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Studying a New Embarking and Disembarking Process for Future Hyperloop Passengers

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Abstract. This paper presents an embarking and disembarking process for the hyperloop, a future high-speed transportation of passengers and goods in tubes. A concept of the (dis)embarking process has been designed and tested with two experiments. The first experiment was performed to compare the new concept to one that is more similar to the current embarking setup of trains on the aspects of efficiency and experience. Participants were asked to (dis)embark in the test settings that simulate the new concept and the conventional situation with luggage. As a result, new passenger flow saves 40% of the time for vehicles to stay on the platform. Follow-up questionnaires and interviews with the participants show that the proposed passenger flow gives a better experience in terms of efficiency, seamlessness and friendliness. The new solution increases the number of doors, which increases the manufacturing complexity and the chance of failure. Narrowing the door size minimizes this effect. Subsequently, a second experiment has been carried out to study the influence of door width on (dis) embarking efficiency and passenger experience following a similar method. It turns out that narrowing the door width does not noticeably influence the embarking time, but the disembarking time does increase. Interviews show that half of the participants sense a negative experience with narrower doors, while the other half do not notice a difference.

Keywords: Boarding · Passenger flow · Luggage solution

1 Introduction

1.1 Background

For years, people have been travelling on road, rail, water and by air. Each mode of transportation has its unique (dis)embarking process and they have not changed much over the years. New transportations, such as hyperloop, present the opportunity to design the (dis)embarking process from the passenger perspective without being restrained from legacy requirements.

Hyperloop is a network of tubes with a low pressure environment that reduce air resistance, allowing a high cruising speed with low energy use (Musk 2013) [1]. In this

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network, transfers and intermediate stops are reduced by having vehicles travel to their destination directly, making it comparable to air travel in terms of passenger process.

There will be a station where passengers get on and off the hyperloop vehicle. Because of the high throughput and departure frequency of the hyperloop system, preparing and planning in advance, and thus luggage pre-collecting of any kind before the boarding process will also not be necessary. Passengers will be guided to one of the platforms with their luggage and get on a vehicle that is almost ready to depart. This system demands an efficient (dis)embarking process that includes both passengers and their luggage, if any, right in front of the vehicle.

Research by Mas et al. [2] shows that in three specific aircraft models, the most efficient way of boarding is not assigning seats and let passengers board and choose a seat they like. Other studies state that, in theory, the Steffen method (where passengers board separately in a given order, illustrated in Fig. 1) is the fastest, because this maximizes the utilization of the aisle, especially for when placing hand luggage (Jaehn and Neumann 2014) [3]. However, the Steffen method can hardly be used in practice, since asking groups of travellers to board separately may decrease customer satisfaction (Steffen 2008) [4].

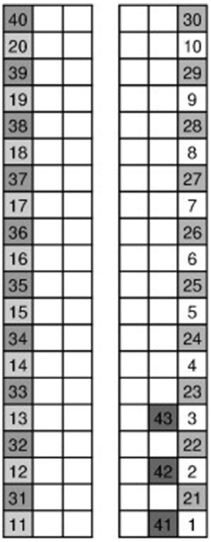


Fig. 1. Steffen method for boarding aircrafts (Steffen 2008).

Self-organizing phenomena in pedestrian crowds have been studied by Helbing et al. [5, 6], revealing dynamics in different ingress and egress environments. Helbing et al. [6] discovered that high interaction frequencies and high numbers of braking or avoidance manoeuvres slow down the average velocity in the desired direction of motion. Bottlenecks form another factor that reduces the pedestrian flow, and the longer the bottleneck, the slower the flow (Helbing et al. 2002) [5]. Besides the literature study, an interview on crowd dynamics with J. Li, an expert on crowd behaviour at Delft University of Technology, has also lead to valuable insights (Li 2018) [7]. She stated that any kind of hesitation in the crowd will cause a chain of reaction delays and slow down the flow or even create conflicts and stampedes in the crowd. Li also mentioned that, in an overcrowded situation, getting into a bottleneck is dangerous because the unawareness of what is happening in the bottleneck causes pressure and anxiety among the crowd. Therefore, eliminating bottlenecks and avoiding passenger hesitations will be beneficial to the (dis)embarking process.

