statistically significant in this research. Instead, it is assumed that this effect is caught in the impact of CSN on overall mode preference. See Appendix D.3.2 for further delineation on this topic.
Lastly, it should be noted that strict carbon social norms had a significant effect on the focal hypothetical travel behavior, whereas research by Gössling et al.(2020) found limited evidence for the impact of current CSN on actual travel behavior. This research thus provides evidence for the potential which resides in CSN. Increasing strictness of CSN could potentially become more impactful on air travel behavior in the future.

Market Penetration

The difference between market penetration levels has a small but positive impact on the preference for Hyperloop (see figure 6.4). Under low market penetration levels, 1 out of 10 friends/family/colleagues occasionally has a positive Hyperloop travel experience, compared to 9 out of 10 friends/family/colleagues under high market penetration.

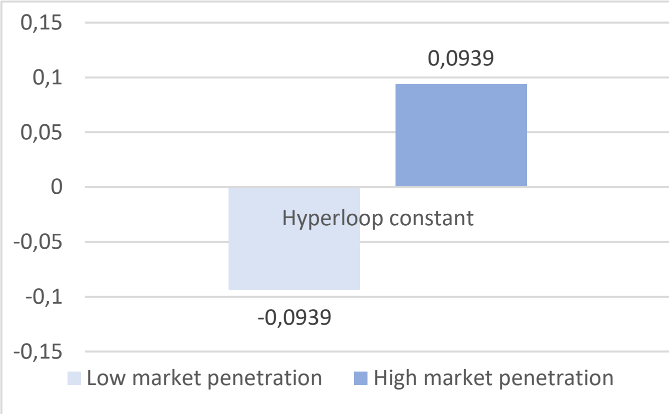


Figure 6.4: Impact market penetration on Hyperloop preference

As discussed in chapter 2, several sources of market penetration effects were expected: social status, peer observation and peer pressure effects. Respondents were asked to what extent these effects applied to them when observing changing market penetration levels. The results are presented in table 6.2. Perceptions related to peer observation (increased safety, ease-of-use, comfort) scored the highest, whereas peer pressure and social status effects scored relatively low. In other words, respondents mainly saw Hyperloop as being more comfortable, safe and easy-to-use under a high market penetration context. This is not surprising since peer observation is one of the key drivers to the diffusion of innovation (Sahin & Rogers, 2006).

These results could also be explained by the hypothetical setting of the experiment. The question remains, how respondents would react to a high Hyperloop market penetration level in a real-life choice situation. Similar to CSN, it can be speculated that this effect would be more impactful on actual travel behavior, as travellers are more likely to *feel* the social dynamics surrounding market penetration.

Table 6.2: Sources of market penetration effects

Perception related to high market penetration	Score
Safety	3,7
Social status	2,2
Peer pressure	2,1
Ease-of-use	3,9
Comfort	3,9

6.2 Impact for different traveller segments

This section presents the impact of differences between traveller segments on their choice between APT, Hyperloop and other transport modes. Results are interpreted from the extended MNL model as presented under section 5.4.2.

6.2.1 Traveller Characteristics

To understand the impact of travellers' characteristics on transport mode choices, this section presents their mitigating or accelerating impact on several traveller decision-making factors.

Income

Table 6.3: Impact of income on APT & Hyperloop constant and sensitivity to Hyperloop travel cost

Income category	APT Constant	Hyperloop Constant	Hyperloop Travel Cost
*Income*Parameter*	(-0.337)	(-0.533)	(0.00314)
Low	3.02	3.45	-0.0184
Middle	2.68	2.92	-0.0153
High	2.35	2.38	-0.0121

The yearly income of respondents affects their preference for APT and Hyperloop over other transport modes (see table 6.3). With increasing income, the preference for APT and Hyperloop decreases with -0.337 and -0.533 respectively. This makes sense, since travellers with higher incomes likely tend to have more access to a car (Commins & Nolan, 2010). Namely, car was the most chosen transport mode besides Hyperloop and APT. Moreover, it showed that the middle and high-income groups more often pick a car over other transport modes as the base alternative (see cross-tabulation under Appendix D.6). Another probable cause could be that the train alternative is often viewed as more expensive than APT (Raad voor de leefomgeving en infrastructuur, 2020). Higher-income groups might therefore sooner opt for the more expensive yet sustainably perceived train.

As expected, increased income also showed to have a mitigating effect (0.00314) on the sensitivity to travel costs of Hyperloop. Logically, travellers with a higher income will be less sensitive to costs, as they can afford more and therefore care more about other mode attributes like travel time. It is surprising, however, that the same mitigating effect was not significant for the sensitivity to APT travel costs. It could be speculated that the lower average APT ticket price causes this insignificance. Lower-income travellers might sooner accept higher APT ticket prices since they are still cheaper than Hyperloop prices on average. Subsequently, no significant income effect on APT ticket prices would be found.

Non-business flight frequency

Table 6.4: Impact of non-business flight frequency on APT constant and sensitivity to Hyperloop sustainability

Non-business Flight Frequency category	APT Constant	Hyperloop Sustainability 'Equal'	Hyperloop Sustainability 'More'	Hyperloop Sustainability 'Less'
*Frequency*Parameter*	(0.535)	(0.245)	(-0.232)	
1< per year	3.02	-0.344	0.776	-0.432
1 – 2 times per year	3.56	-0.0990	0.544	-0.445
>3 per year	4.09	0.146	0.312	-0.458

Non-business flight frequency affects the preference for APT and the sensitivity to Hyperloop sustainability performance (see table 6.4). Frequent flyers (for non-business purposes), when all else is equal, tend to prefer APT over Hyperloop and other transport modes. This behavior is also observed by Bergantino & Madio (2020), who accredit this static behavior to acquired habits or possible flight discounts obtained by frequent flyers. Interestingly, frequent flyers also show to be less sensitive to the sustainability performance of the Hyperloop. It could be speculated that frequent flyers are less sensitive to the environmental impact of their mode choice. This would be in line with Kroesen (2013) who points at several psychological strategies that frequent flyers use to 'explain' the carbon impact of their flight behavior.

An interesting contradiction is found in the results. Frequent flyers are usually high-income travellers (Kennisinstituut voor Mobiliteitsbeleid, 2018). However, high-income travellers in this study show a lower preference for APT. In contrast, frequent flyers in this study show an increased preference for APT. Thus, the two effects cancel each other out, unless a high-income traveller is not a frequent flyer: A high-income traveller who does not fly often, has an exceptionally low preference for APT. This makes sense, since he or she likely has access to a car for trips of 650 kilometers, which enables avoidance of APT (and Hyperloop).

Age

Table 6.5: Impact of age on sensitivity to market penetration

Age category	Hyperloop market penetration
*Age*Market penetration*	*(-0.126)**
20-30	0.165
30 -60	0.0390
60+	-0.0870

**Not significant at 5% significance level (p=0.06)*

Lastly, age is the only background variable to interact with one of the context variables. Namely, with increasing age the sensitivity to Hyperloop market penetration levels decreases. It could be speculated that people with more travel experience are less reliant on information through peer observation and descriptive norms posed by this variable.

6.2.2 Value of Time differences

Different Values of Time (VoT) are measured for business and non-business travelers. The travel purpose of travellers impacts their sensitivity to Hyperloop travel costs, which influences their VoT (see table 6.6). Value of Time relates to the amount of money one unit of travel time reduction is worth to a (business or non-business) traveller. It is often used in infrastructure appraisal to assess the societal value of new infrastructure, which often causes overall travel time reductions (Wardman & Chintakayala, 2012). As travellers value the travel time between transport modes differently, there exist different Value of Time scores between transport modes (Fosgerau & Börjesson, 2015).

The Value of Time of the sample is presented alongside those estimated by Kouwenhoven et al. (2015). Only significant differences were found between the sensitivity to Hyperloop travel costs for business travellers and other travellers. In line with research by Behrens & Pels(2012), business travelers care much less about travel costs. Thus, as expected, business travellers have a much higher

Table 6.6: Value of Time estimates (non-) business travellers

	Non-business traveller		Business traveller	
	This study	*Kouwenhoven et al. (2015)*	*This study*	*Kouwenhoven et al. (2015)*
Value of Time Hyperloop (€/hour)	29	-	43	-
Value of Access-Egress Time Hyperloop (€/hour)	27	-	-*	-
Value of Time APT (€/hour)	21	47	-*	86

**VoT differences not significant at 5% significance level*

VoT, since they generally don't have to carry any or all of their business-related travel expenses.

In comparison to the study by Kouwenhoven et al. (2015), the VoT for APT found in this study is much lower. The most probable explanation lies with the large group of low-income travellers in the sample that is more sensitive to costs. Also, the Covid-19 travel restrictions could have impacted travellers' sensitivity to travel time. In other words, they might have momentarily 'forgotten' the burden of extra travel time and have become more cost-sensitive.

6.2.3 Hyperloop familiarity & Perceptions

To understand the impact of travellers' Hyperloop perceptions and familiarity on their transport mode choices, this section presents their impact on the preference for Hyperloop and APT. See table 6.7 for the results.

The perception of Hyperloop comfort and ease-of-use did not show a significant impact on the overall mode preferences. It could be speculated that this insignificance is caused by a mitigating effect with market penetration levels, which have shown to affect travellers' perception of Hyperloop comfort and ease-of-use. As market penetration levels provided respondents with more information on comfort and ease-of-use, their previously stated perception might have been neglected.

Familiarity

As expected, people with higher familiarity with Hyperloop before the survey show to have a higher preference for the Hyperloop[4]. This result is in line with the findings by Planing et al. (2020), who mainly point at the provision of information as a tool to increase the willingness-to-use of Hyperloop. Namely, travellers who are more informed on Hyperloop might be more accepting of the technology because their initial concerns are mitigated with provided knowledge. A second explanation, however, could be the innovative nature of the respondents. In general, people who belong to the first adopter category as defined by Rogers (1962) show to be more familiar with technological innovation. Their preference for usage of the innovation does not only stem from their level of knowledge but also their overall positive attitude towards technology.

Excitement

Similar to the findings by Planing et al. (2020), respondents who perceived usage of the Hyperloop as more exciting than APT, had a stronger preference for the Hyperloop. Surprisingly, the excitement perception proved to be second-most impactful of the Hyperloop perceptions. This could be explained by the hypothetical nature of the experiment, which might have lead respondents to be less risk-averse and more prone to act on excitement than in real life.
Furthermore, the impact of excitement perception on the preference for APT seems counter-intuitive. APT preference was expected to decrease for respondents who perceive the Hyperloop to be more exciting, however, an effect in the opposite direction was found. It could be speculated that respondents with a strong Hyperloop excitement perception are more thrill-seeking and therefore more excited by traveling with the Hyperloop or APT. This makes sense since the perceived excitement of APT and Hyperloop are quite similar (see section 4.4.1). Still, respondents with a higher excitement perception of Hyperloop prove to be more inclined to choose Hyperloop than APT.

[4] The interaction model without Hyperloop perceptions shows a much stronger impact of familiarity on Hyperloop preference (0.142). This suggests that the Hyperloop perceptions are correlated to Hyperloop familiarity, which seems sensible.

Namely, the excitement effect has a stronger positive impact on the preference for Hyperloop than on the preference for APT.

Table 6.7: Impact of Hyperloop familiarity and perceptions on mode preference

Background variable	Hyperloop constant per subcategory	APT constant per subcategory
Prior Hyperloop familiarity		
*Familiarity*constant*	*(0.0962)*	
I did not know it	3.546	
I had heard of it	3.642	
I had heard of it and looked further into it	3.739	
I knew much about it	3.835	
Hyperloop excitement relative to APT		
*Excitement perception*constant*	*(0.329)*	*(0.223)*
Hyperloop is far less exciting	3.779	3.243
Hyperloop is less exciting	4.108	3.466
Neutral	4.437	3.689
Hyperloop is more exciting	4.766	3.912
Hyperloop is far more exciting	5.095	4.135
Hyperloop safety relative to APT		
*Safety perception*constant*	*(-0.189)*	*(-0.564)*
Hyperloop is far less safe	3.261	2.456
Hyperloop is less safe	3.072	1.892
Neutral	2.883	1.328
Hyperloop is more safe	2.694	0.764
Hyperloop is far more safe	2.505	0.200
Hyperloop sustainability relative to APT		
*Hyperloop Sustainability perception*constant*		*(-0.284)*
Hyperloop is far less sustainable		2.736
Hyperloop is less sustainable		2.452
Neutral		2.168
Hyperloop is more sustainable		1.884
Hyperloop is far more sustainable		1.6
APT sustainability perception		
*APT Sustainability perception*constant*		*(0.147)*
Completely unsustainable		3.167
Unsustainable		3.314
Neutral		3.461
Sustainable		3.608
Completely sustainable		3.755

Safety

Of the Hyperloop perceptions, safety had the largest impact on travellers' preference for APT. The safer Hyperloop is perceived compared to APT by a traveller, the lower his or her preference for APT becomes. Contrary to expectation, however, is the negative effect of Hyperloop safety on its preference. The safer Hyperloop is perceived compared to APT by a traveller, the lower his or her preference for Hyperloop becomes. It could be speculated that respondents with a strong Hyperloop safety perception are more risk-averse and sooner frightened of traveling with both Hyperloop and APT. Namely, on average, Hyperloop and APT are perceived to be similarly safe. This is not surprising since they share similar fear factors, like loss of autonomy or fear of confinement (Bennett &

Vijaygopal, 2021). Still, a higher Hyperloop safety perception has a stronger negative impact on the preference for APT than on the preference for Hyperloop. This means travellers who perceive Hyperloop as safer, are more inclined to opt for Hyperloop over APT.

Sustainability

Lastly, both perceptions regarding the sustainability of APT and Hyperloop impact travellers' preference for APT. Interestingly, a high sustainability perception for Hyperloop seemed to have a larger negative effect on APT preference, than a low sustainability perception of APT on its preference. In other words, seeing Hyperloop as more sustainable had more effect on a travellers' preference for APT than seeing APT as unsustainable. This further corroborates the other findings of the sensitivity to sustainability: travellers suddenly care more for sustainability, when faced with a more sustainable alternative.

As mentioned under 6.1, the considerable importance respondents assigned to sustainability is not in line with travel behavior as presented in the literature (Gössling et al., 2020). This could most likely be explained by the sustainable character of the Hyperloop combined with its competitive travel times.

6.3 Different traveller classes

This section delineates the extent to which differences (i.e. heterogeneity) exist amongst traveller classes regarding their sensitivity to mode attributes and mode preferences. Results are interpreted from the traveller classes model as presented under section 5.4.3.

6.3.1 Model results

Estimation of the Latent Class Choice Model (LCCM) resulted in the identification of two traveller classes: the 'sustainable traveller' and the 'economic traveller' (see table 6.8). The results show an interesting split in the sample between two different types of travellers.

Table 6.8: Model results LCCM

	'Sustainable traveller'		'Economic traveller'	
	Value	p-value	Value	p-value
Constant				
APT	-11.2	0.75*	8.47	0.00
Hyperloop	3.09	0.00	11.4	0.00
Airplane parameters				
Travel time	-0.0350	0.09*	-0.0161	0.00
Travel cost	0.0694	0.76*	-0.0399	0.00
Hyperloop parameters				
Travel time	-0.00476	0.19*	-0.0180	0.00
Travel cost	-0.0182	0.00	-0.0314	0.00
Acces-Egress Time	-0.0152	0.00	-0.0140	0.00
Sustainability 'Equal'	-0.131	0.43*	0.189	0.27*
Sustainability 'More'	1.09	0.00	0.574	0.00
Context effects on Hyperloop constant				
Market Penetration	0.159	0.12*	0.0739	0.52*
CSN on Hyperloop	-0.214	0.03	-0.0490	0.68*

**Not significant at 5% significance level*

6.3.2 Interpretation of traveller classes

Table 6.9 presents the class membership probabilities of the two traveller classes. The higher someone's flight frequency for non-business purposes, the likelier it is that he or she belongs to the 'economic traveller' class.

Table 6.9: Class membership probabilities

		'Sustainable traveller'	'Economic traveller'
Class membership probability		44%	56%
Class membership probability dependent on non-business flight frequency	<1 per year	78%	22%
	1-2 per year	61%	39%
	>3 per year	31%	69%

Sustainable traveller

This is the smaller class of the two (44%) and can be characterised by travellers who are comparably more sensitive to sustainability performance levels of Hyperloop and have a strong dispreference for APT. This strong dispreference for APT was not observed in the other results, which underlines the large differences between different traveller segments. Furthermore, the more a person flies, the less likely it is that he or she falls into the sustainable traveller class. The dislike for APT by this segment is likely caused by APT's environmentally unfriendliness. This is corroborated by the strong sensitivity to Hyperloop sustainability and sensitivity to strict carbon social norms. Similar effects emerged from other results, which also showed a lower preference for APT and higher sensitivity to Hyperloop sustainability by travellers who fly less often.

Travellers from this class are still sensitive to the travel cost and time of the Hyperloop, although to a lesser extent than the economic traveller. Probably due to the consistent avoidance of APT by this segment, the APT travel time, travel cost and constant are not significant at the 5% level as the model could not 'unambiguously estimate' their parameters.