1.2 Proposed Design Solution

Based on the results from the literature research, a design solution for the hyperloop boarding process is proposed [8]. Our design proposition separates the passenger compartments from luggage space (underneath passenger compartments) and influences the (dis)embarking flow by the arrangement of doors and seats. Multiple doors on both sides of the vehicle allow passengers to embark and drop the hold luggage on the one side and disembark and pick up the luggage on the other side (Fig. 2).

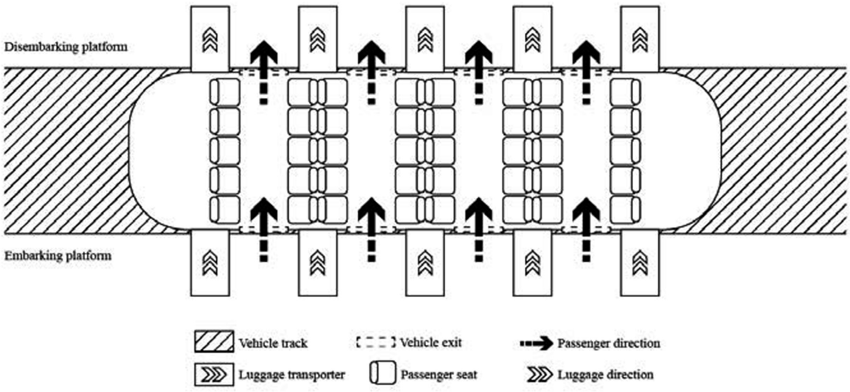


Fig. 2. Concept sketch of the new (dis)embarking solution (top view of hyperloop vehicle on platform).

1.3 Objectives

The aim of the study reported in this paper is to assess the efficiency and the experience of this new way of (dis)embarking by answering two research questions:

1. *Does the proposed design solution achieve higher efficiency and better user experience than the traditional (dis)embarking model?*

And, since the size of the doors affects the complexity of the system and narrow doors are preferred, the second research question:

2. *Does the width of the doors influence the efficiency and passenger experience while (dis)embarking?*

The two research questions were addressed separately in two experiments. After the description of the experiments, the results are discussed and a further improved design solution is presented based on the results.

2 Experiment 1: A Comparison Between the New Design and Traditional Embarking and Disembarking Model

The first experiment was conducted to determine if the new design achieves a higher efficiency and better user experience than the traditional (dis)embarking model.

2.1 Method of Experiment 1

Tests with mockups were performed in a laboratory environment. Ten people (9 males and 1 female) between the age of 24 and 53 years old volunteered to participate in the study. They were recruited from the university and from companies with different backgrounds. The study included observations of participants during their embarking and disembarking processes using the mockups, and questionnaires about their experiences.

Both the traditional setup (A) and the new concept (B) were simulated with two test settings (see Fig. 3). Test setting A was part of one compartment with 10 seats and one door (between the stools). There was an aisle with two seats on each side of the aisle per row. Luggage bins (carton boxes) were located overhead like in most airplanes and trains. Test setting B represented the new proposition: two stools on each side representing the two doors on both sides of the vehicle, one for embarking and the other for disembarking. Boxes in front of the embarking door represented luggage transporters for hold luggage. A dashed line in the middle of the waiting area showed people that they could stand two by two and place their luggage on both sides. The main dimensions are included in Fig. 3.

The researcher recorded the process with a video recorder. A five-point Likert scale questionnaire (in Appendix) on the passenger experience during the process was taken, including questions regarding whether it was clear what to do, and what level of convenience and comfort were experienced.

After the experiment, the videos of the test were analyzed and the time it took for each process was noted separately: (i) total embarking time: all embarking passengers get from the departure platform to their seats with their luggage well placed; (ii) total disembarking time: all disembarking passengers get from their seats to the arrival platform; (iii) total vehicle-on-platform time: the sum of the previous two; (iv) average embarking time per passenger: from in front of the door to being seated with their belongings well-placed; (v) average disembarking time per passenger: from standing up from their seats to getting out of the door with their belongings; and (vi) the average time of the (dis)embarking process per passenger: the sum of the previous two.