Economic traveller

More than half of the sample (56%) belongs to the 'economic traveller' class, which is more sensitive to classic economic determinants of travel behavior: transport time and costs. The economic traveller has a large preference for Hyperloop and APT and a higher chance of being a frequent flyer. It could thus be supposed that these travellers have a preference for fast travel modes over other transport modes (i.e. car, train, bus). As opposed to the sustainable traveller, the economic traveller shows less sensitivity to the sustainability level of the Hyperloop and carbon social norms.

These findings are somewhat in line with the research by Gaker & Walker (2013), who also found a sustainable and non-sustainable traveller class. However, the size of the segments and sensitivity to sustainability are different. Namely, Gaker & Walker (2013) found a small but extremely environmentally motivated traveller class (24%) and a large traveller class that showed not to care about sustainability at all (76%). In contrast, both traveller classes found in this research show to value sustainability at least to a certain extent. Also, the 'sustainable traveller' is not very extreme with regards to sustainability compared to the 'economic traveller'.

6.4 Future context familiarisation by respondents

This section presents the level of familiarisation of future contexts by respondents in the research. This is done to understand the extent to which respondents can familiarise themselves with future contexts.

Table 6.10 shows that respondents, on average, were able to understand the future contexts quite well. This resonates with the significant impact of the future contexts on travellers' choices. Understandably, respondents found it most difficult to imaginatively project the presented contexts to their social environment. Namely, the focal survey had an average response time of 23 minutes, which is a relatively short time to fully immerse oneself in the future context. Respondents scored slightly better at understanding the future contexts as a whole.

Hyperloop market penetration levels were somewhat more difficult to imagine than carbon social norms. This was not anticipated as market penetration levels contained fewer social cues for respondents, which was expectedly more difficult. However, since this future context is multi-faceted, it could have been more difficult to familiarise with. Namely, market penetration levels contain both informative (peer observation) and social (peer pressure, social status) aspects. In contrast, the context of carbon social norms was more unilateral in that regard, containing only social aspects.

Table 6.10: Average self-reported scores for context familiarisation

	Average score (1-5)*	Standard Deviation	Impact on the context variable	P-value
Overall apprehension of the future contexts				
Carbon Social Norms	4.1	0.76	-0.0261	0.65**
Market Penetration	4.0	0.74	0.0384	0.51**
Ability to imagine the difference between two future context levels				
Carbon Social Norms	3.9	0.80	0.00714	0.88**
Market Penetration	3.8	0.88	0.00744	0.88**
Ability to imagine future contexts for one's social environment				
Carbon Social Norms	3.8	0.92	-0.110	0.56**
Market Penetration	3.7	0.91	0.0665	0.73**

**1 represents 'very bad', 5 represents 'very good'*
***Not significant at 5% significance level*

Interestingly, the standard deviations are quite large which shows the variation of respondents' ability to familiarise themselves with the future contexts. Especially respondents' ability to imagine the future contexts for their social environment proved to be more scattered. This seems sensible, since more respondents have reported a lower level of familiarization under this aspect (pointing at the lower average score). In contrast, others will likely have consistently overestimated their level of familiarization throughout all the self-reporting questions. This could also shed some light on the way respondents have self-reported their level of familiarization. It is questionable if all respondents graded themselves in the same manner, some might have underestimated themselves whereas other might have overestimated themselves.

It was further investigated if a respondents' level of familiarisation with the context impacted his or her sensitivity to certain future contexts. A respondent who reported to have familiarised him or herself with the contexts well might have therefore had a more pronounced sensitivity to it. However, no significant effects were found even though 5 out of 6 estimated parameters were in the expected direction. Namely, with an increased level of familiarisation, the negative impact of Carbon Social Norms on Hyperloop became much stronger. Similarly, the positive effect of Hyperloop market penetration became larger with an increased level of familiarisation.

It should be noted that different respondents have likely overestimated their familiarisation level, whereas others have underestimated themselves. This would make recognizing the abovementioned effect much more difficult for the model. Also, respondents might have simply reacted differently to having a high level of familiarisation with the contexts. In other words, respondents who are truly familiar with the future context do not necessarily react in the same way.

6.5 Summary

The results displayed the sensitivity of (different) travellers to mode attributes and future contexts. Below the most important findings per subsection of the results are presented.

Mode attributes

-Hyperloop travel cost is valued somewhat less burdensome than APT travel cost.
-Hyperloop access-egress time is perceived as equally burdensome as actual travel time in the Hyperloop.
-Travellers care more for Hyperloop sustainability performance, in the case Hyperloop is more sustainable than APT. It has shown that travellers care somewhat less about sustainability performance in the case that Hyperloop is less sustainable than APT.

Future contexts

-Future contexts have a relatively small impact on the focal mode choice, although the impact they show is in line with expectation.
-Strict carbon social norms (CSN) cause travellers to divert away from Hyperloop and APT towards other modes. Also, CSN has no significant impact on travellers' sensitivity to mode sustainability which was unexpected. Therefore, Hyperloop stands to benefit from strict CSN under no circumstance.
-Increased Hyperloop market penetration has a positive impact on the preference for Hyperloop. This is mainly caused by positive peer observation effects, followed by social status and peer pressure effects.

Different traveller segments

-Low-income and frequent flyers have a higher preference for APT.
-Business flyers and high-income travelers care significantly less for travel costs.
-Frequent flyers care significantly less for Hyperloop's sustainability performance.
-Sensitivity to market penetration levels declines rapidly with increasing age.
-The perception of Hyperloop safety has the most impact on mode preference, followed by the perception of Hyperloop excitement. APT and Hyperloop sustainability perceptions and familiarity with the Hyperloop have an impact on mode preference as well.
-Two distinct types of traveller classes were found: the sustainable traveller and the economic traveller.

Familiarisation with future contexts

-Respondents showed to understand and familiarised themselves with future contexts quite well. Of the challenges for respondents, the ability to imagine future contexts for one's social environment proved to be the hardest.

7. Scenario analysis

Estimated travellers' sensitivities and preferences from the previous chapter are used to estimate Hyperloop's competitive potential under different introduction scenario's and future contexts. Three different Hyperloop introduction scenarios are analysed. First, the formation of the introduction scenarios is delineated under section 7.1, whereafter the market shares per scenario are presented (section 7.2). Afterward, the overall results and likelihood of the scenarios are deliberated upon (section 7.3).

7.1 Forming of scenarios

Scenarios are based on three different discourses (i.e. 'visions') regarding the Hyperloop that exist in academia, industry and government. These discourses accentuate certain positive or negative characteristics of Hyperloop which experts accredit to the transport mode. Whereas multiple discourses could become reality hand-in-hand, a clear division is made between the discourses to display their isolated impact on potential travel demand. Each of the following subsections will present the discourse which forms the basis of the introduction scenario. In every introduction scenario, certain trade-offs are made between APT and Hyperloop aspects like ticket price and sustainability performance, for which travellers' sensitivities were estimated in this research. These trade-offs represent Hyperloop and APT system alternatives. Subsequently, potential market shares of the Hyperloop, APT and other transport modes are estimated under different future contexts (see figure 7.1).

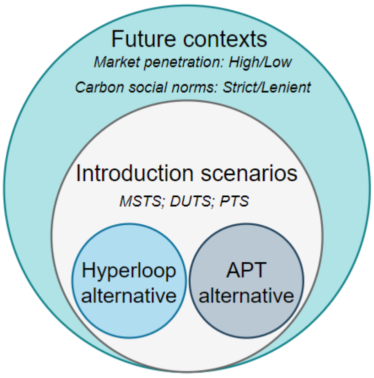


Figure 7.1: Structure of scenario analysis

It should be noted that Hyperloop system alternatives remain rough sketches since there is little to no detailed information available about actual Hyperloop infrastructure design, capital costs and life-cycle assessments (Sane, 2020). In reality, there exists a balancing act between the latter three factors since the infrastructure design influences capital costs and system sustainability performance (van Goeverden et al., 2017). Subsequently, capital costs and system sustainability indirectly influence Hyperloop travel demand through ticket prices and sustainability perception of travellers. Scenario analysis results should therefore be interpreted with care.

To indicate the costs which are incurred by the Hyperloop infrastructure and will be discussed under the scenarios, table 7.1 presents the projected Hyperloop capital infrastructure costs by Delft Hyperloop (2019).

Table 7.1: Projected Hyperloop infrastructure costs
Source: (Delft Hyperloop, 2019)

Part	Cost
Infrastructure costs per km	
Above-ground (two-way)	€38 million
Underground (two-way)	€61 million
High-speed switch	€28 million
Station	€700 million
Capsule	€8 million

7.2 Hyperloop introduction scenarios

This section presents the different Hyperloop introduction scenarios alongside potential market shares of the Hyperloop, APT and other transport modes. Results are used from the extended MNL model that only accounts for traveller characteristics (see appendix D.4.3). Thus, traveller's mode perceptions and familiarity with Hyperloop are not varied between introduction scenarios. Namely, it is very uncertain how travellers' perceptions would differ between scenarios.

Furthermore, it should be noted that potential future market shares are based on the hypothetical mode choices of respondents in this research. Therefore, the estimated Hyperloop market shares are only valid for the future situation as sketched in the survey. This uncertainty should be accounted for in the interpretation of the scenarios.

7.2.1 Current market shares

Current long-distance travel market shares originate from the DATELINE survey carried out in 2002/2003 by the European Union. For a trip length of 650 km, European market shares per transport mode are approximately 20% for APT, 54% for car, 12% for train and 14% for bus (V. Goeverden et al., 2019). Thus, for this study, 20% market share for APT and 80% market share for other transport modes can be viewed as a benchmark.

7.2.2 Mass Sustainable Transport System

This Hyperloop introduction scenario can be characterised by a strong focus on sustainable long-distance transport by society. It relates to the discourse which views Hyperloop as the environmentally friendly substitute to APT. Experts believe the sustainable potential of Hyperloop to be one of the main reasons for its implementation (Shetty, 2019). Furthermore, the current backing by the European Commission behind Hyperloop development is also based on this sustainable rationale (European Commission, 2020; European Institute of Innovation, n.d.).

If this discourse is decisive in the decision-making for Hyperloop implementation, the evolution towards sustainable APT fuels could become a serious barrier to Hyperloop implementation. Namely, the sustainable advantage over Hyperloop could diminish if APT fuels are produced sustainably. However, the technology race between both remains highly uncertain, since APT fuels still are in their early stages of technologic development (Van Wee, personal communication, 2021).

To maximise the sustainable performance of the Hyperloop, governments invest heavily in the sustainable development of the Hyperloop infrastructure and operations. To achieve as much substitution from APT to Hyperloop as possible, its ticket prices are heavily subsidised, similar to current train tickets (De Kleijn, 2019). Moreover, traveling by APT is discouraged by a strict fossil fuel tax as brought forward by Peeters & Melkert (2021).

By building fewer Hyperloop hubs, a more frugal Hyperloop system is implemented which costs less money and carbon emissions to build. Thereby the system relies more on the existing PT system, which is why the access-egress time to Hyperloop stations is relatively long. For the same frugality reasons, fewer vacuum pumps and thinner tube walls are installed, resulting in a less strong vacuum within the tube and therefore slower travel speeds. Slower travel speeds result in an equally long travel time of Hyperloop and APT on a stretch of 650 kilometers.

Table 7.2: Hyperloop & APT aspects under MSTS introduction scenario

System aspect	Value
Hyperloop	
Ticket price	€100,-
Travel time	1 hour 15 minutes
Access-egress time	1 hour 30 minutes
Sustainability	More sustainable than APT
APT	
Travel cost	€150,-
Travel time	1 hour 15 minutes
Access-egress time	4 hours
Sustainability	Not sustainable

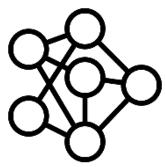
The 'Mass Sustainable Transport System' scenario causes Hyperloop and (to a smaller extent) other electrified transport modes such as trains, electric cars and buses to dominate the long-distance transport market (see table 7.3). This can mainly be attributed to Hyperloop's sustainability and lower ticket prices. The relatively long Hyperloop travel time and sparse Hyperloop hub network do not show to discourage travellers from choosing Hyperloop. This comes to no surprise since traveling with APT including its long access-egress time still takes longer.
Although the variation between different future contexts is small, the lowest market share of APT is observed under the context in which Carbon Social Norms are strict and many travellers already occasionally use the Hyperloop (e.g. in later stages of Hyperloop implementation). Since APT is assumed to remain equally unsustainable in the scenarios as its current form, strict Carbon Social Norms prove to divert traveller away from it.

Table 7.3: Market shares under MSTS introduction scenario

	Future contexts		**Potential market shares**		
	Carbon Social Norms	**Market Penetration of Hyperloop**	**Hyperloop**	**APT**	**Other**
Context 1	Lenient	Low	62.91%[5]	2.21%	34.88%
Context 2	Lenient	High	64.92%	2.07%	33.01%
Context 3	Strict	Low	60.41%	2.14%	37.45%
Context 4	Strict	High	62.48%	2.01%	35.51%

7.2.3 Daily Urban Transport System

A second discourse regarding the Hyperloop system is its potential to increase connectivity between cities and regions, transforming them into a Daily Urban System (Abeling et al., 2016; Hardt Hyperloop, 2019a). For example, people are enabled to work in Berlin and live in Amsterdam due to the shortened travel time by Hyperloop.



This discourse will probably be most supported by regional governments looking to create stronger economic ties to each other. The main advantage of Hyperloop would be its potential to alleviate congestion and increase transport efficiency for >200 km transport (Shetty, 2019). Regional

[5] The number of decimal points is solely used to portray the difference in market shares. It does not indicate the level of certainty.

governments have historically shown to be driving forces behind most infrastructure projects (Mook, personal communication, 2021). This discourse thus creates an economic driving force behind Hyperloop implementation. Another advantage of this discourse is its independence of the evolution in sustainable APT fuels. If this economic discourse is decisive in the decision-making for Hyperloop implementation, Hyperloop's relative sustainable impact and therefore development of sustainable APT fuels matter less.

Here, the Hyperloop infrastructure plays a central role in connecting multiple economic zones, which brings the need for fast and cheap commuting trips. Much is invested in the Hyperloop infrastructure to increase the number of Hyperloop hubs and accelerate Hyperloop speeds. This results in a less frugal transportation system that has a worse overall environmental life-cycle performance than APT. As economic reasoning still holds the dominant position over environmental reasoning, APT fossil fuels are not taxed. However, the Hyperloop system is expected to introduce fierce competition to budget carrier airlines which mostly operate on short flight distances (Boersma, personal communication, 2021). This may cause them to be pushed out of the market, which is why the average APT ticket prices are assumed to increase.

Table 7.4: Hyperloop & APT aspects under DUTS introduction scenario

System aspect	Value
Hyperloop	
Ticket price	€100,-
Travel time	50 minutes
Access-egress time	30 minutes
Sustainability	Less sustainable than APT
APT	
Ticket price	€100,-
Travel time	1 hour 15 minutes
Access-egress time	4 hours
Sustainability	Not sustainable

The Daily Urban Transport System (DUTS) introduction scenario also causes a large market share for Hyperloop together with other transport modes (see table 7.5). APT still retains some market share, however, it has lost its dominant position on the market. Namely, it has lost its traditional economic advantages over other transport modes. The access-egress time to airports is much longer than that of Hyperloop and ticket prices are not competitive. However, since Hyperloop is less sustainable compared to APT, some travellers still stick to flying and other transport modes instead of riding a Hyperloop.

When comparing to the MSTS introduction scenario, the low Hyperloop travel times under the DUTS scenario don't show to cause a higher overall market share. Here, the worse sustainable performance by Hyperloop mainly decreases its potential market share.

Table 7.5: Market shares under DUTS introduction scenario

	Future contexts		**Potential market shares**		
	Carbon Social Norms	**Market Penetration of Hyperloop**	**Hyperloop**	**APT**	**Other**
Context 1	Lenient	Low	49.29%	6.29%	44.43%
Context 2	Lenient	High	51.51%	5.96%	42.52%
Context 3	Strict	Low	46.79%	6.03%	47.17%
Context 4	Strict	High	49.03%	5.73%	45.24%

Especially under the potential context where carbon social norms are strict and Hyperloop is not yet used by many travellers, Hyperloop market share is smaller.

7.2.4 Premium Transport System

The third introduction scenario of Hyperloop relates to the discourse that states that Hyperloop is likely to be limited to the premium transport market of high-income and business travellers (van Goeverden, Milakis, et al., 2018). Not surprising, this discourse is mainly supported by critics of Hyperloop (Shetty, 2019). This introduction scenario could likely occur by a laissez-faires attitude of governments, with little government support.
In contrast to other scenarios, an optimal ticket price is chosen based on recovery of infrastructure costs.

It is doubtful that this introduction scenario would occur, since the public effort needed to implement the Hyperloop would exceed the societal benefits: National and regional governments, the European Union, rail (infrastructure) operators and many other stakeholders would still be needed to oversee implementation of the Hyperloop into the existing transport landscape (Wesdorp, personal communication, 2021). Since mostly the premium transport market is served by the Hyperloop, its doubtful if public bodies are willing to engage in this introduction scenario.