The average embarking and disembarking times per passenger were recorded separately. The sum of these two average times is the average time each passenger spends on (dis)embarking. Average scores for the experience of the new concept (B) and the traditional model (A) were collected using the questionnaires.

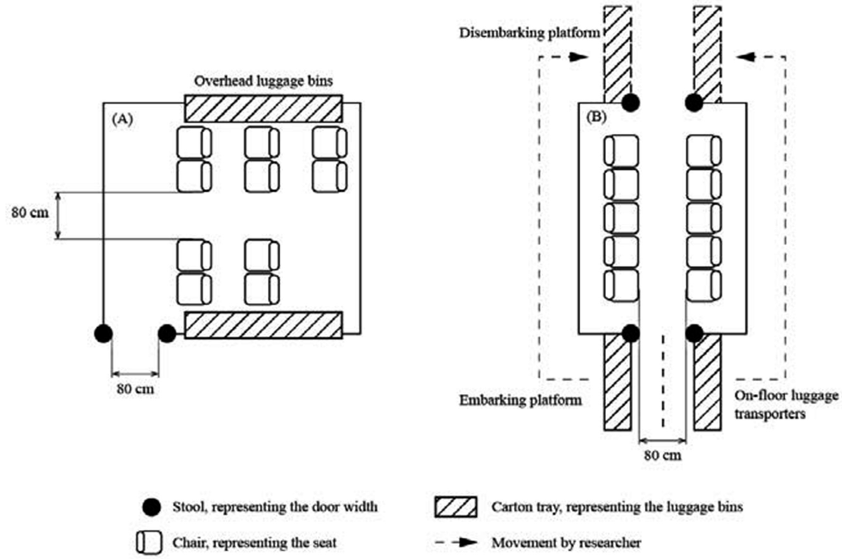


Fig. 3. Test setting A: traditional (dis)embarking experience (left). Test setting B: new (dis) embarking experience (right).

The ten participants were first introduced to test setting A and participants were each given an empty suitcase or a backpack as their personal belongings. They entered the vehicle and looked for a seat when the door was indicated to be open; Once all participants were seated with their belongings placed in the carton boxes, they were told that the door was closed and the vehicle would depart. After 30 s, the researcher indicated that the vehicle arrived at the destination and the door was opened. Participants collected their belongings and walked out through the door.

The same 10 passengers were then introduced to test setting B and participants used the same suitcases and backpacks from the previous test. Participants were told to wait on the embarking side. When they were told the vehicle arrived and the door opened, they placed their belongings in the cardboard boxes on both sides of the entrance door, walked into the aisle and sat down. Then the researcher moved their luggage behind the seats and told them the luggage was automatically moved into the luggage compartment under the passenger floor. They were then told that the door was closed and the vehicle departed. After 30 s, they were told the vehicle arrived at the destination and the door on the disembarking side was open. At this moment, the researcher moved the luggage boxes to the disembarking side on both side of the exit door. Participants walked out of the door on the right and picked up their belongings as they walked out. After the experiment, participants were asked to fill in the questionnaires.

2.2 Results of Experiment 1

Table 1 shows the comparison between test setting A and B in terms of (dis)embarking efficiency. Embarking in the traditional model (A) took 29 s and in concept (B) it took

15 s. Disembarking took 26 s in the case of A and 18 s in the case of B. In total, the time for each vehicle to stay on the platform was 33 s for concept (B), which would imply a 40% time-saving compared to traditional (dis)embarking. Moreover, the average time for each individual passenger to embark and disembark is 15.7 s for concept (B), which would imply a 50% time-saving compared to the traditional setup.

Table 1. Embarking and disembarking times for test setting A and B.