To directly compensate for the investment costs of the Hyperloop infrastructure, ticket prices are set very high. Thus, government spending on ticket subsidies is marginal. The capacity of the Hyperloop system here is deemed to remain limited which further increases the costs and therefore ticket prices per traveller. For the other Hyperloop system aspects, an average value is chosen between the other two scenarios. APT system aspects are assumed to remain equal to the current values.

Table 7.6: Hyperloop & APT aspects under PTS introduction scenario

System aspect	Value
Hyperloop	
Ticket price	€200,-
Travel time	1 hour 15 minutes
Access-egress time	1 hour
Sustainability	Equally sustainable as APT
APT	
Travel cost	€50,-
Travel time	1 hour 15 minutes
Access-egress time	4 hours
Sustainability	Not sustainable

The Premium Transport System scenario shows the lowest potential market share for Hyperloop, whilst APT retains current market shares. To no surprise, the highest adoption rate of Hyperloop under this scenario comes from business travellers and travellers with higher incomes. Thereby this introduction scenario displays the workings of the discourse of the Hyperloop as a premium transport mode, which is mostly accessible for business flyers and higher-income travellers. Table 7.7 presents the potential market shares per traveller subcategory, since these are most interesting for this introduction scenario. The same distributions are also presented for the other introduction scenarios under appendix E.
Interestingly, APT is still competitive, especially to frequent flyers. This group still prefers to use APT

or ride the Hyperloop in this scenario. Namely, they prefer APT and also care less about the unsustainable performance of Hyperloop.

Table 7.7: Market shares per traveller subcategory

	Hyperloop	APT	Other
Overall	16%	20%	63%
Purpose			
Non-business	14%	21%	65%
Business	33%	15%	53%
Age			
20-30	14%	24%	62%
30-60	19%	16%	65%
60+	17%	17%	66%
Income			
Low	13%	26%	62%
Middle	15%	20%	65%
High	22%	14%	64%
Flight Frequency			
1< per year	14%	14%	72%
1 – 2 times per year	16%	21%	63%
>3 per year	20%	27%	53%

The different contexts show to have similar workings on the Premium Transport System scenario compared to other scenarios. Strict carbon social norms mainly divert travellers away from APT and Hyperloop to other transport modes (see table 7.8). An increased Market Penetration of Hyperloop causes more travellers to divert to Hyperloop (i.e. higher market penetration), which is an accelerating effect on itself.

Table 7.8: Market shares under PTS introduction scenario

	Future contexts		**Potential market shares**		
	Carbon Social Norms	**Market Penetration of Hyperloop**	Hyperloop	APT	Other
Context 1	Lenient	Low	16.04%	20.50%	63.47%
Context 2	Lenient	High	17.19%	20.18%	62.63%
Context 3	Strict	Low	14.91%	19.23%	65.86%
Context 4	Strict	High	16.00%	18.95%	65.05%

7.3 Deliberation on scenarios

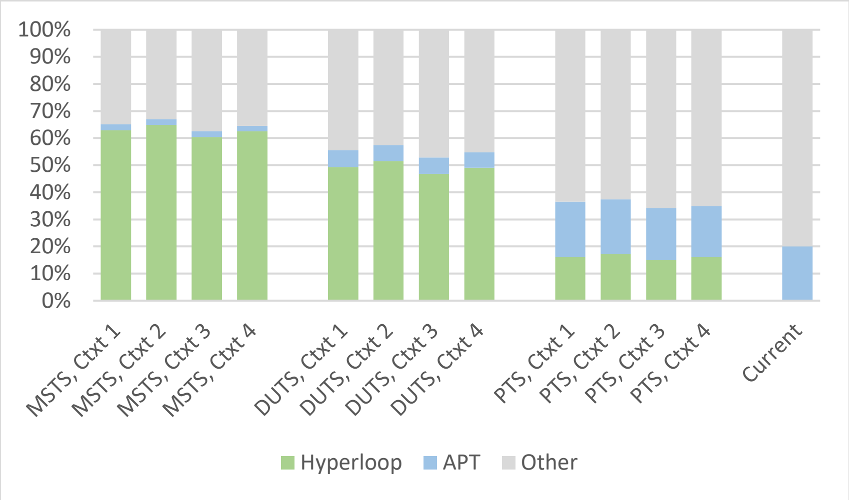


Figure 7.2: Market shares of Hyperloop introduction scenarios, per future context

Market shares vary largely between the introduction scenarios (see figure 7.2), with Hyperloop potentially gaining a significant market share in most scenarios. Logically, the Mass Sustainable Transport System (MSTS) introduction scenario shows the largest market dominance of Hyperloop due to its highly favorable ticket prices and environmental performance. With regard to infrastructure costs, MSTS is the most cost-effective introduction scenario. Namely, it gains more market share than the second-highest market shares scenario, DUTS, with a more frugal transport system.

The DUTS scenario, however, likely stands to gain much demand from extra generated (i.e. induced) demand. As travellers are enabled to commute between distant cities by Hyperloop, additional trips are likely to take place.

Lastly, the Premium Transport System (PTS) scenario causes the least substitution by Hyperloop. Only a small portion of the traveller population can afford the transport mode. On the other hand, under the PTS scenario, mostly frequent (higher income and business) travellers use the Hyperloop. This means the PTS market share based on actual number of Hyperloop rides would be somewhat larger.

Besides the classical economic determinants of travel behavior, travel time and cost, sustainability performance of the transport modes has a respectable impact on market shares. The future contexts presented in this study show to have some, but marginal effects on the mode choice behavior of travellers. Only when future contexts have an impact in favour of the same transport modes, market shares shift several percentage points.

8. Concluding remarks

This chapter concludes the research. First, the findings of this research are concluded (section 8.1) and discussed (8.2). Afterward, policy and design recommendations are provided (8.3), followed by the limitations and the subsequent future research recommendations (8.4).

8.1 Conclusion

Reaching the Paris Climate Agreement by 2050 is currently one of the largest societal challenges. Air Passenger Transport (APT) in its current form hampers emission reductions of the passenger transport sector due to its large environmental impact and evermore growing market share. The Hyperloop might become part of the solution due to its electric propulsion in combination with competitive travel times to APT.

However, studies so far mostly address the technical feasibility of Hyperloop instead of its potential travel demand from travellers. Travel demand forecasts including Hyperloop so far have remained relatively straightforward. Accurate information on this topic is relevant to society, since expected travel demand is an important part of the Hyperloop's financial feasibility. Furthermore, since the Hyperloop is to be fully launched by 2030 at the earliest (Virgin Hyperloop, 2018), travellers' tastes and preferences for Hyperloop are expected to be different due to changing decision-making contexts. To account for these issues, the following main research question was posed:

To what extent will different Hyperloop introduction scenarios and future decision-making contexts influence travellers' choices between APT, Hyperloop and other transport modes?

The main research question is broken down into several sub-questions which are answered separately to be able to answer the main research question.

1. ***To what extent do mode preferences, travel time, travel cost, access- and egress time and mode sustainability affect the travellers' choice between APT, Hyperloop and other transport modes?***

Much of what we know from APT – High-Speed Rail competition can also be applied to the APT-Hyperloop competition. However, travellers showed to be less time-sensitive and more cost-sensitive compared to previous research (Kouwenhoven et al., 2015). These results indicate means that more gains in the competitive potential of Hyperloop could stem from ticket price reductions as opposed to travel time reductions.

In contrast, this research breaks the expectation one would get from previous research concerning sustainability in transport mode choices. Namely, travellers alter their travel behavior based on its sustainable impact, an effect which has not been identified in previous air travel behavior (Alcock et al., 2017; Gössling et al., 2020). These results indicate that the Hyperloop appears as a potentially environmentally-friendly alternative that enables travellers to act on their environmental concerns. Whereas currently, APT is the only competitive choice for long-distance travel.

Lastly, travellers in this research preferred APT and Hyperloop over other transport modes, when all else is equal. Subsequently, the Hyperloop was preferred over APT. Beforehand it was expected that Hyperloop would be less preferred by travellers as they have not been able to witness it first-hand.

However, the opposite showed to be true, most likely due to the high level of familiarity of Hyperloop in the sample.

2. ***To what extent do the future contexts regarding carbon social norms and Hyperloop market penetration levels influence traveller's choices between APT, Hyperloop and other transport modes?***

The results opens the door for more research towards the effects of future contexts on demand forecasts of transport innovation. Namely, the studied future contexts had a (somewhat small) impact on travellers' choices between APT, Hyperloop and other transport modes. These results show that future contexts in Stated Choice Experiments (SCE) can account for background effects that currently are not reality or at least not to a large extent.

Findings underpin the potential impact of carbon social norms on travel behavior, which has not yet established itself in observed air travel behavior (Gössling et al., 2020). When a traveller's significant others frequently react negatively to carbon-heavy transport modes, the traveller shows to divert away from APT and Hyperloop, towards electric cars, buses and trains.

It was found that Hyperloop market penetration has an accelerating feedback effect on itself, which is important to take into account for Hyperloop introduction. In further stages of Hyperloop implementation (i.e. more travellers have had a positive hyperloop experience), travellers show to perceive Hyperloop as more safe, comfortable and easier to use than APT. Only to a small extent did respondents show to associate market penetration levels with peer pressure and social status effects. In other words, Hyperloop's competitive potential stands to grow 'automatically' over different implementation stages, due to the social dynamics of market penetration.

3. ***To what extent are respondents able to familiarise themselves with future contexts in the focal research?***

Even though the question remains how respondents would react to the presented future contexts in real life, the results show that they can adapt to future contexts in SCE. Under the settings set by the survey, respondents proved to be able to familiarise themselves with the future contexts relatively well. Several challenges were expected to arise for respondents facing the future context situation. Of these challenges, understanding the future contexts proved to be less troublesome than imaging the future contexts for one's social environment. Moreover, the interpretation of future contexts effects appeared to be intuitive and younger travellers proved to care more for the market penetration context. This indicates an acceptable level of uncertainty surrounding the hypothetical bias of future contexts.

4. ***How do Hyperloop perceptions, travel behavior, prior Hyperloop familiarity and socio-demographic variables influence travellers' choice between APT, Hyperloop and other transport modes?***

Results indicate that different traveler subcategories show much different adoption levels of Hyperloop. Thus, the competitive potential of Hyperloop among travellers is nuanced and subsequent feasibility studies and marketing strategies should take note of these differences.

Hyperloop & APT perceptions, Hyperloop familiarity
Currently, Hyperloop and APT are perceived differently by different travellers, which has a strong impact on those travellers' mode preferences. Of the perceptions, it appeared that safety and excitement perceptions by travellers were found to be the most important predictors of Hyperloop

and APT preferences: the more exciting and safe a traveller found the Hyperloop over APT, the higher is or her preference for the Hyperloop. Here, the perceived sustainability and familiarity with Hyperloop also predicted one's Hyperloop (dis)like to some extent. In conclusion, focusing on the safety and excitement of Hyperloop in marketing and infrastructure design will yield the most effect.

Travel behavior & socio-demographic variables
Results show that high-income and business travellers are the segments which stated to ride the Hyperloop the most of all segments, when Hyperloop ticket prices are expensive. Much similar to previous research, high-income and business travellers show to have a lower sensitivity to (Hyperloop) ticket prices. In contrast, however, high-income travellers also have a less pronounced preference for Hyperloop and APT over other transport modes. This can most likely be explained due to the higher car ownership rates under higher-income groups and the willingness-to-pay for high train ticket prices. In conclusion, ticket prices of Hyperloop are perceived as less burdensome to high income travellers, although their lower preference for Hyperloop somewhat keeps them from massively switching to Hyperloop.

Frequent flyers show to be less impressed by the Hyperloop and its sustainable potential. They show to have a higher preference for APT and care less about the sustainable performance of the Hyperloop. This means the classic economic determinants of travel behavior, travel time and cost, will mostly determine the competitive potential of Hyperloop for this segment.

Lastly, older travellers show to be much less sensitive to market penetration levels of the Hyperloop. It is expected that these travellers rely less on the peer observation information and peer pressure effects which are embodied by market penetration effects.

5. ***To what extent does heterogeneity exist amongst traveller segments regarding their sensitivity to mode attributes and mode preferences?***

The competitive potential of Hyperloop versus APT and other transport modes is largely different for two different traveller classes. Two classes show to regard their transport mode choice much different compared to the other: the 'economic traveller' (56% of the sample) and the 'sustainable traveller'(44% of the sample). Frequent flyers are more likely to belong to the economic traveller class, that cares more for travel time and cost, cares less about Hyperloop sustainability and does not mind flying. On the other hand, there is the sustainable traveller, that has a large overall dispreference for APT and cares much more about the sustainable performance of the Hyperloop. Identification of these traveller classes corroborates a different finding from this study. Namely, frequent flyers in this study have a lower sensitivity to Hyperloop sustainability.

Furthermore, these findings show an overall shift towards sustainability by travellers. Namely, Gaker & Walker (2013) also found two different traveller groups based on their sustainable tendencies in travel behavior. However, the findings of this research indicate a much larger environmentally friendly traveller segment and the economic traveller segment does show to be somewhat sensitive to sustainability. Similar to the other results regarding sustainability, this shift could be explained by the sustainable potential of Hyperloop, which offers a competitive sustainable alternative to flying.

6. ***Based on different Hyperloop introduction scenarios, what potential market share can a Hyperloop system take over from APT and other transport modes on the focal hypothetical transport corridor under different contexts?***

The results indicate that it matters greatly how the Hyperloop is introduced into the transport landscape, with much difference in Hyperloop market share between introduction scenarios. To maximise the societal benefits such as economic and sustainability benefits, active involvement and financial aid from governments is required. The future contexts show some effect on market shares, although not much. Overall, Hyperloop is very competitive with regards to APT and other transport modes.

Three different Hyperloop introduction scenarios have been delineated and potential market shares were estimated for different traveller segments under different future contexts. The introduction scenarios were composed of different Hyperloop and APT designs. These alternative designs relate to different discourses regarding Hyperloop which currently revolve in academia, industry and governments.

It showed that Hyperloop is very competitive under most introduction scenarios and future contexts. Even under unfavorable introduction scenarios and unfavorable contexts settings, Hyperloop gains a large market share, albeit for high-income and business travellers. The introduction scenario with the most Hyperloop market share is the one where Hyperloop is cheap and more sustainable than APT, even though the Hyperloop is relatively slow.

These findings display how travellers react to different introduction scenarios, which can be of interest to future feasibility studies. Also, the Hyperloop can be further assessed on its financial feasibility. Assessment can be based on investment costs per introduction scenario, the likelihood of the introduction scenario and future context occurring, combined with the subsequent societal value and ticket revenues generated by the Hyperloop.

8.2 Discussion

This section presents several aspects of the research which are expected to influence the interpretation and usability of the results.

Hypothetical bias of the Stated Choice Experiment

Arguably the most important discussion point of this research is the underlying data collection. This was done via a Stated Choice Experiment in which travellers made hypothetical choices under future context situations. Since the Hyperloop is still a hypothetical transport mode and presented future contexts do not yet (fully) exist, a SCE proved to be the most viable option to address the research questions. However, market shares that followed from the SCE should be interpreted with care due to a potential bias created by the following aspects.

Biased and changeable preferences

The setting of the survey could have added to a biased preference for Hyperloop over other transport modes in three different ways. First, the question remains how people will react to the perceived safety of Hyperloop if they can board the transport mode. A hypothetical choice situation harbors no actual risks, whereas a real choice situation does so. Moreover, the recruitment of respondents and introduction to Hyperloop in the survey might have left unintentional cues for respondents to prefer Hyperloop as a transport mode. The Hyperloop is expected to have stood out mostly for respondents in the recruitment.

Secondly, the perceptions of Hyperloop and other transport modes represent those as of 2021, which can still change much before implementation. For example, Hyperloop might become regarded as very unsafe by travellers after one failed test drive [6].
Lastly, perceptions might change among Hyperloop travellers after an initial phase which is marked by enthusiasm. After the initial phase, enthusiasm revolving around the novel transport mode could naturally evolve towards either positive or negative perceptions which will more permanently determine its success.

Dynamics surrounding future contexts
Respondents have shown to be able to familiarise presented future contexts relatively well. However, due to the social aspects of the contexts, it is uncertain how accurate the research has estimated people's sensitivity to them. Social interactions and subsequent familiarisation of social norms are complex (Gavrilets & Richerson, 2017), which were part of the presented future contexts. Even though it is expected that the order of magnitude is estimated reasonably well, the impact of carbon social norms and market penetrations contexts remain at the outcome of unpredictable complex social dynamics.

Moreover, if one of the future contexts does not unfold in the future, estimated market shares will be either somewhat over- or understated, relative to the found impact of that future context. Namely, all choices in the SCE were made under the presented future context situations. However, since it is expected that carbon social norms will very likely have some form of social impact and Hyperloop will very likely gain at least some market penetration, the chance of neither occurring is doubtful.