		(A) Traditional (in seconds)	(B) Concept (in seconds)
Embarking	Total embarking time	29	15
	Average embarking time per passenger	13.1	3.3
Disembarking	Total disembarking time	26	18
	Average disembarking time per passenger	18.9	12.4
Embarking & disembarking	Total vehicle on-platform time	55	33
	Average total time per passenger	32	15.7

Based on the questionnaire responses, the average user-experience scores for both setups were determined (Fig. 4). On 13 out of a total of 15 investigated aspects, the concept achieves a better user experience than the traditional setup. On the embarking platform, the new concept scored lower on making clear what to do, but it was experienced as more comfortable and pleasant compared to traditional model. During both

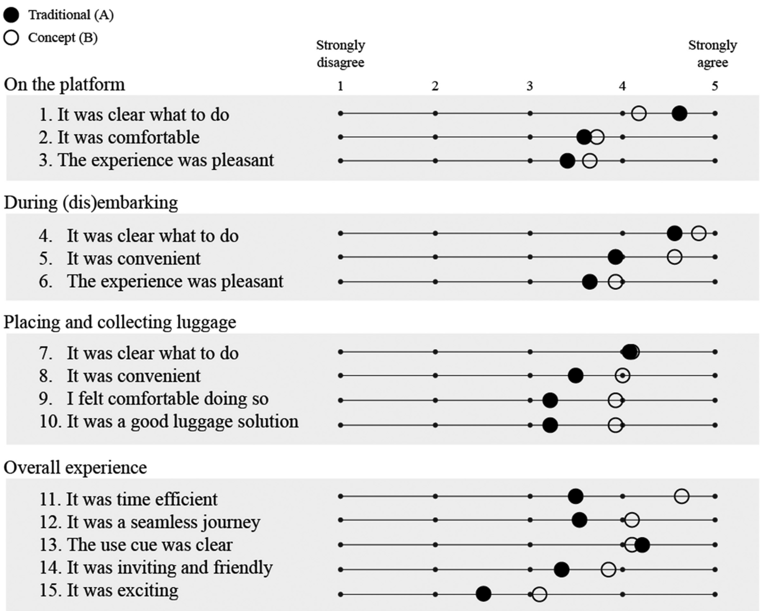


Fig. 4. Average experience score of traditional model (A) and concept (B). (n = 10)

(dis)embarking and placing/collecting luggage, the concept scored better on clarity, convenience, comfort and pleasantness. The overall experience of the concept was more time efficient, more seamless, less clear, more inviting, friendlier and more exciting than the traditional model. On one hand, the concept was considered considerably more time efficient, seamless, inviting and exciting; on the other hand, the procedure on the platform appeared to be less self-explaining. Overall, on 16 out of 18 investigated aspects, the concept achieves a better user experience than the traditional setup.

3 Experiment 2: Influence of Door Width on Passenger Embarking and Disembarking

In the proposed design concept for hyperloop, there are multiple doors on each side of the vehicle for embarking and disembarking. Since the vehicles will be operating in a depressurized environment, each door added to the chassis will need reinforcement around it to maintain the desired strength and stiffness. Therefore, the smaller the size is for each door, the better it can be realized from an engineering and economics point of view. The second experiment was conducted to investigate whether the width of the doors influences the efficiency and passenger experience.

3.1 Method of Experiment 2

In this follow-up experiment, test setting C was realized by reducing the door width of test setting B from 80 cm to 40 cm. It was intended to have passengers (dis)embark one by one. Therefore, unlike test setting B, C has the luggage transporters on only one side (see Fig. 5), while the other dimensions stayed the same as B. The instructions given and the procedure of the test remained the same as with test setting B. The experiment was video recorded and the same measurements as in experiment 1 were made by analyzing the video recording. The researcher also looked for behaviour differences between B and C during (dis)embarking, when passengers were looking for a seat or placing and collecting luggage, to explain possible different results in measurements. After the test, a semi-structured interview was conducted to compare the experience of B and C as well as to identify the reasons for the differences in experience.