Overstated importance of sustainability
Lastly, respondents in this research have acted more environmentally friendly than is currently observed in reality. Previous research indicates that travellers seldomly change their observed air travel behavior for environmental causes (Gössling et al., 2020). However, this research did find a relatively high level of environmental consciousness in travellers' decision-making. This could be caused by the following three reasons:

The first being the hypothetical nature of the stated choice experiment. Kroesen (2013) underpins the attitude-behavior gap of sustainable behavior, which could also be the case for travellers in the survey. The observed (in this case socially accepted) stated choices could differ from their actual observed behavior. Secondly, the high level of education in the sample could have caused somewhat more environmentally friendly behavior (Achtnicht, 2012; Gaker & Walker, 2013). Namely, highly educated individuals are deemed to be more informed on the impact of climate change (Torgler & García-Valiñas, 2007). A third explanation could lie in the fact that the Hyperloop poses a competitive and sustainable transport mode to APT, which enables travellers to act on their environmental concerns.

Selection of mode attributes and levels
It is expected that a different selection of researched mode attributes would have displayed different competitive potential levels for Hyperloop. Namely, other aspects could also influence travellers transport mode choices, which were kept out of scope. For example, the Hyperloop could prove to be even more competitive compared to APT in reality due to its high departure frequency. This is also

[6] See for example the deadly 2006 MagLev train crash which caused much damage to its perceived safety (Hall, 2018)

seen as one of Hyperloop's advantages over other transport modes (Taylor et al., 2016).

The chosen attribute levels have likely also influenced the results. Some assumptions and simplifications have been made in the attribute level selection. This study has chosen three straightforward levels for Hyperloop sustainability: 'less', 'equal' or 'more' environmentally friendly than APT. In reality, however, sustainability performance levels are less straightforward (i.e. complex) and often open for debate. Also the Hyperloop access-egress attribute levels could prove to be more volatile than in the experiment. It was assumed that Hyperloop waiting time at airport is negligible, however, Hyperloop passengers might turn up around the same time, causing unexpected delays.

Sample bias
The research sample included many respondents from the (in)direct network of the researcher, which included many technical students or young professionals with an engineering background. It thus makes sense that the sample was already quite familiar with the Hyperloop, somewhat skewed towards low-income categories and predominantly younger than 30 years old. Expectedly, these aspects of the sample have added to the positive perceptions and preference measured for Hyperloop. Furthermore, the sample bias has likely biased both the sensitivity to travel costs and sustainability performance upwards. Here, especially Hyperloop travel costs are expected to be less impactful compared to travel time in reality due to the underrepresentation of high-income travellers.

Transport mode developments
In the Stated Choice Experiment, transport modes besides Hyperloop were mostly presented as their current form. The future forms of these transport modes could significantly alter the future competitive potential of the Hyperloop. Especially APT could prove to become more sustainable than its current form, pointing at the growing number of developments in sustainable fuels or electrification of airplanes (Peeters & Melkert, 2021). High-speed rail and electric cars are also aimed to be much improved on accessibility and usability (European Commission, 2020).

Questionable results
The Value of Time of travellers in the experiment is almost twice as low compared to Kouwenhoven et al.(2015). This could be caused by the relatively low average income of the sample and the lack of experienced travel time under travel restrictions of the Covid-19 pandemic. This means travellers are likely to be more time-sensitive in reality.

Strict carbon social norms represent a future context where many people express themselves negatively about the environmental impact of transport modes. However, no significant effect was found between strict carbon social norms and travellers' sensitivity to the sustainable performance of Hyperloop. Instead, strict carbon social norms were found to negatively impact travellers' overall preference for Hyperloop. This causes the Hyperloop market share estimations to decline under strict carbon social norms, even for situations where Hyperloop proves to be more sustainable than APT. It is expected that this resulted from the addition of the base alternative to the experiment. Another experimental setup would likely have resulted in a different and potentially significant impact of the abovementioned effect.

8.3 Policy & design recommendations

The policy & design recommendations are aimed at Hyperloop developers and governments who are looking to make the Hyperloop as competitive to travellers as possible.

Focus on Hyperloop ticket price instead of (access-egress) travel time

More gains for Hyperloop market shares can be brought forth by subsidised ticket prices, as opposed to reducing Hyperloop travel time. Whereas there is an expected small bandwidth for reducing Hyperloop travel times (about 25 minutes at a range of 650 kilometers), there is a broader bandwidth of ticket prices reductions to be made. Namely, cost-meeting ticket prices are currently estimated at approximately €200 (van Goeverden, Milakis, et al., 2018), which can still be reduced drastically with government subsidies. Moreover, travellers from this study have shown to be relatively more cost-sensitive than time-sensitive which makes ticket price reductions more effective. Also reducing the access-egress time from and to the Hyperloop proves to have little impact in comparison to ticket price reductions. This means less focus is needed on building a dense Hyperloop hub network to decrease access-egress time.

Here, the question remains for governments what their aim is for the Hyperloop and what their subsequent level of financial aid will be. If they seek to replace APT with the Hyperloop, a combination of flight taxes and high ticket subsidies have shown to be highly effective by this study.

Ensure life-cycle sustainability

It is recommended to ensure life-cycle sustainability for Hyperloop and point out its sustainable performance to potential Hyperloop travellers under marketing efforts. Namely, travellers weigh the sustainable impact of travel modes in their decision-making quite strongly in comparison to previous beliefs. It should be stressed that the environmental impact of Hyperloop also includes the construction emissions of the infrastructure. Travellers show to switch to other transport modes if Hyperloop does not perform better environmentally compared to APT. Specifically, almost half of the studied travellers value the sustainable performance of Hyperloop much more than their opposite half. Since the environmentally-friendly segment is quite sizeable, a positive sustainable impact of Hyperloop could much market share.

Target business travellers in marketing

Business travellers have shown to be the traveller segment with the highest adoption rate of Hyperloop under every introduction scenario. This is due to their relatively high insensitivity to ticket price. This traveller segment currently makes up 32% of all travellers at Schiphol airport due to their high flight frequency (KiM, 2018), which makes the potential environmental benefits of them switching to Hyperloop a lot more interesting. Moreover, in recent years many business travel managers have put more focus on reducing the environmental impact of their employees' travel behavior (Klein-Schiphorst, personal communication, 2021). This trend could therefore provide a foothold for Hyperloop by playing into that demand.

Accentuate Hyperloop safety, excitement and peer observation

In the competition between APT and Hyperloop, the relative safety perception of Hyperloop as opposed to APT proves to be beneficial to Hyperloop. In other words, travellers who perceive Hyperloop as safer than APT will more likely choose Hyperloop over APT. Similarly, travellers who perceive Hyperloop rides as more exciting than flying will more likely choose Hyperloop over APT. Especially in the early phase of Hyperloop implementation, these perceptions could play a large role in Hyperloop adoption.

Parallel to stimulating certain perceptions, Hyperloop promoters should focus on peer observation effects in their marketing. Namely, it has shown that (especially younger) travellers react positively to hearing about positive Hyperloop experiences by family and friends. Travellers mainly deem Hyperloop to be more safe, comfortable and easy to use if many friends and family have already had positive experiences with the Hyperloop. Marketing campaigns should therefore also focus on revealing the (positive) experiences of travellers to another. For example, discount schemes could be applicable here, where travellers can provide discounts to family and friends after their Hyperloop ride. It is expected that these tactics will evoke information exchange between travellers.

8.4 Limitations and Future Research Recommendations

The following section presents several limitations of this research alongside subsequent future research recommendations.

Researching future contexts
A hybrid approach was chosen between varying Hyperloop mode attributes and two future contexts. This was done to account for the current uncertainty of Hyperloop mode attributes and the relative sensitivity of travellers between mode attributes and future contexts. Increasing the number of future contexts in the SCE could prove useful in gaining more insightful findings for the usability of future contexts in stated choice experiments. Expectedly the complexity for respondents will rise with more presented future contexts in the SCE, however, this will enable the researcher to seek the boundaries of respondents' imaginative abilities. To achieve that whilst tempering the choice task burden for respondents, transport mode attributes could be held constant under varying context situations.

The initial list of potential future contexts for this research was derived from transport forecasting literature and policy documents, after which the found contexts were discussed in expert interviews. However, this process mainly amounted to future alternative transport modes or innovation of current transport modes. To perform a better evaluation of possibly relevant future contexts, another approach that includes an ideation phase with more creative inputs could be useful.

Other sources of Hyperloop travel demand
Three different sources of Hyperloop travel demand are considered to be relevant for future research, besides the substitution of APT by Hyperloop. Firstly, Hyperloop is also expected to generate new trips due to its short travel times and short access-egress travel time. Thereby, travellers are enabled to commute between cities that were deemed too far to commute before. Secondly, only direct origin-destination trips were considered for this research. However, a synergy between intercontinental flights and continental Hyperloop transportation could prove to be another large source of Hyperloop travel demand. Lastly, non-flying travellers were left out of scope since the substitution of APT by Hyperloop was the central research focus. However, non-flyers might prove to be an interesting source of demand for Hyperloop, since a part of their concerns is related to flight fear and the environmental impact of APT (Kennisinstituut voor Mobiliteitsbeleid, 2018).

Relationship Hyperloop familiarity, perceptions, early adopters, information provision and preferences
This research has found a positive effect between a travellers' familiarity with Hyperloop and his or her preference for the Hyperloop over other transport modes. However, it remains unclear how the two variables relate precisely. Two explanations can be derived from literature.

From the Diffusion-of-Innovation theory by Rogers (1962), one can postulate that this is an inherent characteristic of early adopters, who have an overall technology-optimistic attitude and are generally well-informed on technology innovation. Their overall technology-optimistic attitude explains their preference for the Hyperloop, whereas their familiarity with Hyperloop is somewhat of a byproduct. A second explanation is posed by Planing et al.(2020) who points at the increased level of exposure to Hyperloop information. Namely, increased exposure to positive Hyperloop information increases a travellers' familiarity with the concept, which increases his or her willingness-to-adopt the Hyperloop. This explanation is corroborated by the Knowledge-Attitidude-Behavior model which states that 'a person's knowledge directly affects his/her attitudes, and indirectly affects behaviors through his/her attitudes' (Yi & Id, 2018, p.3).

Whereas the early-adopter explanation postulates that increased education of travellers would not increase travel demand much, the latter explanation suggests the opposite. This, of course, has repercussions for potential Hyperloop demand. In conclusion, future research towards the relation between Hyperloop familiarity, Hyperloop perceptions, early adopters and information provision could be essential to understanding dynamics concerning demand forecasts of transport innovation.

Specification of Hyperloop infrastructure performances

This research' scenario analysis was performed relatively straightforward due to a lack of available information on Hyperloop infrastructure design. Thereby, scenarios were based on strong assumptions regarding the relationship between Hyperloop sustainability performance, travel speeds, infrastructure design and required investment costs. For future Hyperloop feasibility studies, however, this relationship should be further specified to perform more accurate scenario analyses. The findings of this research could subsequently be used to calculate the travel demand and sustainable impact per passenger kilometer, based on the calculated Hyperloop performances.

Improving validity of this research

As delineated under the discussion, this research could benefit from a more representative sample and addition of other mode attributes. Roughly speaking, the sample consisted of many technical students and highly educated young professionals with an engineering background. It is therefore most likely that another sample would have resulted in less cost-sensitive, less sustainable behavior and a lower preference for Hyperloop. Furthermore, several mode attributes which show to be important to the HSR-APT competition were left out of scope to reduce respondents' choice task complexity and burden. These were service frequency of the transport mode, reliability of a timely journey and other factors related to service (Dobruszkes et al., 2014). The Hyperloop is expected to gain much of its competitive potential from service frequency and reliability, especially to business travellers who are in a hurry to return home (Klein-Schiphorst, personal communication, 2021).

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Appendix A: Hyperloop attributes

A.1 Hyperloop travel time calculation

It is assumed that the Hyperloop will roughly follow rail tracks to make optimal use of already claimed land. This roughly translates to 650 kilometers from Amsterdam to Berlin (1map.com, 2021), which corresponds to a HSR travel distance of 6 hours on which HSR competes only to a small extent with APT (Janic, 2003). To arrive to Hyperloop travel times, the average travel speed is taken over several proposed Hyperloop routes from around the world and multiplied by 650.

Table 0.1 presents the average speeds as used in different proposed Hyperloop tracks from around the world by different Hyperloop development companies. Routes which were proposed for implementation in India showed average speeds which varied closely around theoretical top speed of 1000 km/h, which was deemed to be unrealistic given acceleration and deceleration times. Therefore, the Hyperloop travel time was varied between the average found as posed by Hardt Hyperloop and the average which also included those routes as presented by Hyperloop One.

Table 0.1: Proposed Hyperloop routes

Route	Travel Time (Hours)	Distance (km)	Avg Speed (km/h)	Source
Schiphol – Gare du Nord	1.0	550	550	Hardt Hyperloop
Schiphol – Frankfurt Hbf	0.9	440	498.1	Hardt Hyperloop
Average by Hardt Hyperloop			*524.1*	
Average Travel Time on 650 km	*1.2*			
Glasgow – Liverpool	0.8	545	695.7	Hyperloop One
Mexico City – Guadalajara	0.6	532	840	Hyperloop One
Toronto – Montreal	0.7	640	984.6	Hyperloop One
Cleveland – Chicago	0.7	542.3	813.5	Hyperloop One
Average of routes above			*730.3*	
Average Travel Time on 650 km	*0.9*			
Bengalaru – Chennai	0.4	334	871.3	Virgin Hyperloop
Bengalaru – Thiruvananthapuram	0.7	736	1077.1	KPMG
Delhi- Mumbai	1.0	1317	1274.5	DGW
Mumbai -Chennai	1.1	1102	1049.5	Hyperloop India
Average including Indian routes			*872.6*	
Average Travel Time on 650 km	*0.7*			

A.2 Assumptions Hyperloop design

See (Delft Hyperloop, 2020):

- Hyperloop capsules are controlled from a distance by a manned control center
- In case of emergency there is an opportunity to contact the control center via an intercom. The control center can make the capsule perform an emergency brake.

See (Musk, 2013):

- The pressure on travellers' bodies during Hyperloop acceleration is comparable to the pressure experienced by airplane take-off

See (Virgin Hyperloop, 2021):

- Hyperloop stations are located near or around existing railway stations and airports

Appendix B: Experimental design

This appendix presents the Ngene syntax which has been used to come to the experimental design of the choice sets and one version of the final survey design.

```
design
;alts= APT, HL
; rows=18
; block=6
;orth=sim
;model:
U(HL)= b0 + b1*sush[0,1,2] + b2*tcosth[100,150,200] + b3*aeh[0.3,1,1.3] + b4 * ttimeh[0.5,1.3,2.1]/
U(APT)= b5*tcosta[50,100,150] + b6*ttimea[0.5,1.3,2.1]
$
```

Figure 0.1: Ngene syntax

Table 0.1: Ngene generated design

Choice situation	HL travel time *	HL travel cost	HL A-E Time*	Hyperloop sustainability**	APT travel time*	APT travel cost	Block
1	0.50	100,00	0.30	0	0.50	50,00	1
2	1.30	200,00	1.00	2	0.50	50,00	2
3	0.50	200,00	1.30	1	0.50	100,00	3
4	2.10	150,00	0.30	2	0.50	100,00	4
5	1.30	150,00	1.30	0	0.50	150,00	5
6	2.10	100,00	1.00	1	0.50	150,00	6
7	0.50	150,00	1.30	2	1.30	50,00	6
8	2.10	200,00	0.30	1	1.30	50,00	5
9	1.30	150,00	1.00	1	1.30	100,00	1
10	2.10	100,00	1.30	0	1.30	100,00	2
11	0.50	200,00	1.00	0	1.30	150,00	4
12	1.30	100,00	0.30	2	1.30	150,00	3
13	1.30	100,00	1.30	1	2.10	50,00	4
14	2.10	150,00	1.00	0	2.10	50,00	3
15	0.50	100,00	1.00	2	2.10	100,00	5
16	1.30	200,00	0.30	0	2.10	100,00	6
17	0.50	150,00	0.30	1	2.10	150,00	2
18	2.10	200,00	1.30	2	2.10	150,00	1

*Travel times are represented in hours.minutes.

**Hyperloop sustainability is coded as follows: 0 = less environmentally friendly than APT. 1=equally environmentally friendly as APT. 2=more environmentally friendly than APT.

Table 0.2: Final design: Survey version 1

Choice situation	HL travel time	HL travel cost	HL A-E Time	Hyperloop sustainability	APT travel time	APT travel cost	Block	Context profile
1	0.50	100,00	0.30	0	0.50	50,00	1	C0 & M1
2	1.30	150,00	1.00	1	1.30	100,00	1	C0 & M1
3	2.10	200,00	1.30	2	2.10	150,00	1	C0 & M1
4	1.30	200,00	1.00	2	0.50	50,00	2	C0 & M2
5	2.10	100,00	1.30	0	1.30	100,00	2	C0 & M2
6	0.50	150,00	0.30	1	2.10	150,00	2	C0 & M2
7	0.50	200,00	1.30	1	0.50	100,00	3	C1 & M1
8	1.30	100,00	0.30	2	1.30	150,00	3	C1 & M1
9	2.10	150,00	1.00	0	2.10	50,00	3	C1 & M1
10	2.10	150,00	0.30	2	0.50	100,00	4	C1 & M2
11	0.50	200,00	1.00	0	1.30	150,00	4	C1 & M2
12	1.30	100,00	1.30	1	2.10	50,00	4	C1 & M2

Appendix C: Interviewees

Table 0.1: Interviewees overview

Name	Company classification	Thesis-related expertise
Boersma	Airport	Airport strategy
Marges	Hyperloop developer	Hyperloop developments
Van Wee	Academia	Transport innovation
Mook	Consulting	HSR & Aviation economics and competition
Serra	Consulting	Mode choice, transport innovation
Mertens	Consulting	Transport innovation
Smit	Train operator	Hyperloop feasibility
Wesdorp	Rail Infrastructure	Rail-Hyperloop infrastructure integration
Bonsen	Hyperloop student team	Hyperloop engineering design
Klein-Schiphorst	Business travel management	Business travel developments

Appendix D: Model estimation

D.1 Coding of context levels & attributes

As the Hyperloop sustainability and the contexts are categorical variables, their attribute levels as varied in the SCE should be coded. This can be done either through dummy coding or effects coding, which mostly differ from another in interpretation of the parameters. They do not cause different estimates for utility differences between attribute levels (Molin, 2019c). However, this research prefers to use effects coding.

In dummy coding the reference level is confounded with the fixed constant, as both have value zero (Bliemer et al., 2017). This is not the case in effects coding. Effects coded attribute levels represent the difference from the average utility contribution of the variable, which can generally be seen as the ASC of that alternative in case all alternatives derive the same utility from their attributes (Molin, 2019a, 2021). Furthermore, there is no clear base level across all alternatives and context levels, which would be a situation where why dummy coding could be preferred.

Table 0.1: Applied effects coding

Variable	**Effects coded variables**	
Hyperloop sustainability	HLSMore	HLSEqual
More environmentally friendly	1	0
Equally environmentally friendly	0	1
Less environmentally friendly	-1	-1
Carbon social norms	CSN	
Rarely negative	-1	
Often negative	1	
Market penetration	MP	
1 out of 10	-1	
9 out of 10	1	

D.2 Model performance indicators

- LogLikelihood

The LogLikelihood is the output of the Maximum Likelihood Estimation procedure as described under section 5.1. It denotes the model fit on the data. In other words, it denotes the fit of the estimated parameters on the data.

- **McFadden's Rho Squared**

To be able to comment on the model fit the Mcfadden's Rho Squared is reported alongside the model estimation. It denotes the percentage of the initial uncertainty explained by the model (Chorus, 2019). The null model LL_0 presents the LogLikelihood for the starting values of the parameters (which are generally set at 0), which is comparable to 'throwing a dice'. Subsequently, the LL_β is the LogLikelihood of the model including the estimated parameters and is divided by the LL_0 which results in the inverse of the rho-squared.

$$\rho^2 = 1 - \frac{LL_\beta}{LL_0}$$

Where:

ρ^2 = McFadden's Rho Squared

LL_β = LogLikelihood of the estimated model

LL_0 = LogLikelihood of the null model

- **The Likelihood Ratio Statistic**

To compare the model fit of two nested models (i.e. one model is a 'submodel' of the other), the Likelihood Ratio Statistic (LRS) is used. The LRS value is subsequently compared to the threshold value of the chi-squared χ^2 table. This table sets out threshold values based on the number of added parameters to the model, thereby setting a 'penalty' for the numbert of parameters used (Chorus, 2019). The more parameters are added to the model, the higher the threshold value is.

$$LRS = -2 * (LLa - LLb)$$

Where:

LLa = LogLikelihood of the parsimonious model

LLb = LogLikelihood of the model with increased number of parameters

- **Bayesian Information Criterion (BIC)**

When comparing two models which are not nested, the Bayesian Information Criterion can be used. This performance indicator is of good use for comparing different LCCM models, when determining the appropriate number of classes (Molin & Maat, 2015). Essentially, as LCCM models tend to overfit the data, a penalty is set for the number of estimated parameters k. The more parsimonious a model is whilst achieving a better model fit LL, the lower (i.e. better) BIC value is reported.

$$BIC = -2 * LL + k * \ln(N)$$

LL = Final LogLikelihood

k = number of estimated parameters

ln(N) = logarithm of N

N = amount of observations (respondents multiplied by amount of choice sets per respondent)

D.3 Basic MNL Model

D.3.1 Adding base alternative

D.3.1.1 Model Estimation

As mentioned under section 3.1.2, non-linear effects for the travel cost and time parameters are tested. However, none of the specified non-linear effects were found to be significant at the 5% significance level or even at the 10% significance level. Therefore only linear parameters are estimated in the simple MNL model.

As the base alternative 'Other transport mode' does not include any attributes, the Maximum Likelihood Estimation procedure cannot derive any information on the trade-offs between mode attributes for the observations in which the base alternative was chosen (Molin, 2019b). To test whether the addition of the base alternative has a negative impact on model estimation, two simple MNL models are estimated. One including the base alternative (3 alternative model) and one excluding the base alternative (2 alternative model).
Interestingly, the 3 alternative model performed better than the 2 alternative model when looking at the estimated parameters. Namely, the effect of Hyperloop being equally sustainable compared to APT was more pronounced in the 3 alternative model compared to the 2 alternative model[7]. This is in line with expectation: If Hyperloop is equally unsustainable as APT, the decision-maker will be more inclined to pick another transport mode. Simultaneously, equal sustainability performance levels will likely play a role in the trade-offs between APT and Hyperloop when solely choosing between those alternatives. The other parameters were found to be almost equally pronounced in both models.

Table 0.2 presents the model performance of the 3 alternative versus 2 alternative model. The two model performances cannot be directly compared based on model performance indicators as the dataset is different in the sense that respondents were deemed to have more choices in the 3 alternative model.

Table 0.2: Model performance 2 alternatives vs 3 alternatives model

Model	Final LL	Rho-Square	Adjusted Rho-square
2 alternatives	-1.256.853	0.0629	0.259
3 alternatives	-2.253.297	0.167	0.163

[7] Both the utility contribution as the p-value of the corresponding parameter are larger in the 3 alternative model. The standard error was approximately equal in both models. This makes sense, since the p-value (via the t-test) relies on the utility contribution and the standard error.

Estimation results of the model excluding the base alternative:

Table 0.3: Estimation results 2 alternative model

Name	Value	Std err	t-test	p-value	Robust Std err	Robust t-test	p-value
ASC_HYPERLOOP	2.59	0.331	7.81	0.00	0.319	8.11	0.00
APT_TravelCost	-0,0191	0.00138	-13.86	0.00	0.00140	-13.69	0.00
APT_TravelTime	-0,0105	0.00163	-6.45	0.00	0.00165	-6.38	0.00
HL_Acces-Egress	-0,00991	0.00214	-4.62	0.00	0.00215	-4.60	0.00
HL_SustainabilityEqual	0.0732	0.0719	1.02	0.31*	0.0717	1.02	**0.31***
HL_SustainalityMore	0.807	0.0805	10.03	0.00	0.0816	9.89	0.00
HL_TravelCost	-0,0188	0.00134	-14.00	0.00	0.00138	-13.62	0.00
HL_TravelTime	-0,0103	0.00162	-6.39	0.00	0.00166	-6.23	0.00

**Not significant at 5% significance level*

Estimation results of the model including the base alternative:

Table 0.4: Estimation results 3 alternative model

Name	Value	Std err	t-test	p-value	Robust Std err	Robust t-test	p-value
ASC_APT	1.12	0.223	5.02	0.00	0.214	5.24	0.00
ASC_HYPERLOOP	3.52	0.242	14.55	0.00	0.243	14.50	0.00
APT_TravelCost	-0,0164	0.00157	-10.43	0.00	0.00155	-10.57	0.00
APT_TravelTime	-0,00579	0.00182	-3.18	0.00	0.00183	-3.16	0.00
HL_Acces-Egress	-0,00679	0.00176	-3.86	0.00	0.00174	-3.89	0.00
HL_SustainabilityEqual	-0.113	0.0609	-1.86	0.06*	0.0600	-1.89	**0.06***
HL_SustainalityMore	0.539	0.0629	8.57	0.00	0.0619	8.71	0.00
HL_TravelCost	-0,0144	0.00109	-13.24	0.00	0.00108	-13.36	0.00
HL_TravelTime	-0,00726	0.00133	-5.47	0.00	0.00132	-5.50	0.00

**Not significant at 5% significance level*

The indicator variable which corresponds to the attribute level ‘equally environmentally friendly’ was not significant at the 5% significance level (p=0,06), however, it was still deemed to be insightful and was therefore kept in the model.

D.3.2.2 PythonBiogeme Syntax: Simple MNL Model

```
from biogeme import *
from headers import *
from loglikelihood import *
from statistics import *

#Parameters to be estimated
# Arguments:
#   - 1  Name for report; Typically, the same as the variable.
#   - 2  Starting value.
#   - 3  Lower bound.
#   - 4  Upper bound.
#   - 5  0: estimate the parameter, 1: keep it fixed.
#
ASC_HYPERLOOP = Beta('ASC_HYPERLOOP',0,-10,10,0,'Hyperloop cte.')
ASC_APT = Beta('ASC_APT',0,-10,10,0,'APT cte.')
ASC_OTHER = Beta('ASC_OTHER',0,-10,10,1,'Other cte.')
B_HLTT = Beta('B_HLTT',0,-10,10,0,'Hyperloop travel time')
B_HLTC = Beta('B_HLTC',0,-10,10,0,'Travel cost')
B_HLAE = Beta('B_HLAE',0,-10,10,0,'Hyperloop A-E')
B_HLSM = Beta('B_HLSM',0,-10,10,0,'Hyperloop SusIndicator1')
B_HLSE = Beta('B_HLSE',0,-10,10,0,'Hyperloop SusIndicator2')
B_APTTT = Beta('B_APTTT',0,-10,10,0,'APT Travel time')
B_APTTC = Beta('B_APTTC',0,-10,10,0,'APT Travel cost')


V1 = ASC_HYPERLOOP + B_HLTT * HLTT + B_HLTC * HLTC + B_HLAE * HLAE + B_HLSM * HLSM + B_HLSE * HLSE
V2 = ASC_APT + B_APTTT * APTTT + B_APTTC * APTTC
V3 = ASC_OTHER

# Associate utility functions with the numbering of alternatives
V = {1: V1,
     2: V2,
     3: V3}

# Associate the availability conditions with the alternatives

av = {1: HYPERLOOP_AV,
      2: APT_AV,
      3: OTHER_AV}

# The choice model is a logit, with availability conditions
logprob = bioLogLogit(V,av,CHOICE)

# Defines an itertor on the data
rowIterator('obsIter')

# DEfine the likelihood function for the estimation
BIOGEME_OBJECT.ESTIMATE = Sum(logprob,'obsIter')
```

D.3.2 Adding context effects

D.3.2.1 Model estimation

It was expected that Carbon Social Norms (CSN) would have an interaction effect on the sensitivity of travellers for the different Hyperloop sustainability performance levels. However, no significant interaction effects were found. Even though the parameter estimates were in the anticipated direction (strict carbon social norms increases sensitivity to sustainability performance levels), P-values of 0.51 and 0.42 were found for the indicator variables. This means there is little confidence that the found estimates could be generalised to the population. Interestingly, the interaction effects with the indicator values proved to be have a lower p-value (0.13 and 0.14) under the 2 alternative model. This leads to believe that the 3 alternative model provides less information on the interaction between CSN and the sensitivity to Hyperloop sustainability due to the information loss of adding the base alternative. It should therefore not be ruled out that the effect does exist in the population. Furthermore, because the sustainability score for APT was fixed, interaction between CSN and the sustainability attribute is likely caught by the constant. The constant proved to be impacted by CSN.

Also, the parameter that represents the effect of Carbon Social Norms on the constant of APT (B_APT_CSN) is not significant at the 5% significance level, however, it is kept in the model as it shows an expectable utility contribution with a somewhat acceptable p-value.

Table 0.5 presents the model performance of the context-dependent model compared to the simple MNL. The LRS value is higher than the χ^2 threshold value of 7,815 which indicates the context-dependent model has a better model fit than the simple MNL model.

Table 0.5: Model performance context-dependent model

Model	Final LL	Adjusted Rho-square	LRS	Chi-square (p= 0,05)
Simple MNL	-2.253	0.163		
Context-dependent	-2.248	0.164	11	7,815

Table 0.6: Model estimation context-dependent MNL

Name	Value	Std err	t-test	p-value	Robust Std err	Robust t-test	p-value
Constants							
ASC_APT	1.12	0.223	5.03	0.00	0.214	5.24	0.00
ASC_HYPERLOOP	3.53	0.242	14.58	0.00	0.243	14.55	0.00
APT parameters							
APT_TravelCost	-0.0164	0.00157	-10.43	0.00	0.00155	-10.55	0.00
APT_TravelTime	-0.00579	0.00182	-3.17	0.00	0.00184	-3.15	0.00
Hyperloop parameters							
HL_Acces-Egress	-0.00682	0.00176	-3.87	0.00	0.00174	-3.91	0.00
HL_SustainabilityEqual	-0.114	0.0610	-1.87	0.06*	0.0601	-1.90	**0.06***
HL_SustainalityMore	0.541	0.0630	8.59	0.00	0.0620	8.73	0.00
HL_TravelCost	-0.0144	0.00109	-13.27	0.00	0.00108	-13.39	0.00
HL_TravelTime	-0.00728	0.00133	-5.48	0.00	0.00132	-5.50	0.00
B_APTASC_CarbonSocialNorms	-0.103	0.0634	-1.62	0.11*	0.0640	-1.60	**0.11***
B_HLASC_CarbonSocialNorms	-0.112	0.0469	-2.39	0.02	0.0473	-2.37	0.02
B_HLASC_MarketPenetration	0.0939	0.0432	2.17	0.03	0.0428	2.20	0.03

**Not significant at 5% significance level*

D.3.2.2 PythonBiogeme Syntax: Basic MNL

```
from biogeme import *
from headers import *
from loglikelihood import *
from statistics import *

#Parameters to be estimated
# Arguments:
#   - 1  Name for report; Typically, the same as the variable.
#   - 2  Starting value.
#   - 3  Lower bound.
#   - 4  Upper bound.
#   - 5  0: estimate the parameter, 1: keep it fixed.
#
ASC_HYPERLOOP = Beta('ASC_HYPERLOOP',0,-10,10,0,'Hyperloop cte.')
ASC_APT = Beta('ASC_APT',0,-10,10,0,'APT cte.')
ASC_OTHER = Beta('ASC_OTHER',0,-10,10,1,'Other cte.')
B_HLTT = Beta('B_HLTT',0,-10,10,0,'Hyperloop travel time')
B_HLTC = Beta('B_HLTC',0,-10,10,0,'Travel cost')
B_HLAE = Beta('B_HLAE',0,-10,10,0,'Hyperloop A-E')
B_HLSM = Beta('B_HLSM',0,-10,10,0,'Hyperloop SusIndicator1')
B_HLSE = Beta('B_HLSE',0,-10,10,0,'Hyperloop SusIndicator2')
B_APTTT = Beta('B_APTTT',0,-10,10,0,'APT Travel time')
B_APTTC = Beta('B_APTTC',0,-10,10,0,'APT Travel cost')
B_HL_MP = Beta('B_HL_MP',0,-10,10,0,'HL Market Penetration')
B_APT_CSN = Beta('B_APT_CSN',0,-10,10,0,'APT Carbon Social Norms')
B_HL_CSN = Beta('B_HL_CSN',0,-10,10,0,'Hyperloop Carbon Social Norms')


V1 = ASC_HYPERLOOP + B_HLTT * HLTT + B_HLTC * HLTC + B_HLAE * HLAE + B_HLSM * HLSM + B_HLSE * HLSE + B_HL_CSN * CSN + B_HL_MP * MP
V2 = ASC_APT + B_APTTT * APTTT + B_APTTC * APTTC + B_APT_CSN * CSN
V3 = ASC_OTHER

# Associate utility functions with the numbering of alternatives
V = {1: V1,
     2: V2,
     3: V3}

# Associate the availability conditions with the alternatives

av = {1: HYPERLOOP_AV,
      2: APT_AV,
      3: OTHER_AV}

# The choice model is a logit, with availability conditions
logprob = bioLogLogit(V,av,CHOICE)

# Defines an itertor on the data
rowIterator('obsIter')

# DEfine the likelihood function for the estimation
BIOGEME_OBJECT.ESTIMATE = Sum(logprob,'obsIter')
```

D.4 Extended MNL model

D.4.1 Model estimation

The extended MNL model including interaction effects with background variables was estimated stepwise. Interaction effects of interest were added one by one, removing the effects that were not significant. Exceptions were made for interaction parameters that had a p-value (somewhat) above 0.05, but were still deemed too relevant to remove from the model following the publication by Amrhein et al. (2019).