3.2 Results Experiment 2

Passenger Behaviour

In the experiment, all participants first placed their luggage on the luggage transporter and stood in a line to wait for the vehicle. When the door opened, they entered one by one (spontaneously) and picked random seats. Passengers chose to sit in the seat that was neither next to anyone nor opposite to anyone in zigzag pattern (Fig. 6). This was different from test setting B, where participants lined up in two rows before embarking and 8 out of 10 of them sat on the same side as the line they had been in. When the vehicle arrived, participants walked out of the vehicle and picked up their luggage. Comparing to setting B, people in the back had to wait longer for the first ones to pick up their luggage.

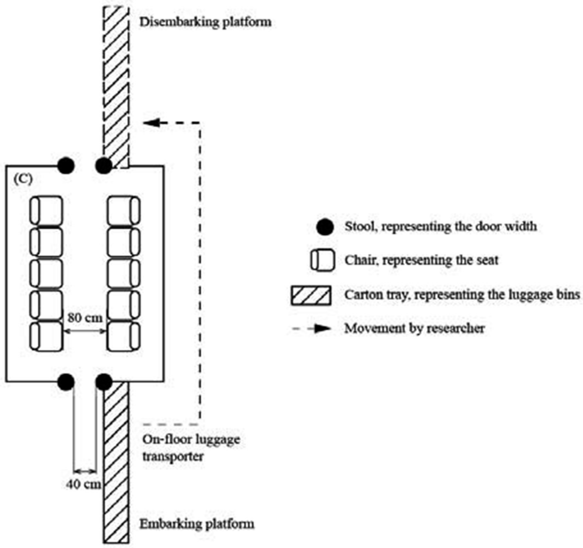


Fig. 5. Test setting C: the (dis)embarking concept with narrow doors (40 cm).

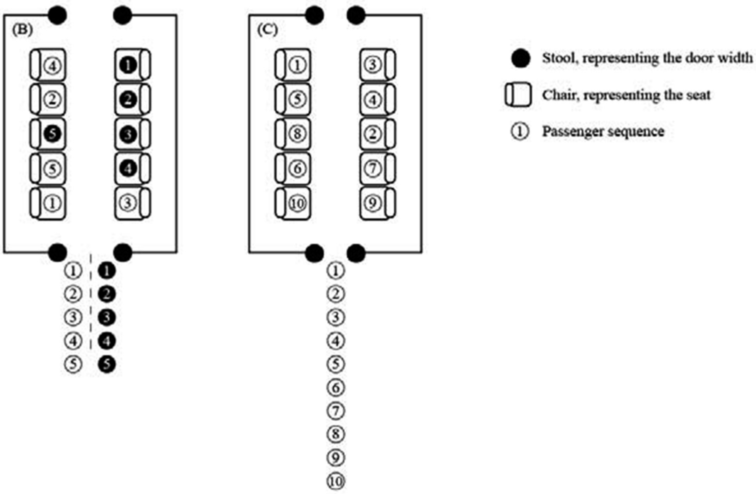


Fig. 6. Participants embark sequence in test setting B (left) and C (right).

(Dis)embarking Times

Analyzing the video recording of the experiment, narrow doors had little influence on the total embarking time (Table 2). However, the total disembarking time increased 39% and the disembarking time per passenger increased 27% on average. The video showed that a jam occurred during disembarking the narrow door setup. Some participants had to wait for others to collect their luggage first in order to be able to exit the door and collect their luggage. In the wide door setting (B), no jam was observed. In total, the time for the vehicle to stay on platform was 40 s, compared to 33 s for wide doors and the embarking and disembarking time per passenger was 19.3 s for narrow doors, compared to 15.7 s for wide doors.

Table 2. (Dis)embarking time comparison between setup B and C.

		(B) Wide (in seconds)	(C) Narrow (in seconds)
Embarking	Total embarking time	15	15
	Average embarking time per passenger	3.3	3.6
Disembarking	Total disembarking time	18	25
	Average disembarking time per passenger	12.4	15.7
Embarking & disembarking	Total vehicle on-platform time	33	40
	Average total time per passenger	15.7	19.3

Passenger Experience
The interview revealed that 5 out of 10 participants did not feel an obvious difference regarding the overall experience of wide and narrow doors. Among the other 5 participants, 4 of which mentioned that there was a longer queue for embarking through a narrow door and that it felt slower and more cramped; two of them felt that participants before them completely blocked the disembarking flow when picking up their luggage at the door in the setup with narrow doors.