Three separate models were estimated and later combined into the extended MNL model (F+C+P). The first model included the following traveller characteristics (C): age, education, income, travel purpose, flight frequency for business purposes and flight frequency for other purposes.
The second model included the following perceptions (P) of respondents regarding the Hyperloop compared to APT: safety, comfort, status, ease-of-use, excitement, Hyperloop sustainability and APT sustainability. A third interaction model included respondents' familiarity (F) to Hyperloop. The model only including traveller characteristics is used for the scenario analysis, which is why its PythonBiogeme syntax is also presented below besides the full

Table 0.7 presents the model performance of the different interaction models. The base model is considered to be the basic model as presented under section 5.4.1. The F+C+P model performs best compared to the base model, given its high LRS value which is higher than the chi-square threshold.

Table 0.7: Interaction model performances

Model	Additional parameters to base model	Rho-Squared	Final Log-Likelihod	LRS	Chi-square
Base model	-	0.164	-2248	0	-
Hyperloop Familiarity (F)	2	0.166	-2243	10.078	5.99
Traveller Characteristics (C)	8	0.179	-2200	95.686	15.51
Perceptions (P)	11	0.184	-2184	126.632	19.68
Extended model *F+C+P*	15	0.200	-2137	221.314	25

Table 0.8: Extended MNL 'F+C+P' model estimation results

Name	Value	Std err	t-test	p-value	Robust Std err	Robust t-test	Robust p-value
Basic model parameters							
ASC_APT	3.02	0.514	5.87	0.00	0.517	5.83	0.00
ASC_HYPERLOOP	3.45	0.414	8.34	0.00	0.423	8.17	0.00
APT_TravelCost	-0.0176	0.00163	-10.80	0.00	0.00160	-11.00	0.00
APT_TravelTime	-0.00632	0.00189	-3.34	0.00	0.00190	-3.34	0.00
HL_Acces-Egress	-0.00708	0.00180	-3.92	0.00	0.00180	-3.94	0.00
HL_SustainabilityEqual	-0.344	0.106	-3.24	0.00	0.104	-3.30	0.00
HL_SustainalityMore	0.776	0.110	7.05	0.00	0.112	6.90	0.00
HL_TravelCost	-0.0184	0.00165	-11.10	0.00	0.00164	-11.19	0.00
HL_TravelTime	-0.00771	0.00136	-5.67	0.00	0.00136	-5.67	0.00
B_HLASC_CarbonSocialNorms	-0.115	0.0478	-2.41	0.02	0.0482	-2.40	0.02
B_HLASC_MarketPenetration	0.165	0.0564	2.92	0.00	0.0552	2.99	0.00
B_APTASC_CarbonSocialNorms	-0.11	0.0656	-1.68	0.09*	0.0660	-1.67	**0.10***
Traveller characteristics							
B_Income_ASCAPT	-0.337	0.0931	-3.62	0.00	0.0976	-3.46	0.00
B_Income_HLTravelCost	0.00314	0.00142	2.21	0.03	0.00141	2.23	0.03
B_Income_ASCHyperloop	-0.533	0.221	-2.41	0.02	0.220	-2.42	0.02
B_Otherfreq_ASCAPT	0.535	0.0926	5.77	0.00	0.0908	5.89	0.00
B_Otherfreq_HLSustainabilityEqual	0.245	0.0928	2.64	0.01	0.0922	2.66	0.01
B_Otherfreq_HLSustainabilityMore	-0.232	0.0956	-2.42	0.02	0.0978	-2.37	0.02
B_Purpose_HLTravelCost	0.00481	0.000953	5.05	0.00	0.000977	4.92	0.00
B_Age_HL_MarketPenetration	-0.126	0.0650	-1.94	0.05*	0.0666	-1.89	**0.06***
Perceptions & Hyperloop familiarity							
B_Safety_ASCAPT	-0.564	0.0905	-6.23	0.00	0.0953	-5.92	0.00
B_Safety_ASCHL	-0.189	0.0624	-3.03	0.00	0.0630	-3.00	0.00
B_Sustainable_ASCAPT	-0.284	0.0678	-4.19	0.00	0.0737	-3.86	0.00
B_Excitement_ASCAPT	0.223	0.0756	2.95	0.00	0.0798	2.80	0.01
B_Excitement_ASCHL	0.329	0.0549	5.98	0.00	0.0539	6.09	0.00
B_Familiarity_ASCHyperloop	0.0962	0.0500	1.92	0.05*	0.0490	1.96	0.05
B _APTSustainability_ASCAPT	0.147	0.0632	2.32	0.02	0.0616	2.38	0.02

**Not significant at 5% significance level*

D.4.2 PythonBiogeme Syntax: Extendend ‘F+C+P’ Model

```
ASC_HYPERLOOP = Beta('ASC_HYPERLOOP',0,-10,10,0,'Hyperloop constant.')
ASC_APT = Beta('ASC_APT',0,-10,10,0,'APT constant.')
ASC_OTHER = Beta('ASC_OTHER',0,-10,10,1,'Other constant.')
B_HLTT = Beta('B_HLTT',0,-10,10,0,'Hyperloop travel time')
B_HLTC = Beta('B_HLTC',0,-10,10,0,'Travel cost')
B_HLAE = Beta('B_HLAE',0,-10,10,0,'Hyperloop A-E')
B_HLSE = Beta('B_HLSE',0,-10,10,0,'Hyperloop SusIndicator1')
B_HLSM = Beta('B_HLSM',0,-10,10,0,'Hyperloop SusIndicator2')
B_APTTT = Beta('B_APTTT',0,-10,10,0,'APT Travel time')
B_APTTC = Beta('B_APTTC',0,-10,10,0,'APT Travel cost')
B_HL_MP = Beta('B_HL_MP',0,-10,10,0,'HL Market Penetration')
B_HL_CSN = Beta('B_HL_CSN',0,-10,10,0,'Hyperloop Carbon Social Norms')
B_APT_CSN = Beta('B_APT_CSN',0,-10,10,0,'APT Carbon Social Norms')
B_Age_HL_MP = Beta('B_Age_HL_MP',0,-10,10,0,'Age * HL Market Penetration')
B_Income_Hyperloop = Beta('B_Income_Hyperloop',0,-10,10,0,'Income * Hyperloop Constant')
B_Income_APT = Beta('B_Income_APT',0,-10,10,0,'Income * APT Constant')
B_Income_HLTC = Beta('B_Income_HLTC',0,-10,10,0,'Income * Hyperloop travel cost')
B_Purpose_HLTC = Beta('B_Purpose_HLTC',0,-10,10,0,'Purpose * Hyperloop trave cost')
B_Otherfreq_APT = Beta('B_Otherfreq_APT',0,-10,10,0,'Non-business flight frequency * APT Constant')
B_Otherfreq_HLSE = Beta('B_Otherfreq_HLSE',0,-10,10,0,'Non-business flight frequency * SusIndicator1')
B_Otherfreq_HLSM = Beta('B_Otherfreq_HLSM',0,-10,10,0,'Non-business flight frequency * SusIndicator2')
B_Safety_HL = Beta('B_Safety_HL',0,-10,10,0,'Safety * Hyperloop Constant')
B_Safety_APT = Beta('B_Safety_APT',0,-10,10,0,'Safety * APT Constant')
B_Sustainable_APT = Beta('B_Sustainable_APT',0,-10,10,0,'Sustainability * APT Constant')
B_Excitement_HL = Beta('B_Excitement_HL',0,-10,10,0,'Excitement * Hyperloop Constant')
B_Excitement_APT = Beta('B_Excitement_APT',0,-10,10,0,'Excitement * APT Constant')
B_Familiarity_Hyperloop = Beta('B_Familiarity_Hyperloop',0,-10,10,0,'Hyperloop Familiarity * Hyperloop constant')
B_APTS = Beta('B_APTS',0,-10,10,0,'APT Sustainability * APT Constant ')

V1 = ASC_HYPERLOOP + B_HLTT * HLTT + B_HLTC * HLTC + B_HLAE * HLAE + B_HLSM * HLSM + B_HLSE * HLSE + B_HL_CSN * CSN + B_HL_MP * MP\
 + B_Income_Hyperloop * Income + B_Income_HLTC * HLTC * Income + B_Purpose_HLTC * HLTC * Purpose + B_Otherfreq_HLSM * HLSM * Otherfreq\
 + B_Otherfreq_HLSE * HLSE * Otherfreq + B_Safety_HL * Safety + B_Excitement_HL * Excitement + B_Age_HL_MP * Age * MP + B_Familiarity_Hyperloop * Familiarity
V2 = ASC_APT + B_APTTT * APTTT + B_APTTC * APTTC + B_APTS * APTS + B_APT_CSN * CSN + B_Income_APT * Income + B_Otherfreq_APT * Otherfreq\
 + B_Safety_APT * Safety + B_Sustainable_APT * Sustainable + B_Excitement_APT * Excitement
V3 = ASC_OTHER
```

D.4.3 Extended MNL including traveller characteristics (C)

Table 0.9 presents the extended traveller characteristics model which has been applied to the scenario analysis.

Table 0.9: Model results MNL including traveller characteristics (C)

Name	Value	Std err	t-test	p-value	Robust Std err	Robust t-test	Robust p-value
Basic model parameters							
ASC_APT	0.919	0.250	3.67	0.00	0.243	3.78	0.00
ASC_HYPERLOOP	4.05	0.308	13.17	0.00	0.308	13.17	0.00
B_APTTC	-0.0167	0.00159	-10.50	0.00	0.00158	-10.60	0.00
B_APTTT	-0.00585	0.00185	-3.16	0.00	0.00185	-3.15	0.00
B_HLAE	-0.00684	0.00178	-3.84	0.00	0.00177	-3.86	0.00
B_HLSE	-0.339	0.105	-3.23	0.00	0.103	-3.29	0.00
B_HLSM	0.764	0.109	7.01	0.00	0.111	6.90	0.00
B_HLTC	-0.0178	0.00163	-10.94	0.00	0.00160	-11.12	0.00
B_HLTT	-0.00747	0.00135	-5.55	0.00	0.00134	-5.57	0.00
B_HL_CSN	-0.113	0.0473	-2.38	0.02	0.0476	-2.36	0.02
B_HL_MP	0.162	0.0558	2.91	0.00	0.0545	2.98	0.00
B_APT_CSN	-0.103	0.0641	-1.60	0.11*	0.0644	-1.60	**0.11***
Traveller characteristics							
B_Income_ASCAPT	-0.336	0.0855	-3.94	0.00	0.0865	-3.89	0.00
B_Income_HLTravelCost	0.00299	0.00141	2.13	0.03	0.00139	2.15	0.03
B_Income_ASCHyperloop	-0.541	0.218	-2.48	0.01	0.216	-2.50	0.01
B_Otherfreq_ASCAPT	0.502	0.0906	5.53	0.00	0.0904	5.55	0.00
B_Otherfreq_HLSustainabilityEqual	0.240	0.0917	2.62	0.01	0.0909	2.64	0.01
B_Otherfreq_HLSustainabilityMore	-0.229	0.0945	-2.43	0.02	0.0964	-2.38	0.02
B_Purpose_HLTravelCost	0.00480	0.000933	5.15	0.00	0.000934	5.14	0.00
B_Age_HL_MarketPenetration	-0.122	0.0644	-1.89	0.06*	0.0657	-1.85	**0.06***

**Not significant at 5% significance level*

D.4.4 MNL including travel purpose

Table 0.10 presents the separate model which has been estimated to derive at the different Value of Time estimates for business & non-business travellers.

Table 0.10: Model results MNL including travel purpose

Name	Value	Std err	t-test	p-value	Robust Std err
Basic model parameters					
ASC_APT	1.12	0.223	5.02	0	0.214
ASC_HYPERLOOP	3.56	0.244	14.61	0	0.245
B_APTTC	-0.0164	0.00157	-10.42	0	0.00155
B_APTTT	-0.00577	0.00183	-3.16	0	0.00184
B_APT_CSN	-0.102	0.0634	-1.61	0.11	0.064
B_HLAE	-0.00686	0.00178	-3.86	0	0.00176
B_HLSE	-0.114	0.0614	-1.86	0.06	0.0603
B_HLSM	0.544	0.0634	8.58	0	0.0625
B_HLTC	-0.0152	0.00111	-13.71	0	0.0011
B_HLTT	-0.00735	0.00134	-5.49	0	0.00133
B_HL_CSN	-0.113	0.0472	-2.39	0.02	0.0476
B_HL_MP	0.0948	0.0435	2.18	0.03	0.0431
Travel purpose					
B_Purpose_HLTC	0.00489	0.000851	5.74	0	0.000863

**Not significant at 5% significance level*

D.5 Traveller classes model

D.5.1 Model estimation

A Latent Class Choice Model (LCCM) was estimated to account for taste heterogeneity from a more comprehensive angle, as described under 3.2.3.

To estimate the LCCM a large portion of the sample was removed due to non-trading behavior. Four non-traders only opted for APT, whereas 50 respondents minimally chose Hyperloop 10 out of 12 choice sets. Only after deletion of these respondents and the removal of the context parameter Carbon Social Norms on APT constant (which was already not significant in the MNL models), the LCCM could be reasonably be estimated. Expectedly, these problems have to do with the large number of (alternative-specific) parameters and the reduced sample size after removing non-traders. Starting values varying between -0,1 and 0,1 were applied to the parameters to mitigate the issue of LCCM models getting stuck in local optima (Uebersax, 2000). The 2-class model which is presented under table 0.11 proved to perform better than to the one class (MNL including contexts) and three class model based on its BIC value.

Table 0.11: LCCM model performances

Classes	LL	BIC
1 Class (MNL)	-1819.350	3722.463
2	**-1.771**	**3.717.654**
3	-1.748.888	3.764.295

To investigate the background variables of the classes, covariates were added to the class membership function. Covariates were based on the traveller characteristics (socio-economic and travel behavior variables) as those were of most interest to the scenario analysis for which the LCCM output was intended. Covariates were added one by one to the class membership function. Addition of the covariates to the class membership function resulted in one significant covariate: the frequency of non-business trips by the traveller. Table 0.12 presents the final LCCM including the covariate of flight frequency (B_Otherfreq).

Table 0.12: LCCM 2 class model results

	Name	Value	Std err	t-test	p-value	Robust Std err	Robust t-test	p-value
Constants								
APT constant	ASC_APT_1	-11.2	54.3	-0.21	0.84*	35.2	-0.32	0.75*
	ASC_APT_2	8.47	1.62	5.24	0.00	1.61	5.25	0.00
Hyperloop constant	ASC_HYPERLOOP_1	3.09	0.554	5.57	0.00	0.592	5.22	0.00
	ASC_HYPERLOOP_2	11.4	1.69	6.74	0.00	1.59	7.14	0.00
APT parameters								
APT travel cost	B_APTTC_1	0.0694	0.356	0.19	0.85*	0.229	0.30	0.76*
	B_APTTC_2	-0.0399	0.00547	-7.29	0.00	0.00541	-7.37	0.00
APT travel time	B_APTTT_1	-0.0350	0.0322	-1.09	0.28*	0.0208	-1.69	0.09*
	B_APTTT_2	-0.0161	0.00393	-4.10	0.00	0.00389	-4.15	0.00
Hyperloop parameters								
Hyperloop A-E Time	B_HLAE_1	-0.0152	0.00460	-3.30	0.00	0.00488	-3.11	0.00
	B_HLAE_2	-0.0140	0.00485	-2.88	0.00	0.00472	-2.96	0.00
Hyperloop Sustainability	B_HLSE_1	-0.131	0.159	-0.82	0.41*	0.166	-0.79	0.43*
	B_HLSE_2	0.189	0.181	1.04	0.30*	0.173	1.09	0.27*
	B_HLSM_1	1.09	0.161	6.75	0.00	0.161	6.75	0.00
	B_HLSM_2	0.574	0.179	3.21	0.00	0.175	3.28	0.00
Hyperloop travel cost	B_HLTC_1	-0.0182	0.00289	-6.29	0.00	0.00283	-6.43	0.00
	B_HLTC_2	-0.0314	0.00407	-7.73	0.00	0.00397	-7.93	0.00
Hyperloop travel time	B_HLTT_1	- 0.00476	0.00337	-1.41	0.16*	0.00365	-1.30	0.19*
	B_HLTT_2	-0.0180	0.00452	-3.99	0.00	0.00470	-3.84	0.00
Context parameters								
Hyperloop - Carbon Social Norms	B_HL_CSN_1	-0.214	0.0977	-2.19	0.03	0.0988	-2.17	0.03
	B_HL_CSN_2	-0.0490	0.111	-0.44	0.66*	0.117	-0.42	0.68*
Hyperloop - Market Penetration	B_HL_MP_1	0.159	0.0995	1.59	0.11*	0.103	1.54	0.12*
	B_HL_MP_2	0.0739	0.111	0.67	0.51*	0.116	0.64	0.52*
Class Membership Parameters	B_Otherfreq	0,58	0.0933	6.21	0.00	0.0927	6.26	0.00
	delta_s2	-1,98	0.317	-6.22	0.00	0.311	-6.36	0.00