4 Discussion

For the envisaged hyperloop system, a vehicle consists of 5 compartments, each with 10 passenger seats, carrying 50 passengers in total. This means that 5 compartments of 10 passengers (dis)embark at the same time. Our assumption has been that the time it takes for all passengers to (dis)embark will be the same as in the test settings experiments.

Compared to the traditional (dis)embarking process, our small-scale experiment to evaluate the proposed concept presented in the introduction suggests a 50% time-saving on average for each passenger and 40% for the overall (dis)embarking process. It also suggested that a better passenger experience could be achieved in terms of comfort, convenience and the perceived efficiency. In the new concept, narrowing the width of the doors seemed to reduce efficiency and led to a negative passenger experience.

Eliminating bottlenecks can be one of the reasons that increases efficiency. The new concept increases passenger flow when the width of the doors and the width of the aisle are the same (in test setting B), which corresponds to Helbing et al.'s [5] findings regarding bottlenecks. Another aspect of the design is that the path for passengers is designed to reduce hesitations. In the traditional (dis)embarking model, passengers in the main aisle are unconsciously making decisions at every line of seats. With the new design, fewer decisions are necessary and decisions are easier to make, as there is only one aisle with all seats facing the aisle. Passengers immediately get a glance of the environment and, therefore, less hesitations are involved in the process, which according to Helbing et al. [6], increases the velocity of flow. Furthermore, without turnings during (dis)embarking and interactions while dealing with luggage, less conflicts occur in the passenger flow. Less braking and avoidance during (dis)embarking also makes the flow faster as described in Helbing et al.'s [6] research on pedestrian flow.

Reducing the width of the doors (in test setting C) seems to cause a bottleneck in the process of (dis)embarking and in theory that can be the reason for smaller flow velocity (Helbing et al. 2002) [5]. However, the embarking time of the narrow doors is the same as the wide doors, which means that in this setup, door width does not directly reduce efficiency. For disembarking, the test with narrow doors takes more time than the one with wide doors, which may be due to the luggage pick up process. In the narrow door setup, people could only place and pick up their luggage from the luggage transporter on one side while in the other setup, they have a wider on platform space to pick up luggage on both sides. The narrow-door setup could be improved by moving the luggage collection area few meters away from the vehicle exit so that people collecting their luggage can get out of the way. In terms of passenger experience, the longer queue at the embarking platform could perhaps be reduced by placing luggage transporters on both sides of the queue. Passengers arriving later can make use of the luggage system when the previous luggage is loaded.

Since it was a test with only 10 participants for one time each experiment, the exact time for embarking and disembarking mentioned in this chapter can only serve as a first indication and repetition of the experiments is recommended. Other limitations of the experiments are listed below:

- Out of the 10 participants, 6 were acquaintances of the researcher, which may have made the interview results more positive than it would be with non-acquaintances;
- All participants experienced the different test settings in the same sequence (A, B, C). Later tests might have been more efficient because they were familiar with the environment and procedure; in order to prevent a learning effect, future tests should counterbalance this effect by mixing the order;
- Participants did not (dis)embark in the same order and their personal behaviour might have an influence on the result. This effect can be minimized by repeating the tests with other participants;
- When comparing test setting B and C, the variables are the door width and the arrangement of the luggage system (two lines in B and one line in C). For further research, it is suggested to control the luggage transporter and only change the width of the doors;

- Participants were given empty suitcases in the test, while heavier luggage could require more time and effort and would make the test more realistic;
- The perception of door width was tested with two stools instead of solid walls and this might have made the experiments more efficient since they could see the interior before embarking as well as the luggage collection area before disembarking.

It is recommended to take the aforementioned aspects into account when repeating the experiments.