**Not significant at 5% significance level*

D.5.2 PythonBiogeme Syntax: LCCM

```
# Parameters Class 1 RUM
ASC_HYPERLOOP_1 = Beta('ASC_HYPERLOOP_1',0,-100,100,0,'Hyperloop cte.')
ASC_APT_1 = Beta('ASC_APT_1',0,-100,100,0,'APT cte.')
ASC_OTHER_1 = Beta('ASC_OTHER_1',0,-100,100,1,'Other cte.')
B_HLTT_1 = Beta('B_HLTT_1',0,-100,100,0,'Hyperloop travel time')
B_HLTC_1 = Beta('B_HLTC_1',0,-100,100,0,'Travel cost')
B_HLAE_1 = Beta('B_HLAE_1',0,-100,100,0,'Hyperloop A-E')
B_HLSM_1 = Beta('B_HLSM_1',0,-100,100,0,'Hyperloop SusIndicator1')
B_HLSE_1 = Beta('B_HLSE_1',0,-100,100,0,'Hyperloop SusIndicator2')
B_APTTT_1 = Beta('B_APTTT_1',0,-100,100,0,'APT Travel time')
B_APTTC_1 = Beta('B_APTTC_1',0,-100,100,0,'APT Travel cost')
B_HL_MP_1 = Beta('B_HL_MP_1',0,-100,100,0,'HL Market Penetration')
B_APT_MP_1 = Beta('B_APT_MP_1',0,-100,100,1,'APT Market Penetration')
B_APT_CSN_1 = Beta('B_APT_CSN_1',0,-100,100,0,'APT Carbon Social Norms')
B_HL_CSN_1 = Beta('B_HL_CSN_1',0,-100,100,0,'Hyperloop Carbon Social Norms')

# Parameters Class 2 RUM
ASC_HYPERLOOP_2 = Beta('ASC_HYPERLOOP_2',0,-100,100,0,'Hyperloop cte.')
ASC_APT_2 = Beta('ASC_APT_2',0,-100,100,0,'APT cte.')
ASC_OTHER_2 = Beta('ASC_OTHER_2',0,-100,100,1,'Other cte.')
B_HLTT_2 = Beta('B_HLTT_2',0,-100,100,0,'Hyperloop travel time')
B_HLTC_2 = Beta('B_HLTC_2',0,-100,100,0,'Travel cost')
B_HLAE_2 = Beta('B_HLAE_2',0,-100,100,0,'Hyperloop A-E')
B_HLSM_2 = Beta('B_HLSM_2',0,-100,100,0,'Hyperloop SusIndicator1')
B_HLSE_2 = Beta('B_HLSE_2',0,-100,100,0,'Hyperloop SusIndicator2')
B_APTTT_2 = Beta('B_APTTT_2',0,-100,100,0,'APT Travel time')
B_APTTC_2 = Beta('B_APTTC_2',0,-100,100,0,'APT Travel cost')
B_HL_MP_2 = Beta('B_HL_MP_2',0,-100,100,0,'HL Market Penetration')
B_APT_MP_2 = Beta('B_APT_MP_2',0,-100,100,1,'APT Market Penetration')
B_APT_CSN_2 = Beta('B_APT_CSN_2',0,-100,100,0,'APT Carbon Social Norms')
B_HL_CSN_2 = Beta('B_HL_CSN_2',0,-100,100,0,'Hyperloop Carbon Social Norms')

# Class membership parameters
delta_s1 = Beta('delta_s1',0,-100,100,1)
delta_s2 = Beta('delta_s2',0,-100,100,0)


# Class specific models
# Class 1 (RUM-MNL)
V1_1 = ASC_HYPERLOOP_1 + B_HLTT_1 * HLTT + B_HLTC_1 * HLTC + B_HLAE_1 * HLAE + \
B_HLSM_1 * HLSM + B_HLSE_1 * HLSE + B_HL_CSN_1 * CSN + B_HL_MP_1 * MP
V2_1 = ASC_APT_1 + B_APTTT_1 * APTTT + B_APTTC_1 * APTTC
V3_1 = ASC_OTHER_1

# Class 2 (RUM-MNL)
V1_2 = ASC_HYPERLOOP_2 + B_HLTT_2 * HLTT + B_HLTC_2 * HLTC + B_HLAE_2 * HLAE + \
B_HLSM_2 * HLSM + B_HLSE_2 * HLSE + B_HL_CSN_2 * CSN + B_HL_MP_2 * MP
V2_2 = ASC_APT_2 + B_APTTT_2 * APTTT + B_APTTC_2 * APTTC
V3_2 = ASC_OTHER_2


# Associate utility functions with the numbering of alternatives
V1 = {1: V1_1,
      2: V2_1,
      3: V3_1}

V2 = {1: V1_2,
      2: V2_2,
      3: V3_2}

# Associate the availability conditions with the alternatives
one =  DefineVariable('one',1)

av = {1: one,
      2: one,
      3: one}

# Class membership model
utilClass1 = delta_s1
utilClass2 = delta_s2

probClass1 = exp(utilClass1) / (exp(utilClass1) + exp(utilClass2))
probClass2 = exp(utilClass2) / (exp(utilClass1) + exp(utilClass2))

# The choice model is a logit, with availability conditions
prob1 = bioLogit(V1,av,CHOICE)
prob2 = bioLogit(V2,av,CHOICE)

# Defines an iterator on the data
rowIterator('obsIter')

# Define the likelihood function for the estimation
BIOGEME_OBJECT.ESTIMATE = Sum(log(probClass1 * prob1 + probClass2 * prob2),'obsIter')

# Statistics
BIOGEME_OBJECT.PARAMETERS['optimizationAlgorithm'] = "CFSQP"
BIOGEME_OBJECT.PARAMETERS['numberOfThreads'] = "1"
```

D.6 Cross tabulation base alternative

Cross tabulation in SPSS resulted in the following distribution of the base alternative per income group. The car alternative includes both self-driving cars as regular cars, and is slightly more often chosen by the middle and high-income groups.

Table 0.13: Chosen base alternative per income subcategory

	Car	**Train**	**Bus**
Low-income	62%	37%	1%
Middle-income	65%	35%	0%
High-income	64%	36%	0%

Appendix E: Scenario analysis

This appendix presents the potential market share distributions per traveller subcategories (e.g. low, middle high-income) that were found to have a significant different impact on the focal travel behavior. Market shares are also presented for different contexts.

E.1 Potential market shares: Mass Sustainable Transport System

Table 0.1: Potential market shares MSTS, context 1

Context **Carbon Social Norms:** Lenient **Share of occasional Hyperloop users:** Low			
	Hyperloop	**APT**	**Other**
Overall	63%	2%	35%
Purpose			
Non-business	62%	2%	35%
Business	67%	2%	32%
Age			
20-30	64%	3%	34%
30-60	62%	2%	37%
60+	62%	2%	36%
Income			
Low	66%	3%	31%
Middle	62%	2%	36%
High	59%	2%	39%
Flight Frequency			
1< per year	67%	1%	32%
1 - 2 times per year	63%	2%	35%
>3 per year	56%	4%	40%

Table 0.2: Potential market shares MSTS, context 2

Context **Carbon Social Norms:** Strict **Share of occasional Hyperloop users:** High			
	Hyperloop MSTS	**APT**	**Other**
Overall	62%	2%	36%
Purpose			
Non-business	62%	2%	36%
Business	65%	2%	33%
Age			
20-30	65%	2%	33%
30-60	60%	2%	38%
60+	58%	2%	40%
Income			
Low	67%	2%	30%
Middle	61%	2%	37%
High	57%	2%	41%
Flight Frequency			
1< per year	66%	1%	33%
1 - 2 times per year	63%	2%	35%

>3 per year	56%	3%	40%

Table 0.3: Potential market shares MSTS, context 3

Context **Carbon Social Norms:** Lenient **Share of occasional Hyperloop users:** High			
	Hyperloop MSTS	**APT**	**Other**
Overall	65%	2%	33%
Purpose			
Non-business	65%	2%	33%
Business	68%	2%	31%
Age			
20-30	67%	2%	30%
30-60	63%	2%	36%
60+	60%	2%	38%
Income			
Low	70%	2%	28%
Middle	63%	2%	35%
High	60%	2%	38%
Flight Frequency			
1< per year	68%	1%	30%
1 - 2 times per year	65%	2%	33%
>3 per year	59%	4%	38%

Table 0.4: Potential market shares MSTS, context 4

Context **Carbon Social Norms:** Strict **Share of occasional Hyperloop users:** Low			
	Hyperloop MSTS	**APT**	**Other**
Overall	60%	2%	37%
Purpose			
Non-business	60%	2%	38%
Business	64%	2%	34%
Age			
20-30	61%	3%	36%
30-60	59%	2%	39%
60+	60%	2%	38%
Income			
Low	64%	2%	33%
Middle	59%	2%	39%
High	57%	2%	42%
Flight Frequency			
1< per year	65%	1%	34%
1 - 2 times per year	61%	2%	37%
>3 per year	54%	4%	42%

E.2 Potential market shares: Daily Urban Transport System

Table 0.5: Potential market shares DUTS, context 1

Context **Carbon Social Norms:** Lenient **Share of occasional Hyperloop users:** Low			
	Hyperloop DUTS	**APT**	**Other**
Overall	49%	6%	44%
Purpose			
Non-business	48%	6%	45%
Business	55%	5%	40%
Age			
20-30	51%	7%	42%
30-60	48%	5%	47%
60+	48%	5%	46%
Income			
Low	52%	7%	40%
Middle	48%	6%	46%
High	46%	5%	49%
Flight Frequency			
1< per year	50%	4%	46%
1 - 2 times per year	50%	6%	44%
>3 per year	47%	9%	43%

Table 0.6: Potential market shares DUTS, context 2

Context **Carbon Social Norms:** Strict **Share of occasional Hyperloop users:** High			
	Hyperloop DUTS	**APT**	**Other**
Overall	49%	6%	45%
Purpose			
Non-business	48%	6%	46%
Business	54%	5%	42%
Age			
20-30	52%	6%	41%
30-60	46%	5%	49%
60+	44%	5%	51%
Income			
Low	54%	7%	40%
Middle	47%	6%	47%
High	44%	5%	51%
Flight Frequency			
1< per year	49%	4%	48%
1 - 2 times per year	50%	6%	44%
>3 per year	48%	9%	44%

Table 0.7: Potential market shares DUTS, context 3

Context **Carbon Social Norms:** Lenient **Share of occasional Hyperloop users:** High			
	Hyperloop DUTS	**APT**	**Other**
Overall	52%	6%	43%
Purpose			
Non-business	51%	6%	43%
Business	56%	5%	39%
Age			
20-30	55%	7%	39%
30-60	49%	5%	46%
60+	46%	6%	48%
Income			
Low	56%	7%	37%
Middle	50%	6%	44%
High	47%	5%	48%
Flight Frequency			
1< per year	51%	4%	45%
1 - 2 times per year	52%	6%	42%
>3 per year	50%	9%	41%

Table 0.8: Potential market shares DUTS, context 4

Context **Carbon Social Norms:** Strict **Share of occasional Hyperloop users:** Low			
	Hyperloop DUTS	**APT**	**Other**
Overall	47%	6%	47%
Purpose			
Non-business	46%	6%	48%
Business	53%	5%	43%
Age			
20-30	48%	7%	45%
30-60	45%	5%	50%
60+	46%	5%	49%
Income			
Low	50%	7%	43%
Middle	45%	6%	49%
High	44%	5%	52%
Flight Frequency			
1< per year	47%	4%	49%
1 - 2 times per year	47%	6%	47%
>3 per year	45%	9%	46%

E.3 Potential Market Shares: Premium Transport Mode

Table 0.9: Potential market shares PTS, context 1

Context **Carbon Social Norms:** Lenient **Share of occasional Hyperloop users:** Low			
	Hyperloop PTS	**APT**	**Other**
Overall	16%	20%	63%
Purpose			
Non-business	14%	21%	65%
Business	33%	15%	53%
Age			
20-30	14%	24%	62%
30-60	19%	16%	65%
60+	17%	17%	66%
Income			
Low	13%	26%	62%
Middle	15%	20%	65%
High	22%	14%	64%
Flight Frequency			
1< per year	14%	14%	72%
1 - 2 times per year	16%	21%	63%
>3 per year	20%	27%	53%

Table 0.10: Potential market shares PTS, context 2

Context **Carbon Social Norms:** Strict **Share of occasional Hyperloop users:** High			
	Hyperloop PTS	**APT**	**Other**
Overall	16%	19%	65%
Purpose			
Non-business	14%	20%	67%
Business	32%	14%	55%
Age			
20-30	15%	22%	63%
30-60	18%	15%	67%
60+	15%	16%	69%
Income			
Low	13%	24%	63%
Middle	15%	18%	67%
High	21%	13%	66%
Flight Frequency			
1< per year	13%	13%	74%
1 - 2 times per year	16%	20%	64%
>3 per year	20%	25%	55%

Table 0.11: Potential market shares PTS, context 3

Context **Carbon Social Norms:** Lenient **Share of occasional Hyperloop users:** High			
	Hyperloop PTS	**APT**	**Other**
Overall	17%	20%	63%
Purpose			
Non-business	15%	21%	64%
Business	34%	14%	52%
Age			
20-30	16%	24%	60%
30-60	19%	16%	65%
60+	16%	17%	67%
Income			
Low	14%	25%	61%
Middle	16%	19%	64%
High	23%	14%	63%
Flight Frequency			
1< per year	14%	14%	72%
1 - 2 times per year	17%	21%	62%
>3 per year	21%	26%	52%

Table 0.12: Potential market shares PTS, context 4

Context **Carbon Social Norms:** Strict **Share of occasional Hyperloop users: Low**			
	Hyperloop DUTS	**APT**	**Other**
Overall	15%	19%	66%
Purpose			
Non-business	13%	20%	67%
Business	31%	14%	55%
Age			
20-30	13%	23%	64%
30-60	17%	15%	68%
60+	16%	16%	68%
Income			
Low	12%	24%	64%
Middle	14%	18%	68%
High	21%	13%	66%
Flight Frequency			
1< per year	12%	13%	74%
1 - 2 times per year	15%	20%	65%
>3 per year	19%	26%	56%

Appendix F: Survey

Welkom! Alvast hartelijk dank voor uw deelname aan deze enquête. Hiermee helpt u mee aan een stevige onderbouwing van mijn masterscriptie. Het invullen van de enquête zal u naar verwachting **15 minuten** kosten.

In deze enquête wordt naar uw voorkeuren gevraagd voor reizen met het vliegtuig of de Hyperloop als vervoermiddel voor lange afstanden. Op de volgende pagina wordt de Hyperloop in meer detail uitgelegd.

Uw data zijn vertrouwelijk en worden volledig anoniem opgeslagen. Door deel te nemen aan de enquête geeft u akkoord voor wetenschappelijk gebruik en opslag van uw data in de TU Delft database. U kunt op elk moment stoppen met de enquête zonder hiervoor een reden op te geven.

U kunt op de laatste pagina uw mailadres achterlaten om kans te maken op een Bol.com tegoedbon (t.w.v. €45,-). Voor vragen over de enquête of het gebruik van de data, kunt u mij mailen: l.marthaler@student.tudelft.nl.

Met vriendelijke groet,
Lukas Marthaler

→

Introductie vliegtuig en Hyperloop
Om u een beeld te geven van beide vervoermiddelen, worden hieronder verschillende aspecten beschreven van het vliegtuig en de Hyperloop.

Vliegtuig
Het vliegtuig wordt met motoren voortgedreven door verbranding van kerosine en haalt meestal een topsnelheid van circa 950 km/uur.

Hyperloop
De Hyperloop is nog nergens ter wereld gebouwd voor publiek gebruik en laat zich grofweg omschrijven als:

-Een afgesloten metalen capsule die met behulp van elektro-magnetische kracht vooruit zweeft. De aandrijving van de Hyperloop komt voort uit elektriciteit.

-De capsule zweeft door een vacuüm getrokken buis. Binnen in de capsule is de luchtdruk 'normaal'. Dat is de luchtdruk die u nu ook ervaart.

-Doordat er geen luchtweerstand optreedt bij het voortbewegen in de buis, kan de Hyperloop capsule een theoretische topsnelheid van circa 1000 km/uur bereiken. Naar verwachting zal de snelheid met passagiers circa 700 km/uur bedragen.

-Capsules worden op afstand bestuurd door een bemande controlepost.

-In geval van nood bestaat er de mogelijkheid om contact op te nemen met de controlepost via een intercom (een telefoontoestel aan de wand). De controlepost kan de capsule tot stilstand brengen op een veilige plek.

-De druk op uw lichaam die u ervaart tijdens het versnellen van een Hyperloop capsule, is vergelijkbaar met de druk die u ervaart tijdens het opstijgen van een vliegtuig.

-Hyperloopstations bevinden zich in of op loopafstand van bestaande treinstations en luchthavens.

-Hieronder ziet u een illustratie van het interieur, de buitenkant van de Hyperloop buis en een animatie van de Hyperloop.