5 Conclusion

In this paper, two experiments have been carried out to evaluate a new concept of passenger (dis)embarking for a future hyperloop environment. The new concept separates the vehicle into compartments of 10 seats in two rows facing an aisle in the direction perpendicular to the travel direction. Passengers embark from one side, walk into the seats and disembark from the other. The luggage compartment is located underneath the passenger floor and the luggage is dropped during passenger embarking and collected right after disembarking. Results of these experiments indicate that the new design can reduce (dis)embarking time and improve passenger experience compared to traditional model of boarding (train/aircraft). The width of the door does influence the disembarking time but no noticeable influence was found on the embarking time. In this test setting, a narrow door design did not only increase disembarking time but also had a negative influence on passenger experience. However, suggestions have been made to adjust the narrow-door setup to minimize the influence on time efficiency and passenger experience for further research.

Acknowledgements. The authors are grateful to Prof. P. Vink for the latest information in the field of aviation passenger experience. They appreciate that J. Li pointed out the interesting study by Helbing et al. (2002 and 2005). Special thanks to Buccaneer Delft for providing the testing environment and connections to the participants.

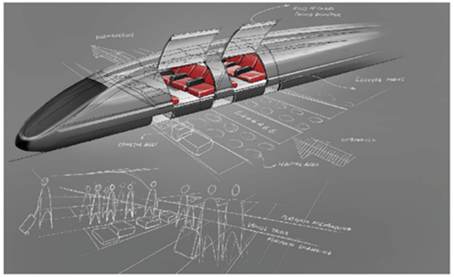
Appendix: Questionnaire for Experiment 2

PART 2: Questionnaire

Test A

	Strongly Disagree 1	2	3	4	Strongly Agree 5
When I was on the platform:					
It was clear what to do	☐	☐	☐	☐	☐
It was comfortable when waiting for the vehicle	☐	☐	☐	☐	☐
The experience was pleasant	☐	☐	☐	☐	☐
During boarding and disembarking:					
It was clear what to do	☐	☐	☐	☐	☐
It was convenient to get in and get seated and the other way around	☐	☐	☐	☐	☐
The experience was pleasant	☐	☐	☐	☐	☐
Regarding the way to place and collect my large luggage:					
It was clear what to do	☐	☐	☐	☐	☐
It was convenient	☐	☐	☐	☐	☐
I felt comfortable doing so	☐	☐	☐	☐	☐
It was a good luggage solution	☐	☐	☐	☐	☐
Overall experience:					
It was time efficient	☐	☐	☐	☐	☐
It was a seamless journey	☐	☐	☐	☐	☐
The process was clear to me	☐	☐	☐	☐	☐
It was an inviting and friendly (dis)embarking experience	☐	☐	☐	☐	☐
It was an exciting (dis)embarking experience	☐	☐	☐	☐	☐

Test B



	Strongly Disagree 1	2	3	4	Strongly Agree 5
When I was on the platform:					
It was clear what to do	☐	☐	☐	☐	☐
It was comfortable when waiting for the vehicle	☐	☐	☐	☐	☐
The experience was pleasant	☐	☐	☐	☐	☐
During boarding and disembarking:					
It was clear what to do	☐	☐	☐	☐	☐
It was convenient to get in and get seated and the other way around	☐	☐	☐	☐	☐
The experience was pleasant	☐	☐	☐	☐	☐
Regarding the way to place and collect my large luggage:					
It was clear what to do	☐	☐	☐	☐	☐
It was convenient	☐	☐	☐	☐	☐
I felt comfortable doing so	☐	☐	☐	☐	☐
It was a good luggage solution	☐	☐	☐	☐	☐
Overall experience:					
It was time efficient	☐	☐	☐	☐	☐
It was a seamless journey	☐	☐	☐	☐	☐
The process was clear to me	☐	☐	☐	☐	☐
It was an inviting and friendly (dis)embarking experience	☐	☐	☐	☐	☐
It was an exciting (dis)embarking experience	☐	☐	☐	☐	☐

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