Hyperloop interieur (Bron: Hardt Hyperloop)

Hyperloop buis (Bron: Virgin Hyperloop One)

Hyperloop animatie (Bron: Delft Hyperloop)

← →

Uw beeld van het vliegtuig en de Hyperloop

In hoeverre was u bekend met de Hyperloop voor deze enquête?

- Ik kende het niet
- Ik had er wel eens van gehoord
- Ik had er wel eens van gehoord, en nader onderzocht
- Ik wist er al veel van

Wat is uw beeld van reizen met de Hyperloop ten opzichte van (afkorting: t.o.v.) reizen met het vliegtuig?

	1: Veel minder	2: Minder	3: Gelijk	4: Meer	5: Veel meer
Hoe veilig schat u de Hyperloop in t.o.v. het vliegtuig?	○	○	○	○	○
Hoe comfortabel schat u de Hyperloop in t.o.v. het vliegtuig?	○	○	○	○	○
Hoe milieuvriendelijk schat u de Hyperloop in t.o.v. het vliegtuig?	○	○	○	○	○
Hoe plezierig schat u gebruik van de Hyperloop in t.o.v. gebruik van het vliegtuig?	○	○	○	○	○
Hoe gemakkelijk schat u een reis met de Hyperloop in t.o.v. een reis met het vliegtuig?	○	○	○	○	○
Hoeveel indruk denkt u te kunnen maken op collega's, vrienden of familie met een Hyperloop reis t.o.v. een reis met het vliegtuig?	○	○	○	○	○

In uw ogen, hoe milieuvriendelijk is het vliegtuig?

- Heel milieuonvriendelijk
- Milieuonvriendelijk
- Neutraal
- Milieuvriendelijk
- Heel milieuvriendelijk

Maakte u voor de Covid-19 pandemie minimaal 1 keer per jaar een internationale vlucht voor zakelijke doeleinden?

- Ja
- Nee

Voor de komende keuzesituaties dient u zich in te beelden dat u een **zakelijke reis** gaat maken. Denk bijvoorbeeld aan congressen, vergaderingen of andere zakelijke aangelegenheden die u maakt voor werkdoeleinden.
Op de volgende pagina worden de keuzesituaties uitgelegd.

← →

In uw ogen, hoe milieuvriendelijk is het vliegtuig?

- Heel milieuonvriendelijk
- Milieuonvriendelijk
- Neutraal
- Milieuvriendelijk
- Heel milieuvriendelijk

Maakte u voor de Covid-19 pandemie minimaal 1 keer per jaar een internationale vlucht voor zakelijke doeleinden?

- Ja
- Nee

Voor de komende keuzesituaties dient u zich in te beelden dat u een **niet-zakelijke reis** gaat maken. Denk bijvoorbeeld aan vakantie, familiebezoek, trouwerijen, etc.
Op de volgende pagina worden de keuzesituaties uitgelegd.

← →

Uitleg keuzesituaties

Om uw voorkeuren tussen de Hyperloop en het vliegtuig te meten, volgen hierna denkbeeldige keuzesituaties. Per keuzesituatie veranderen de **kenmerken van de vervoermiddelen** en **toekomstbeelden** van de maatschappij. Hieronder staat een voorbeeld van een keuzesituatie. Onder het voorbeeld worden de keuzesituaties verder toegelicht.

VOORBEELD

Toekomstbeelden

Uw vrienden/familie/collega's uiten zich **zelden** negatief tegenover reizen met transportmiddelen met een grote CO2-uitstoot
Grofweg **9 op de 10** van uw vrienden/familie/collega's reist wel eens met de Hyperloop en ervaart dat als positief

Kenmerken vervoermiddelen

	Hyperloop	Vliegtuig
Reistijd	1u30min	0u50min
Voor/Na reistijd	1u00min	4u00min
Totale reiskosten	€200	€50
Milieuvriendelijk	Meer milieuvriendelijk dan vliegtuig	Neutraal

Welk vervoermiddel heeft uw voorkeur in deze keuzesituatie?
**Onderstaande meerkeuzevraag is een voorbeeld, u mag, maar hoeft deze dus niet in te vullen.*

- Hyperloop ○
- Vliegtuig ○

TOELICHTING

Kenmerken vervoermiddelen

Reistijd
Het aantal uren (u) en minuten (min) die u besteedt in het vliegtuig of de Hyperloop. Bijvoorbeeld: 0u50min staat voor 50 minuten reistijd.

Voor/Na Reistijd
De reistijd vanaf uw huis tot u in het vliegtuig of Hyperloop stapt, plus de tijd van aankomst tot uw eindbestemming.

Totale reiskosten
De ticketprijs plus administratiekosten.

Milieuvriendelijk
De milieuvriendelijkheid van het gehele Hyperloop systeem is nog onbekend. Daarom kan in de keuzesituaties de Hyperloop minder, even of meer milieuvriendelijk dan het vliegtuig zijn.

Toekomstbeelden:
Voordat een mogelijk Hyperloop systeem gebouwd is, zal de wereld om ons heen al zijn veranderd. Om hier rekening mee te houden, worden tijdens de keuzesituaties verschillende toekomstbeelden gepresenteerd. U dient zich voor te stellen dat de gepresenteerde toekomstbeelden werkelijkheid zijn.

Sociale norm omtrent CO2 uitstoot van transportmiddelen
Net als roken dat afgelopen decennia steeds meer bekritiseerd werd, kan het zo zijn dat mensen in uw omgeving zich vaker negatief gaan uiten over het gebruik van transportmiddelen met een grote CO2-uitstoot. Er dienen zich hierbij twee situaties voor:

1. Uw vrienden/familie/collega's uiten zich **zelden** negatief tegenover reizen met transportmiddelen met een grote CO2-uitstoot
2. Uw vrienden/familie/collega's uiten zich **vaak** negatief tegenover reizen met transportmiddelen met een grote CO2-uitstoot

Het gebruik van Hyperloop door mensen in uw omgeving:
Net als met het groeiende gebruik van de elektrische auto, kan het zijn dat steeds meer mensen in uw omgeving gebruik gaan maken van de Hyperloop. Er dienen zich hierbij twee situaties voor:

1. Grofweg **1 op de 10** van uw vrienden/familie/collega's reist wel eens met de Hyperloop en ervaart dat als positief
2. Grofweg **9 op de 10** van uw vrienden/familie/collega's reist wel eens met de Hyperloop en ervaart dat als positief

Het gebruik van Hyperloop door mensen in uw omgeving:
Net als met het groeiende gebruik van de elektrische auto, kan het zijn dat steeds meer mensen in uw omgeving gebruik gaan maken van de Hyperloop. Er dienen zich hierbij twee situaties voor:

1. Grofweg **1 op de 10** van uw vrienden/familie/collega's reist wel eens met de Hyperloop en ervaart dat als positief
2. Grofweg **9 op de 10** van uw vrienden/familie/collega's reist wel eens met de Hyperloop en ervaart dat als positief

BELANGRIJK
Hierna volgen **12** denkbeeldige keuzesituaties, waarin u uw voorkeur moet aangeven voor de Hyperloop of het vliegtuig. U dient u zich voor te stellen dat:

- U vandaag de dag gebruik kunt maken van de Hyperloop als vervoermiddel.
- U een enkele reis gaat maken van ongeveer 650 kilometer vanuit Nederland. Voor uw beeldvorming: dat is ongeveer de afstand tussen Amsterdam en Berlijn.

>> BEGIN KEUZESITUATIES >>

← →

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Delft University of Technology

Keuzesituaties
Ter herinnering: Voor de komende keuzesituaties dient u zich in te beelden dat u een **niet-zakelijke reis** gaat maken. Denk bijvoorbeeld aan vakantie, familiebezoek, trouwerijen, etc.

1.

Uw vrienden/familie/collega's uiten zich **zelden** negatief tegenover reizen met transportmiddelen met een grote CO2-uitstoot
Grofweg **1 op de 10** van uw vrienden/familie/collega's reist wel eens met de Hyperloop en ervaart dat als positief

	Hyperloop	Vliegtuig
Reistijd	1u30min	0u50min
Voor/Na reistijd	1u30min	4u00min
Totale reiskosten	€150	€150
Milieuvriendelijk	Minder milieuvriendelijk dan vliegtuig	Neutraal

Welk vervoermiddel heeft uw voorkeur in deze keuzesituatie?

- Hyperloop ○
- Vliegtuig ○

Stel u maakt een reis van ongeveer 650 kilometer in de bovenstaande situatie; Zou u dan reizen met uw hierboven geprefereerde vervoermiddel of met een ander vervoermiddel?

- Hierboven geprefereerde vervoermiddel (Hyperloop of vliegtuig) ○
- Ander vervoermiddel (elektrische auto, zelfrijdende auto, trein, bus) ○

12.

Uw vrienden/familie/collega's uiten zich **vaak** negatief tegenover reizen met transportmiddelen met een grote CO_2 uitstoot
Grofweg **9 op de 10** van uw vrienden/familie/collega's reist wel eens met de Hyperloop en ervaart dat als positief

	Hyperloop	Vliegtuig
Reistijd	0u50min	2u10min
Voor/Na reistijd	0u30min	4u00min
Totale reiskosten	€150	€150
Milieuvriendelijk	Even milieuvriendelijk als vliegtuig	Neutraal

Welk vervoermiddel heeft uw voorkeur in deze keuzesituatie?

- Hyperloop ○
- Vliegtuig ○

Stel u maakt een reis van ongeveer 650 kilometer in de bovenstaande situatie; Zou u dan reizen met uw hierboven geprefereerde vervoermiddel of met een ander vervoermiddel?

- Hierboven geprefereerde vervoermiddel (Hyperloop of vliegtuig) ○
- Ander vervoermiddel (elektrische auto, zelfrijdende auto, trein, bus) ○

Welk vervoermiddel heeft uw voorkeur in deze keuzesituatie?

- Hyperloop ○
- Vliegtuig ○

Stel u maakt een reis van ongeveer 650 kilometer in de bovenstaande situatie; Zou u dan reizen met uw hierboven geprefereerde vervoermiddel of met een ander vervoermiddel?

- Hierboven geprefereerde vervoermiddel (Hyperloop of vliegtuig) ○
- Ander vervoermiddel (elektrische auto, zellfrijdende auto, trein, bus) ○

Ander vervoermiddel

Met welk ander vervoermiddel dan het vliegtuig of de Hyperloop zou u het meest waarschijnlijk een reis van ongeveer 650 kilometer maken?
U dient zich hierbij voor te stellen dat alle auto's en bussen elektrisch worden voortgedreven.

- Auto ○
- Zelfrijdende auto ○
- Trein ○
- Bus ○
- Anders, namelijk: ○

→

Interpretatie van de toekomstbeelden
Met de volgende vragen wil ik graag uw interpretatie van de toekomstbeelden achterhalen. Er zijn geen goede of foute antwoorden, elk persoon kan de toekomstbeelden anders hebben ervaren.

Ter herinnering: dit waren de verschillende toekomstbeelden

Sociale norm omtrent CO2 uitstoot van transportmiddelen
1. Uw vrienden/familie/collega's uiten zich **zelden** negatief tegenover reizen met transportmiddelen met een grote CO2-uitstoot
2. Uw vrienden/familie/collega's uiten zich **vaak** negatief tegenover reizen met transportmiddelen met een grote CO2-uitstoot

Hyperloopgebruik door mensen in uw omgeving
1. Grofweg **1 op de 10** van uw vrienden/familie/collega's reist wel eens met de Hyperloop en ervaart dat als positief
2. Grofweg **9 op de 10** van uw vrienden/familie/collega's reist wel eens met de Hyperloop en ervaart dat als positief

VRAGEN

*'Grofweg **9/10 van uw vrienden/familie/collega's** reist wel eens met de Hyperloop en ervaart dat als positief'*
Uit bovenstaande toekomstsituatie kan iedereen iets anders afleiden. Geef voor ieder van de volgende uitspraken aan, in hoeverre u deze heeft afgeleid uit de toekomstsituatie.

	1: Helemaal niet van toepassing	2: Niet van toepassing	3: Deels wel, deels niet van toepassing	4: Van toepassing	5: Helemaal van toepassing
Reizen met de Hyperloop is veilig	○	○	○	○	○
Reizen met de Hyperloop geeft mij in deze situatie weinig aanzien in mijn sociale omgeving	○	○	○	○	○
Ik ervaar sociale druk om met de Hyperloop re reizen	○	○	○	○	○
Reizen met de Hyperloop is gemakkelijk	○	○	○	○	○
Reizen met de Hyperloop is comfortabel	○	○	○	○	○
Anders, namelijk:	○	○	○	○	○

In hoeverre begreep u de toekomstbeelden?

	Heel slecht	Slecht	Neutraal	Goed	Heel goed
Sociale norm omtrent CO2 uitstoot van transportmiddelen	○	○	○	○	○
Hyperloopgebruik door mensen in uw omgeving	○	○	○	○	○

In hoeverre kon u zich de toekomstbeelden voorstellen voor uw eigen sociale omgeving?

	Heel slecht	Slecht	Neutraal	Goed	Heel goed
Sociale norm omtrent CO2 uitstoot van transportmiddelen	○	○	○	○	○
Hyperloopgebruik door mensen in uw omgeving	○	○	○	○	○

In hoeverre kon u zich het **verschil** voorstellen tussen de volgende toekomstbeelden:

1. Uw vrienden/familie/collega's uiten zich **zelden** negatief tegenover reizen met transportmiddelen met een grote CO2-uitstoot
2. Uw vrienden/familie/collega's uiten zich **vaak** negatief tegenover reizen met transportmiddelen met een grote CO2-uitstoot

Heel slecht	Slecht	Neutraal	Goed	Heel goed
○	○	○	○	○

In hoeverre kon u zich het **verschil** voorstellen tussen de volgende toekomstbeelden:

1. Grofweg **1 op de 10** van uw vrienden/familie/collega's reist wel eens met de Hyperloop en ervaart dat als positief
2. Grofweg **9 op de 10** van uw vrienden/familie/collega's reist wel eens met de Hyperloop en ervaart dat als positief

Heel slecht	Slecht	Neutraal	Goed	Heel goed
○	○	○	○	○

← →

Uw reizigerskenmerken

Als laatste wil ik u vragen de volgende vragen te beantwoorden, om een beeld te krijgen van u als reiziger.

Wat is uw geslacht?

- Man
- Vrouw
- Anders

Wat is uw geboortejaar? *(vier cijfers, b.v. 1991)*

Wat is uw hoogst genoten opleiding? Dit is dus uw hoogst afgeronde opleiding waarvan u een diploma in het bezit heeft.

- Basisonderwijs
- Vmbo-b, vmbo-k, mbo1, LTS
- Vmbo-g, vmbo-t (mavo), havo-, vwo-onderbouw
- Mbo2, Mbo3
- Mbo4
- Havo, vwo
- Hbo-, wo-bachelor
- Wo-master, doctor
- Weet niet of onbekend

Tot welke categorie behoort ongeveer uw eigen jaarlijkse bruto besteedbaar inkomen? Dit is het loon van het gehele jaar zonder aftrek van belastingen en pensioenpremies.

- Minder dan €10.000
- €10.000 tot €19.999
- €19.999 tot €29.999
- €30.000 tot €39.999
- €40.000 tot €49.999
- €50.000 tot €59.999
- €60.000 tot €69.999
- €70.000 tot €79.999
- €80.000 tot €89.999
- €90.000 tot €99.999
- €100.000 tot €199.999
- €200.000 of meer
- Weet ik niet

Wat is uw voornaamste dagelijkse bezigheid?

- Student
- Gepensioneerd
- Werkzoekend, op zoek naar een betaalde baan
- Werkend, fulltime (40 uur of meer per week)
- Werkend, partttime (minder dan 40 uur per week)
- Niet werkend
- Mantelzorger
- Vrijwilliger
- Anders

Gemiddeld hoe vaak maakt u gebruik van het vliegtuig voor een **niet-zakelijke** internationale reis binnen Europa?

(ga hier uit van de situatie voor Covid-19)

- Nooit
- Minder dan 1 keer per jaar
- 1 of 2 keer per jaar
- 3 of 4 keer per jaar
- 5 of 6 keer per jaar
- Meer dan 6 keer per jaar

Gemiddeld hoe vaak maakt u gebruik van het vliegtuig voor een **zakelijke** internationale reis binnen Europa?

(ga hier uit van de situatie voor Covid-19)

- Nooit
- Minder dan 1 keer per jaar
- 1 of 2 keer per jaar
- 3 of 4 keer per jaar
- 5 of 6 keer per jaar
- Meer dan 6 keer per jaar

Mocht u bepaalde aspecten zijn opgevallen, of heeft u andere opmerkingen gerelateerd aan de enquête of het onderwerp, hoor ik die graag! Hieronder kunt u uw opmerking plaatsen.

Laat hieronder uw mailadres achter als u mee wilt doen aan de loting van de Bol.com tegoedbon (t.w.v. €45,-). Uw emailadres zal na maximaal één maand na afloop van het onderzoek worden verwijderd.

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TUDelft
Delft University of Technology

Bedankt voor uw tijd om aan deze enquête deel te nemen.
Uw antwoord is geregistreerd.